On the Transmission Mechanism of Asia-Pacific Yield Curve Characteristics*

Abstract

This study investigates the transmission mechanism of Asia-Pacific sovereign bond yields using a monthly data set which reaches over the period from January, 2003 until December, 2017. Sovereign bond yields are decomposed into three latent factors – level, curvature and slope – using the Dynamic Nelson-Siegel procedure proposed by Diebold and Li (2006). The yield curve propagation mechanism is examined using the dynamic connectedness framework of Diebold and Yılmaz (2012, 2014) which is based on a time-varying parameter vector autoregression (TVP-VAR). The results suggest that the net transmitters of shocks are Australia, Hong Kong, Korea and Singapore whereas China, India, Indonesia, Japan and Malaysia have been net receivers of shocks. Across factors those results are consistent except for the Korean curvature factor. In addition, findings revealed that the highest market interconnectedness can be found in the level factor followed by the slope and the curvature factor. Notably, all dynamic connectedness indices strongly increased during the Global Financial Crisis (2009) which illustrates that Asia-Pacific monetary policy is interconnected with each other especially during periods of economic unrest.

Keywords: TVP-VAR; Dynamic Connectedness; Yield Curve Decomposition; Yield Curve Spillovers.
JEL codes: C32; C5; G12; G15

*We would like to thank two anonymous referee for many helpful comments. However, any remaining errors are solely ours.

1 Introduction

The Asia-Pacific region has grown rapidly in recent years and currently accounts for 35% of the world's gross domestic product and exhibit more than 57% of intra-regional trade[1]. This evolution is remarkable since the Asia-Pacific region heavily relied on foreign borrowing in the 1990s. Since the outbreak of the Asian Financial Crisis (1997) greater awareness has been created towards the importance of regional integration. It has drawn the attention of policymakers to develop the local bond markets which should reduce the risk emerging from currency mismatches and channelize the region's saving to its long term investment needs. Back then the *Association of Southeast Asian Nations (ASEAN)* has been playing a catalyst role for regional integration whereas later on proliferation initiatives to form Asian free trade and financial areas have been introduced to facilitate integration even further. Since then various measures on financial liberalisation – such as Asian Bond markets initiative and ASEAN +3 Bond market forum – have been initiated to develop and integrate the region's local bond market (Tsukuda et al., 2017). The Asian bond markets have experienced tremendous growth in the last decade. The total size of the Asian bond market has increased from approximately 5,357 USD billions in 2003 to 17,398 USD billions in 2017 (see Table 1) [2]. Park (2017) shows that the growth of the Chinese and Korean bond market is found to be phenomenally increasing over the last decade. Finally, Horioka et al. (2014) shows that in recent years the development of financial liberalization has increased foreign capital flows into the local sovereign bond market (see Figure 1). The effects of financial liberalization and increasing demand for the emerging market assets by the investors for diversification benefits led to integration of bond markets in the region.

One of the earliest attempts to investigate the bond market integration has been conducted by Ilmanen (1995) who find that excess bond returns are significantly correlated across countries and that even a small set of global instruments can predict international bond return. In addition, Engsted and Tanggaard (2007) find suggestive evidence that expected inflation has also a major role to play when it comes to bond market integration.

[1]Source: International Monetary Fund (IMF)
[2]Source: Asian Development Bank

In contrast, the results of Clare et al. (1995) suggest that there is low correlation across international bond markets which in turn is beneficial for risk and portfolio diversification strategies. With a clear focus on the Asian bond market integration, Johansson (2008) suggest that correlations across bond returns are time-varying and exhibit pronounced co-movements during high volatility phases.

The bond market integration warrants the attention of central banks, as they rely on the implications of the expectations hypothesis (Campbell and Shiller, 1991; Sarno et al., 2007) to influence the economy through investment, output and employment. The decoupling effect of short term to long term yields leads to the differentiation of short-term and long-term rates integration. Kumar and Okimoto (2011) provide suggestive evidence that the degree of bond market integration across G7 economies highly depend on bond maturities. Their findings suggest that integration at short end of yield curve is dictated by the synchronicity of business cycles across the countries where as the integration of long end of the yield curve is determined by the global investor savings and preferences. This finding is supported by Sutton (2000). Instead of analyzing the interest rate of all maturities, it is possible to decompose the yield curve information into three latent factors which are represented by the level, curvature and slope factor (Nelson and Siegel, 1987). According to Litterman and Scheinkman (1991) those three factors capture more than 99% of the movement of various bond yields. In more detail, the level factor represents long-term yield rates, the curvature factor stands for medium-term yield rates and the slope factor illustrates short-term yield rates. In other words, a level shock would influence the interest of all maturities, a curvature shock would make the interest rates more or less "hump-shamped" and hence influences the medium-term yield rates whereas a slope shock would adjust the short-term yield rates by much more than long-term yield rates (Wu, 2003). Driessen et al. (2003) identify that the yield curve level factor is influenced by global shocks, whereas the slope of the yield curve is driven by country-specific shocks. In addition, Jotikasthira et al. (2015) find that long-term rates are correlated primarily because of the term-premia associated with them. Thus, it is expected that the level factor would exhibit a higher degree of market interconnectedness compared with the slope and curvature factor.

In an attempt to investigate the Asian bond market integration and its time-varying interdependencies, we are analyzing sovereign bond yields at various maturity spectrums. Hereby, we are utilizing a monthly dataset which ranges over the period from January, 2003 until December, 2017. In a first step, the yield curves of Asia-Pacific economies are decomposed into the aforementioned three latent factors by employing the dynamic Nelson-Siegel model as proposed by Diebold and Li (2006). The threelatentfactorscaptures the long-term, medium-term, and short-term movements. Since the bond market integration differs by bond maturities and exhibit co-movements in times of high uncertainty we are analyzing the time-varying interdependencies using the dynamic connectedness framework of Diebold and Yılmaz (2012, 2014) based on a time-varying parameter vector autoregressive model with a heteroskedastic variance-covariance structure as it was proposed in Koop and Korobilis (2014). Earlier studies have already applied this combination (Antonakakis and Gabauer, 2017; Korobilis and Yilmaz, 2018; Gabauer and Gupta, 2018; Antonakakis et al., 2018) and concluded that it leads to essential advantages over the rolling-window alternative, (i) no arbitratily chosen rolling-window is necessary, (ii) the integrated Kalman filter procedure makes this framework less outlier-sensitive and (iii) there is no loss of observations which is especially important for low frequency data.

Hence the contribution of the study is twofold. First, studies that are concentrating on the linkages across Asia-Pacific bond markets are scarce. This study analyzes the Asia-Pacific bond market integration which are reflecting the domestic monetary and economic policy stance. The Asia-Pacific economies which are under investigation exhibit diverse stages of economic and financial development supporting the understanding of the propagation mechanisms between and across emerging and developed countries. To get further insights about the market integration we clearly distinguish between short, medium, and long-term bond market integration.

Second, we are examining the time-varying interdependencies and interconnectedness using a TVP-VAR model with heteroskedastic variance-covariances structure. This TVP-VAR connectedness approach can be seen as an alternative to the traditional rolling-window VAR method of Diebold and Yılmaz (2009, 2012, 2014). Hereby, the time-varying structure of the parameters advances the traditional methodology substantially, since (i) there is no need to arbitrarily choose a rolling window-size, (ii) there is no loss of observations which in turn allows analyzing low-frequency data, and finally, (iii) the estimator is not outlier-sensitive since this algorithm is based on a Kalman filter approach. To the best of our knowledge, the investigation of various bond yield characteristics using this methodology is novel to the literature. The empirical results are supporting already well-established findings and provides more detailed insights in the time-varying transmission mechanisms of the Asia-Pacific bond market.

This study provides evidence that the bond market integration depends on the bond maturity, as pointed out in Kumar and Okimoto (2011). In addition, we find suggestive evidence that the interconnectedness of the level factor is highest followed by the slope factor and the curvature factor which is in-line with Jotikasthira et al. (2015). This in turn means that short-term and long-term interest rates are highly interrelated after the Global Financial Crisis (GFC) in 2009 whereas this is not true for medium-term interest rates. Interestingly, the results suggest that slope and level integration diverges from the curvature integration after the GFC. This would imply that even though short-term and long-term interest rates and hence short-term and long-term monetary policy is highly interconnected across countries, medium-term monetary policy actions are different. In addition, our results point out that the interconnectedness of all factor increased substantially at the beginning of the GFC. This effect has been expected *a priori* since the yield curve inverted during this period. Furthermore, we find that the dynamic total connectedness measures are time-varying and economic event dependent. This finding is in-line with Clare et al. (1995) since high co-movements of bond returns occur during volatile periods. Finally, our results coincide with those of Johansson (2008) since the market interconnectedness measures are varying over time.

Furthermore, we fi

nd that for all markets Australia, Hong Kong and Singapore are net transmitter of shocks whereas China, India, Indonesia, Japan and Malaysia are receivers of shocks. In the case of Korea, we find that it is a net transmitter of short-term and long-term interest rates shocks whereas it is a net receiver of medium-term interest rate shocks. The trade linkages and similarities in financial characteristic indicate to be of major importance in this respect.

Section 2 reviews existing literature on bond market integration and the expected results. Section 3 outlines the applied models whereas Section 4 illustrates the empirical results of the yield curve transmission mechanisms, and finally, Section 5 concludes this study.

2 Bond market Integration

According to expectation hypothesis theory, changes in the monetary policy rate should impact the maturity spectrum of interest rates in the same direction. A volume of research tested the expectation hypothesis of term structure of interest rates across various countries (Campbell and Shiller, 1991; Sarno et al., 2007). The results were always inconclusive and majority of the research rejected the expectation hypothesis (Sutton, 2000). Thus the earlier research studied the dynamics of term structure of interest rate in the closed economy context ignoring the international influence on the domestic term structure (Holmes et al., 2011).

The structural change in the economy, financial liberalization and common global shock led to convergence of bond yields across the countries. The main factor underlying the bond market integration is diminishing interest of investors towards the home bias bonds leading to international diversification. This change in the preference of the investors is because of the reduction in the hedging cost, country specific growth rates and inflation. Complementing these factors, international trade linkages across the countries, large current account surpluses, excess global savings led to the need for international investment and diversification. Thus the convergence of bond yields occurs directly or through arbitrage opportunities. Such convergence is invariant to the stance of the monetary policy.

The central bank influences the short term rates through monetary policy actions, which inturn affect the long term rates. At the short end of yield curve, the degree of integration depends on the synchronicity of the business cycles between countries. The divergent business cycles between countries leads to lower integration at the short end of the yield curve.

Sutton (2000) found that the rejection of expectation hypothesis is profoundly because of the behavior of long term rates in the global bond markets. They provided evidence that term premia in the long end of the yield curve are influenced by the international factor. Chantapacdepong and Shim (2015) showed that loosening of country's policy action towards the capital flows in bonds increases the bond yield correlations with other countries. Thus, at the long end of yield curve, the degree of integration depends on global investor preferences, savings and capital flows. Given the, increase in the movement foreign capital in Asian markets, we expect higher integration at the long end of the yield curve. The medium term interest rates are related to the current stance of monetary policy and doesn't link to the macroeconomic shocks (Dewachter and Lyrio, 2006; Diebold and Li, 2006). The trade linkages and the regional factors play a vital role at medium end of the yield curve (Sowmya et al., 2016). Further it was found that interdependencies in the medium term rates is found be less in comparison with the long and short term rates.

3 Data and Methodology

We compile a dataset of monthly sovereign zero coupon yield curve for Australia, China, Hong Kong, India, Indonesia, Japan, (South) Korea, Malaysia, and Singapore over a period from January, 2013 to December, 2017. Twelve maturities are considered for each country: 3, 6, 12, 24, 26, 48, 60, 72, 84, 96, 108 and 120 months. The data is retrieved from *Bloomberg*.

Since we are interested in short-term, medium-term and long-term bond market integration, we employ the dynamic Nelson-Siegel (Diebold and Li, 2006) to extract three latent factors – level, curvature and slope. According to Litterman and Scheinkman (1991) these three factors retrieve 99% of the yield curve movements whereas the level factor represents long-term rates, the curvature demonstrates the medium-term rates and the slope illustrates the short-term rates.

Table 2 presents the most essential summary statistics of the (first differenced) factors which are essential for multivariate time series modelling. The raw and transformed series are shown in Figure 2. According to the Augmented Dickey-Fuller unit-root test (Dickey and Fuller, 1981) all series are stationary at the 1% significance level. In addition, the test statistics suggest that most series are significantly autocorrelated and/or exhibit ARCH errors (Fisher and Gallagher, 2012). This implies that estimating a TVP-VAR with heteroscedastic variance-covariances structure seems to be appropriate.

Additionally, we calculated the unconditional correlations prior and post the Lehman Brothers bankruptcy - which is often used as proxy for the beginning of the Great Recession of 2008 - to see whether the factor correlations have changed across countries. It seems that all level factor correlations have increased besides two related to Japan. In case of the slope factor correlations, all have increased as well except for some related to Japan and India. Finally, the trend of curvature correlation coefficients seems to be decreasing as more than 80% of the correlations are lower after the Lehman Brothers bankruptcy.

[Insert Figure 2 and Table 2 around here]

3.1 Dynamic Nelson-Siegel Model

The model introduced by Nelson and Siegel (1987) is expressed as a function that decomposes the large set of yields into small unobserved factors. These three latent factors – level, curvature and slope – are capable of capturing various potential shapes yield curve can assume. Central banks and practitioners are using this framework to estimate the bond yields at a given point in time. The yield curve according to the dynamic Nelson-Siegel model a la Diebold and Li (2006) is formulated as a VAR model in its state space representation which can be written as follows:

$$
\begin{aligned}
\boldsymbol{z}_t(\boldsymbol{\tau}) &= \begin{pmatrix} 1 & \left(\frac{1-exp(-\lambda\tau_1)}{\lambda\tau_1}\right) & \left(\frac{1-exp(\lambda\tau_1)}{\lambda\tau_1} - exp(-\lambda\tau_1)\right) \\ 1 & \left(\frac{1-exp(-\lambda\tau_2)}{\lambda\tau_2}\right) & \left(\frac{1-exp(\lambda\tau_2)}{\lambda\tau_2} - exp(-\lambda\tau_2)\right) \\ \vdots & \vdots & \vdots \\ 1 & \left(\frac{1-exp(-\lambda\tau_m)}{\lambda\tau_m}\right) & \left(\frac{1-exp(\lambda\tau_m)}{\lambda\tau_m} - exp(-\lambda\tau_m)\right) \end{pmatrix}' \boldsymbol{x}_t + \boldsymbol{u}_t \qquad \boldsymbol{u}_t \sim N(\boldsymbol{0}, \boldsymbol{R}) \\
\tilde{\boldsymbol{x}}_t &= \boldsymbol{\Gamma}\tilde{\boldsymbol{x}}_{t-1} + \boldsymbol{\eta}_t \qquad \boldsymbol{\eta}_t \sim N(\boldsymbol{0}, \boldsymbol{G})
\end{aligned}
$$

where $\boldsymbol{z}_t(\boldsymbol{\tau})$ and $\boldsymbol{u}_t$ represent $m \times 1$ dimensional vectors for yield rates with given maturities and error terms, respectively. The coefficient matrix in the measurement equation is following the structure introduced by Nelson and Siegel (1987), $\boldsymbol{x}_t = [L_t, S_t, C_t]$ is an 3×1 dimensional vector and comprises the yield rate shape parameters which are varying over time. L_t stands for the level factor representing the long-term yield rates, C_t is the curvature factor representing the medium-term yield rates and S_t illustrates the slope factor representing the short-term yield rates. Continuing with the transition equation: $\tilde{\boldsymbol{x}}_t = \boldsymbol{x}_t - \bar{\boldsymbol{x}}_t$ is the demeaned time-varying shape parameter matrix, $\boldsymbol{\Gamma}$ illustrates the dynamic relationship across shape parameters, $\boldsymbol{\eta}_t$ is a 3×1 dimensional error vector which is assumed to be independent from $\boldsymbol{u}_t$. Furthermore, $\boldsymbol{G}$ is an $m \times m$ dimensional diagonal matrix and $\boldsymbol{R}$ is a 3×3 dimensional variance-covariance matrix, allowing the latent factors to be correlated.[3]

3.2 TVP-VAR-Based Dynamic Connectedness Approach

To investigate the transmission mechanism of yield curve characteristics, a TVP-VAR-based connectedness framework is applied[4]. It extends the connectedness approach of Diebold and Yılmaz (2012, 2014) by using the TVP-VAR model of Koop and Korobilis (2014) overcoming the burden of (i) arbitrarily chosen rolling-window sizes, which causes highly volatile or smoothed parameters, (ii) losing observations and (iii) outlier sensitivity (Antonakakis and Gabauer, 2017; Korobilis and Yilmaz, 2018). According to the Bayesian information criterion (BIC) a TVP-VAR lag length of order one should be considered. Thus, the employed TVP-VAR(1) can be written as,

$$\boldsymbol{y}_t = \boldsymbol{\Phi}_t \boldsymbol{y}_{t-1} + \boldsymbol{\epsilon}_t \qquad \boldsymbol{\epsilon}_t | \boldsymbol{I}_{t-1} \sim N(\boldsymbol{0}, \boldsymbol{\Sigma}_t) \tag{1}$$

$$vec(\boldsymbol{\Phi}_t) = vec(\boldsymbol{\Phi}_{t-1}) + \boldsymbol{\xi}_t \qquad \boldsymbol{\xi}_t | \boldsymbol{I}_{t-1} \sim N(\boldsymbol{0}, \boldsymbol{\Xi}_t) \tag{2}$$

where $\boldsymbol{I}_{t-1}$ constitutes the information available until $t-1$, $\boldsymbol{y}_t$, $\boldsymbol{\epsilon}_t$ and $\boldsymbol{y}_{t-1}$ represent $m \times 1$ dimensional vectors and $\boldsymbol{\Phi}_t$ and $\boldsymbol{\Sigma}_t$ are $m \times m$ dimensional matrices. Furthermore, $vec(\boldsymbol{\Phi}_t)$ and $\boldsymbol{\xi}_t$ are $m^2 \times 1$ dimensional vectors and $\boldsymbol{\Xi}_t$ is an $m^2 \times m^2$ dimensional matrix.

[3]Since the details of the estimation procedure is beyond the scope of this study, interested readers are referred to Diebold and Li (2006)

[4]Since the details of the TVP-VAR algorithm – which rests on a multivariate Kalman filter and decay factors – is not the main purpose of this study readers are referred to Antonakakis and Gabauer (2017). The specification of the decay factors follows the benchmark model of Koop and Korobilis (2014) setting the decay factor equal to 0.99 and 0.96. This setting is applied since both studies rely on monthly data.

Since the connectedness approach by Diebold and Yılmaz (2012, 2014) rests on the generalized forecast error variance decompositions (GFEVD) developed by Koop et al. (1996) and Pesaran and Shin (1998) the TVP-VAR has to be transformed to its vector moving average (VMA) representation: $\boldsymbol{y}_t = \sum_{i=1}^{p} \boldsymbol{\Phi}_{it}\boldsymbol{y}_{t-i} + \boldsymbol{\epsilon}_t = \sum_{i=0}^{\infty} \boldsymbol{\Lambda}_{it}\boldsymbol{\epsilon}_{t-i}$.

Afterwards, the (unscaled) GFEVD, $\psi^g_{ij,t}$, is computed. This measure is called the pairwise directional connectedness FROM variable j on variable i which in other words represents the impact a shock in variable j has on variable i. In a next step, these variance shares are normalized, so that each row sums up to one, meaning that all variables together explain 100% of variable i's forecast error variance. This is calculated as follows:

$$\psi^g_{ij,t}(K) = \frac{\boldsymbol{\Sigma}^{-1}_{iit} \sum_{h=0}^{K-1} (\boldsymbol{e}'_i \boldsymbol{\Lambda}_{ht} \boldsymbol{e}_j)^2}{\sum_{h=0}^{K-1} (\boldsymbol{e}'_i \boldsymbol{\Lambda}_{ht} \boldsymbol{\Sigma}_t \boldsymbol{\Lambda}'_{ht} \boldsymbol{e}_i)} \qquad \tilde{\psi}^g_{ij,t}(K) = \frac{\sum_{t=1}^{K-1} \psi^g_{ij,t}}{\sum_{j=1}^{m} \sum_{t=1}^{K-1} \psi^g_{ij,t}} \tag{3}$$

where $\sum_{j=1}^{m} \tilde{\psi}^g_{ij,t}(K) = 1$, $\sum_{i,j=1}^{m} \tilde{\psi}^g_{ij,t}(K) = m$ and $\boldsymbol{e}_i$ is a selection vector with a one on the ith position and zero others.

All relevant connectedness measures can be computed in five steps. First, we are interested in how much variable i transmits to all other variables j, (total directional connectedness TO others), which is defined as

$$C^g_{i\to j,t}(K) = \sum_{j=1, i\neq j}^{m} \tilde{\psi}^g_{ji,t}(K) \tag{4}$$

Second, we want to know how much variable i receives from all variables j (total directional connectedness FROM others), which is defined as

$$C^g_{i\leftarrow j,t}(K) = \sum_{j=1, i\neq j}^{m} \tilde{\psi}^g_{ij,t}(K) \tag{5}$$

Third, the subtraction of the total directional connectedness TO others by the total directional connectedness FROM others leaves us with the NET total directional connectedness, which can be interpreted as the influence variable i has on the analyzed network.

$$C^g_{i,t} = C^g_{i\to j,t}(K) - C^g_{i\leftarrow j,t}(K). \tag{6}$$

If $C^g_{i,t} > 0$ ($C^g_{i,t} < 0$), it means that variable i influences the network more (less) than being influenced by it. Alternatively, it provides information whether variable i is driving or driven by the network.

Fourth, to get more detailed insights in bidirectional linkages, we break down the NET total directional connectedness to result with the net pairwise directional connectedness measures,

$$NPDC_{ij}(K) = \tilde{\psi}_{jit}(K) - \tilde{\psi}_{ijt}(K). \quad (7)$$

If $NPDC > 0$ ($NPDC < 0$) it means that variable i (j) is driving variable j (i).

Fifth, the integration of the analyzed network is calculated by the total connectedness index (TCI) which can be constructed as follows:

$$C^g_t(K) = m^{-1} \sum_{i,j=1,i\neq j}^{m} \tilde{\psi}^g_{ij,t}(K). \quad (8)$$

This measures illustrates how high a network is interconnected. If the influence of all variables j on variable i is high (low) the TCI is close to one (zero) which indicates that the variables are highly interrelated (independent).

4 Empirical Results

4.1 Level Factor Interdependencies

Table 3 presents the level factors' transmission mechanism. The total connectedness index is 41.3% which indicates that on average 41.3% of one level factor's forecast error variance can be explained by all other level factors and 58.7% of the level factor can be explained by the level factor itself.

In more detail, the shocks of Australia are primarily transmitted to Hong Kong (20.1%), Korea (13.7%) and Singapore (12.9%), whereas the shocks of Singapore affect Hong Kong (10.7%), Australia (10.3%) and Korea (8.1%). The three main receivers of Hong Kong related shocks are Australia (17.9%), Singapore (12.9%) and Korea (9.5%)

whereas Korea transmits to Australia (11.5%), Hong Kong (9.8%) and Singapore (6.6%). There exists a high integration between the level factors of Australia, Hong Kong, Korea and Singapore. Interdependencies in the long term factor for these countries is because of capital market openness especially after the Asian Bond market crisis. This in line with findings of Chantapacdepong and Shim (2015) who found that loosening of bond inflow measures leads to increase in the correlation of bond yields with the other countries in respect to Asia Pacific region. Similar interdependencies exist in the stock markets among these economies. In this regard, note that, Chevallier et al. (2018) examine the equity market linkages between these countries, and the results also corroborated that interdependencies between Australia, Hong Kong and Singapore is high, manifesting into a strong regional cluster.

We find that Singapore is also strongly influencing Malaysia (7.6%). The geographical proximity and strong bilateral trade linkages between these countries are the most likely underlying reasons driving such co-movements. This result seems to reflect the findings of Flavin et al. (2002) who have shown that geographical proximity, common border and bilateral trade linkages increases the cross-country asset market correlation.

It is noteworthy to highlight that, the influence of Japan on the level factor of the Asia-Pacific economies is limited. This result is consistent with the findings of Tsukuda et al. (2017) and Chevallier et al. (2018) in terms of Japan's impact on bonds and stock markets of the Asia-Pacific region. Japan is undoubtedly the largest investor of foreign securities in the Eastern Asian region, however their investments are predominantly exposed to highly-rated US and European debt securities. This explains why Japan's exposure in the Asia-Pacific market is rather limited, and why the integration in the Asia-Pacific market is lower than it could be (Lee et al., 2013).

Furthermore, results indicate that the own-country impact is rather high in China (73.1%) and India (68.5%), which in turn is not surprising because, both China and India have strict restrictions in terms of capital flows into their sovereign bond markets. Foreign investment in the Indian bond market is restricted to USD 30 billion, which accounts for only 4% of the total sovereign debt market. Similarly, foreign investments in the Chinese bond market account for only 3.61% of the total security market in the country. The results of the study suggest that financial openness; trade linkages play a vital role in the integration of long term factor in the Asia Pacific region.

[Insert Table 3 around here]

Figure 3 shows the dynamic net total connectedness measures for each country. We find suggestive evidence that Australia is throughout the period of analysis a dominant transmitter of shocks. This can be due to the fact that Australia's top 10 trading partners are majorly from Asian economies[5] which integrates Australia with other Asian economies. This result is in-line with Paramati et al. (2015), who find that the influence of Australia on Asian markets has significantly increased after the GFC, with the interdependence being driven by strong bilateral trade linkages in the region. Similar transmission mechanisms can be observed in the case of Singapore, Hong Kong and partially for Korea. All aforementioned countries have a large influence and have been more influenced by others than China, India, Indonesia, Japan and Malaysia.

[Insert Figure 3 around here]

4.2 Curvature Factor Interdependencies

Table 4 presents the transmission mechanism of the curvature factors of Asia-Pacific economies. The curvature factor is capturing the humpedness of the yield curve which in turn represents medium-term yield movements. Earlier research conclude that movement in the middle-end of the yield curve does not have any significant influence due to the economic fundamentals (Diebold and Li, 2006; Dewachter and Lyrio, 2006). However, Mönch (2012) provide evidence that the curvature is informative in capturing the future movements of the yield curve. Hence, the regional integration in curvature indicates the co-movements in expectations of future yield curves. The linkages in the curvature factors is the lowest relative to the other yield curve factors. The total connectedness index is down to 20.2% illustrating that the majority of the dynamics can be explained by the own-variance. This result is consistent with the literature that suggests that the curvature is rather non-responsive to external shocks and more independent than short-term and

[5] See asianbondsonline.adb.org

long-term interest rates (Sowmya et al., 2016). The lower level of integration could be because of the level of liquidity at the medium end of the yield curve. This lower level of independence could be attractive to investors for diversification purposes and thus for portfolio risk management. We find that Australia, Hong Kong and Singapore are net transmitters of shocks whereas China, India, Japan and Korea are receivers of shocks. The findings of Korea differ which can be explained by the low interdependence across the Asian curvature factor market and due to the non-responsiveness of economic fundamentals (Diebold and Li, 2006; Dewachter and Lyrio, 2006). The low interdependence can be shown by the fact that every level factor is more influenced by others than its the case with the curvature factor. However, results are quite similar to the one of the level factor.

[Insert Table 4 around here]

Figure 4 presents the net total directional connectedness of the curvature factors across time and economies. All dynamics exhibits much lower spillovers than in the other two cases. Interestingly, we find that economies, such as Hong Kong, Indonesia, Japan, Korea and Malaysia exhibit more pronounced spillovers during the introduction of the Asian bond market (2004) which can be an indicator of similar medium-term monetary policy actions.

[Insert Figure 4 around here]

4.3 Slope Factor Interdependencies

Table 5 refers to the slope dynamics of the term structure which represents short-term interest rate movements that are influenced through short-term monetary policy. Thus, the slope of the yield curve is determined by domestic and not by global factors and hence reflect central bank decisions (Jotikasthira et al., 2015). The convergence of Asia-Pacific business cycles and monetary policy actions lead to increased slope factor integration (Kumar and Okimoto, 2011).

We continue to focus on the propagation mechanism of slope factors which is shown in Table 5. The total connectedness index of the slope factor is 32.2% which means that the slope factor dynamics are more interrelated then the curvature factors but less integrated than the level factors. This finding is expected since the level factor is driven by common global factors whereas the slope factor is driven by domestic factors. The important bilateral spillovers are the same as previously discussed in the level factor case. The dominant transmitters of shocks are Australia, Singapore, Hong Kong and Korea.

Additionally, own-country influence in the slope factor is highest in China (82.1%), indicating china is more responsive to the domestic rather than external shocks. These findings suggest that China is non-responsive towards external factors at the short-end of the yield curve. These results corroborate with Tsukuda et al. (2017), who has shown that the Chinese bond markets are weakly integrated with the regional and global bond markets.

At the same time, the Malaysian slope factor is mainly influenced by Indonesia and vice versa. Malaysian and Indonesian economies share similar characteristics from ethnicity to the financial system. Both economies follow an Islamic financial system and are worldwide dominant issuers of the Sukuk bonds. Furthermore, foreign investments in the sovereign bond market of these economies are high compared to other Asia-Pacific economies. Thus, these two economies serve as an example, whereby the synchronicity of financial systems lead to increased integration at the short-end of the yield curve.

In addition, the intermarket linkages between Hong Kong and Singapore is found to be quite high. Even though, Hong Kong and Singapore are small open economies with scarce natural resources they have developed into international trade and financial centers in the Asia-Pacific region[6]. Moreover, Hong Kong constitutes about 12.3% of total Singaporean exports and ranks second among the top trading partners next to China (14.5%)[7]. Thus, the similar characteristics of the economies, coupled with trade and financial linkages are likely to have led to the increased integration of the slope factor in the region.

[Insert Table 5 around here]

Figure 5 corroborates that Singapore Korea, Hong Kong and Australia are the net transmitter of shocks in the region. India, Japan and Malaysia are found to be the main net receiver of shocks nearly throughout the whole period of analysis.

[6]See, www.scmp.com.
[7]See www.worldstopexports.com.

All over all our previous findings are rather consistent since they are thorough the study suggesting the same economies as transmitters and receivers of shocks with the only exception being Korea in the case of curvature dynamics.

[Insert Figure 5 around here]

4.4 Yield Curve Integration

Figure 6 shows the dynamic total connectedness over the period from January, 2003 to December, 2017 of all three latent factors. The results indicate that all indices are varying over time and are economic event dependent. The peaks highlight the introduction of the Asia-Pacific bond market (2004) and the Global Financial Crisis (2009). Furthermore, we see that all factors exhibit similar co-movements from the beginning until 2013. From 2013 onwards, the level and slope interconnectedness measures increase whereas the curvature interconnectedness measure is slightly decreasing. This can be explained by the US tapering of FED's quantitative easing policy which had a severe impact on Asia-Pacific economies.

In addition, we see that the level factor exhibits the highest values throughout the period of analysis indicating that the long-term interest rates are highly interconnected. This in turn means that long-term monetary policy actions are similar in the Asia-Pacific region and that monetary policy actions are not as independent as one might think.

Finally, the dynamic total connectedness measure of the curvature factor is analyzed which according to economic theory is rather non-responsive of external shocks. Hence, it can be seen as being influenced by country-specific economic indicators. We see that throughout the period of analysis, except for the small increase during the GFC, the trend seems to be decreasing indicating that curvature becomes more and more independent which is in-line with the assumption that it is non-responsive to external influence.

[Insert Figure 6 around here]

Thus, the total connectedness results for the three yield curve factors clearly indicate that the Asia-Pacific bond market integration is high in level followed by the slope and curvature factors. This implies that in the long-run interest rates movements are closely interrelated which is essential for refinancing schemes. These findings are in-line with economic theory since long-term financing involves more uncertainty than short-term financing. The short-lived erratic behaviour of the short-term interest rate interconnectedness during the GFC illustrates the negative spillover to the short-term financing scheme of banks and firms. Lastly, the dynamic connectedness of the curvature factor decreases over time which illustrates that the influence of external sources, even if already low, decreases even further. This could indicate that the negative US housing market spillover is near

5 Concluding Remarks

This study investigates the time-varying interdependencies in the term structure of interest rates in Asia-Pacific countries across maturity spectrum. First, the term structure of interest rates is decomposed into three latent factors using the Dynamic Nelson-Siegel model. Subsequently, the transmission mechanism of each of the three factors which are capturing the long-term, medium-term and short-term movements is investigated via a TVP-VAR-based connectedness approach.

The study finds that interconnectedness is highest in the level factor whereas the lowest interconnectedness in observed in the curvature factor. Australia, Hong Kong and Singapore are the dominant transmitter of shocks whereas China, India, Indonesia, Japan and Malaysia are net receivers of shocks. Korea is a net transmitter of short-term and long-term shocks however a receiver of medium-term shocks. The results of the study supports and adds to the existing literature that financial openness and trade linkages play a vital role in the integration of long term rates. On the other hand, similar financial characteristics of economies coupled with trade and financial linkages play a vital role in the integration of short term rates in the region.

The investigation of regional integration helps policymakers to assess the degree of short-term, medium-term and long-term monetary policy independence and hence its vulnerabilities with respect to financial contagion. It helps the monetary policy authorities in particular to evaluate the efficacy of their policy actions given the sensitivity of one market affecting the other. Furthermore, the provided results are also interesting for market participants investing in Asia pacific bond markets to consider regional influences, contagion mechanism in framing the diversification and hedging strategies in their portfolios.

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Table 1: Size of LCY bond market in Asian Region

Country	2003	2017
China	328.03	6326.39
Hong Kong	15.16	147.59
India	29.36	88.92
Indonesia	59.09	155.65
Japan	4670.36	9520.22
Korea	165	827.04
Malaysia	53.33	166.3
Singapore	37.1	166.02

Notes: The amount are entered in USD denominate for comparison and data is sourced from Asian bond online. The Australian data is not available.

Table 2: Summary Statistics

	Australia	China	Hong Kong	India	Indonesia	Japan	Korea	Malaysia	Singapore
Level Factor									
ADF (BIC)	-9.849***	-7.402***	-9.331***	-8.810***	-12.238***	-6.474***	-9.990***	-10.152***	-8.283***
	(0.367)	(0.511)	(0.335)	(0.700)	(0.493)	(0.979)	(0.369)	(0.959)	(0.878)
$Q(12)$	12.399**	26.245***	27.171***	19.524***	41.765***	101.995***	7.233	39.328***	52.793***
	(0.044)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.349)	(0.000)	(0.000)
$Q^2(12)$	3.692	7.006	26.440***	3.756	9.198	7.770	45.043***	1.571	7.724
	(0.831)	(0.375)	(0.000)	(0.823)	(0.172)	(0.291)	(0.000)	(0.990)	(0.296)
Unconditional Correlation (2003/01 - 2008/08) [2008/09 - 2017/12]									
Australia	(1.00) [1.00]	(0.08) [0.18]	(0.64) [0.67]	(0.06) [0.31]	(-0.07) [0.39]	(-0.44) [-0.24]	(0.40) [0.64]	(0.12) [0.50]	(0.38) [0.60]
China	(0.08) [0.18]	(1.00) [1.00]	(0.21) [0.22]	(0.07) [0.17]	(-0.46) [0.22]	(0.09) [-0.11]	(0.08) [0.28]	(0.23) [0.34]	(0.12) [0.13]
Hong Kong	(0.64) [0.67]	(0.21) [0.22]	(1.00) [1.00]	(0.02) [0.28]	(-0.10) [0.37]	(-0.34) [-0.25]	(0.34) [0.49]	(0.02) [0.50]	(0.38) [0.67]
India	(0.06) [0.31]	(0.07) [0.17]	(0.02) [0.28]	(1.00) [1.00]	(0.00) [0.28]	(0.02) [0.20]	(0.02) [0.25]	(0.29) [0.34]	(0.18) [0.18]
Indonesia	(-0.07) [0.39]	(-0.46) [0.22]	(-0.10) [0.37]	(0.00) [0.28]	(1.00) [1.00]	(0.01) [-0.07]	(0.02) [0.55]	(-0.04) [0.54]	(0.10) [0.31]
Japan	(-0.44) [-0.24]	(0.09) [-0.11]	(-0.34) [-0.25]	(0.02) [0.20]	(0.01) [-0.07]	(1.00) [1.00]	(-0.17) [-0.06]	(-0.08) [-0.07]	(-0.39) [-0.25]
Korea	(0.40) [0.64]	(0.08) [0.28]	(0.34) [0.49]	(0.02) [0.25]	(0.02) [0.55]	(-0.17) [-0.06]	(1.00) [1.00]	(0.00) [0.58]	(0.31) [0.45]
Malaysia	(0.12) [0.50]	(0.23) [0.34]	(0.02) [0.50]	(0.29) [0.34]	(-0.04) [0.54]	(-0.08) [-0.07]	(0.00) [0.58]	(1.00) [1.00]	(0.36) [0.43]
Singapore	(0.38) [0.60]	(0.12) [0.13]	(0.38) [0.67]	(0.18) [0.18]	(0.10) [0.31]	(-0.39) [-0.25]	(0.31) [0.45]	(0.36) [0.43]	(1.00) [1.00]
Curvature Factor									
ADF (BIC)	-9.849***	-7.402***	-9.331***	-8.810***	-12.238***	-6.474***	-9.990***	-10.152***	-8.283***
	(0.367)	(0.511)	(0.335)	(0.700)	(0.493)	(0.979)	(0.369)	(0.959)	(0.878)
$Q(12)$	12.399**	26.245***	27.171***	19.524***	41.765***	101.995***	7.233	39.328***	52.793***
	(0.044)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.349)	(0.000)	(0.000)
$Q^2(12)$	3.692	7.006	26.440***	3.756	9.198	7.770	45.043***	1.571	7.724
	(0.831)	(0.375)	(0.000)	(0.823)	(0.172)	(0.291)	(0.000)	(0.990)	(0.296)
Unconditional Correlation (2003/01 - 2008/08) [2008/09 - 2017/12]									
Australia	(1.00) [1.00]	(-0.02) [-0.03]	(0.18) [0.15]	(-0.04) [0.29]	(0.13) [0.10]	(0.01) [0.20]	(0.09) [-0.14]	(0.16) [0.01]	(-0.09) [-0.11]
China	(-0.02) [-0.03]	(1.00) [1.00]	(0.04) [-0.10]	(0.04) [-0.24]	(-0.12) [0.23]	(0.31) [-0.03]	(0.12) [-0.18]	(0.00) [-0.06]	(0.13) [-0.20]
Hong Kong	(0.18) [0.15]	(0.04) [-0.10]	(1.00) [1.00]	(-0.01) [0.15]	(0.26) [0.11]	(0.43) [0.17]	(0.11) [-0.07]	(0.14) [0.08]	(0.25) [0.18]
India	(-0.04) [0.29]	(0.04) [-0.24]	(-0.01) [0.15]	(1.00) [1.00]	(0.01) [0.06]	(0.22) [0.12]	(0.02) [-0.10]	(0.03) [0.12]	(0.20) [-0.14]
Indonesia	(0.13) [0.10]	(-0.12) [0.23]	(0.26) [0.11]	(0.01) [0.06]	(1.00) [1.00]	(0.17) [-0.15]	(-0.18) [-0.37]	(0.36) [-0.06]	(0.06) [-0.06]
Japan	(0.01) [0.20]	(0.31) [-0.03]	(0.43) [0.17]	(0.22) [0.12]	(0.17) [-0.15]	(1.00) [1.00]	(0.21) [0.16]	(0.17) [0.09]	(0.23) [0.14]
Korea	(0.09) [-0.14]	(0.12) [-0.18]	(0.11) [-0.07]	(0.02) [-0.10]	(-0.18) [-0.37]	(0.21) [0.16]	(1.00) [1.00]	(-0.23) [-0.08]	(0.15) [-0.04]
Malaysia	(0.16) [0.01]	(0.00) [-0.06]	(0.14) [0.08]	(0.03) [0.12]	(0.36) [-0.06]	(0.17) [0.09]	(-0.23) [-0.08]	(1.00) [1.00]	(0.21) [0.06]
Singapore	(-0.09) [-0.11]	(0.13) [-0.20]	(0.25) [0.18]	(0.20) [-0.14]	(0.06) [-0.06]	(0.23) [0.14]	(0.15) [-0.04]	(0.21) [0.06]	(1.00) [1.00]
Slope Factor									
ADF (BIC)	-9.545***	-9.283***	-10.363***	-8.454***	-9.022***	-6.654***	-10.372***	-9.370***	-8.098***
	(0.999)	(0.478)	(0.444)	(0.780)	(0.977)	(0.970)	(0.930)	(0.987)	(0.792)
$Q(12)$	15.818***	23.628***	16.085***	35.145***	6.024	88.913***	8.503	27.227***	44.835***
	(0.008)	(0.000)	(0.007)	(0.000)	(0.503)	(0.000)	(0.224)	(0.000)	(0.000)
$Q^2(12)$	10.232	1.641	29.517***	5.259	16.930***	7.447	43.269***	5.872	6.270
	(0.113)	(0.988)	(0.000)	(0.612)	(0.005)	(0.325)	(0.000)	(0.524)	(0.469)
Unconditional Correlation (2003/01 - 2008/08) [2008/09 - 2017/12]									
Australia	(1.00) [1.00]	(-0.06) [0.11]	(0.18) [0.48]	(0.12) [-0.05]	(-0.20) [0.33]	(-0.03) [-0.20]	(0.10) [0.52]	(-0.20) [0.39]	(0.08) [0.46]
China	(-0.06) [0.11]	(1.00) [1.00]	(-0.08) [0.01]	(0.06) [0.23]	(-0.10) [0.19]	(-0.03) [-0.05]	(0.02) [0.25]	(-0.01) [0.17]	(0.02) [0.06]
Hong Kong	(0.18) [0.48]	(-0.08) [0.01]	(1.00) [1.00]	(-0.05) [-0.08]	(0.10) [0.13]	(-0.12) [-0.27]	(0.05) [0.37]	(0.13) [0.42]	(0.37) [0.68]
India	(0.12) [-0.05]	(0.06) [0.23]	(-0.05) [-0.08]	(1.00) [1.00]	(0.04) [-0.06]	(-0.15) [-0.14]	(-0.02) [0.14]	(-0.01) [0.00]	(-0.03) [0.06]
Indonesia	(-0.20) [0.33]	(-0.10) [0.19]	(0.10) [0.13]	(0.04) [-0.06]	(1.00) [1.00]	(0.01) [-0.07]	(0.15) [0.23]	(0.25) [0.41]	(0.06) [0.09]
Japan	(-0.03) [-0.20]	(-0.03) [-0.05]	(-0.12) [-0.27]	(-0.15) [-0.14]	(0.01) [-0.07]	(1.00) [1.00]	(-0.13) [-0.18]	(-0.11) [-0.24]	(-0.33) [-0.28]
Korea	(0.10) [0.52]	(0.02) [0.25]	(0.05) [0.37]	(-0.02) [0.14]	(0.15) [0.23]	(-0.13) [-0.18]	(1.00) [1.00]	(0.03) [0.47]	(0.10) [0.47]
Malaysia	(-0.20) [0.39]	(-0.01) [0.17]	(0.13) [0.42]	(-0.01) [0.00]	(0.25) [0.41]	(-0.11) [-0.24]	(0.03) [0.47]	(1.00) [1.00]	(0.34) [0.35]
Singapore	(0.08) [0.46]	(0.02) [0.06]	(0.37) [0.68]	(-0.03) [0.06]	(0.06) [0.09]	(-0.33) [-0.28]	(0.10) [0.47]	(0.34) [0.35]	(1.00) [1.00]

Notes: ***,**,* denote significance at 1%, 5% and 10% significance level; ADF(BIC): Augmented Dickey-Fuller unit-root test where lags are selected using BIC; Q(12) and $Q^2(12)$: Weighted portmanteau test with 12 lags.

Table 3: Level Factor Connectedness Table

	Australia	China	Hong Kong	India	Indonesia	Japan	Korea	Malaysia	Singapore	FROM
Australia	42.188	1.039	17.861	2.951	2.738	6.459	11.518	4.907	10.340	57.812
China	4.589	73.100	2.384	3.055	3.343	3.470	2.607	5.554	1.897	26.900
Hong Kong	20.139	1.872	43.911	2.714	2.514	5.007	9.816	3.291	10.737	56.089
India	5.096	2.014	6.097	68.524	3.695	0.602	2.415	7.059	4.498	31.476
Indonesia	5.108	3.305	3.967	2.799	68.048	0.864	8.838	2.626	4.445	31.952
Japan	9.450	2.516	3.484	0.676	1.082	73.765	1.381	1.357	6.290	26.235
Korea	13.706	1.643	9.477	1.644	6.096	1.056	51.932	6.313	8.133	48.068
Malaysia	8.364	5.015	5.100	5.597	3.929	2.717	6.861	54.782	7.635	45.218
Singapore	12.898	0.743	12.911	2.435	3.082	4.737	6.637	4.472	52.084	47.916
Contribution TO others	79.350	18.146	61.282	21.871	26.479	24.911	50.072	35.578	53.975	TCI
Net spillovers	21.539	-8.754	5.193	-9.605	-5.472	-1.325	2.004	-9.639	6.059	41.296

Notes: Values reported are variance decompositions based on a 36-months-ahead forecasts.
In both periods, a TVP-VAR(0.99,0.96) lag length of order 1 is selected by the BIC.

Table 4: Curvature Factor Connectedness Table

	Australia	China	Hong Kong	India	Indonesia	Japan	Korea	Malaysia	Singapore	FROM
Australia	83.206	1.394	2.904	3.036	0.732	2.186	1.284	2.627	2.632	16.794
China	2.456	83.675	0.699	3.354	1.569	3.011	1.120	2.061	2.055	16.325
Hong Kong	2.456	1.259	76.188	2.058	2.914	7.755	1.414	1.122	4.832	23.812
India	3.385	3.162	2.877	81.391	0.955	3.545	0.737	1.568	2.380	18.609
Indonesia	1.663	2.022	3.823	0.711	82.178	1.131	2.838	3.935	1.699	17.822
Japan	2.432	1.665	6.071	3.831	1.406	76.516	1.275	1.694	5.110	23.484
Korea	1.547	1.403	2.232	0.790	4.697	1.485	82.392	3.260	2.195	17.608
Malaysia	1.231	2.429	2.939	1.835	3.910	1.230	2.544	77.737	6.146	22.263
Singapore	3.205	1.664	5.498	1.892	1.080	2.200	3.396	5.827	75.237	24.763
Contribution TO others	18.375	14.998	27.042	17.508	17.263	22.542	14.608	22.095	27.049	TCI
Net spillovers	1.580	-1.327	3.230	-1.101	-0.559	-0.942	-3.000	-0.168	2.286	20.164

Notes: Values reported are variance decompositions based on a 36-months-ahead forecasts.
In both periods, a TVP-VAR(0.99,0.96) lag length of order 1 is selected by the BIC.

Table 5: Slope Factor Connectedness Table

	Australia	China	Hong Kong	India	Indonesia	Japan	Korea	Malaysia	Singapore	FROM
Australia	63.556	1.172	9.540	1.071	1.854	2.253	8.778	2.850	8.927	36.444
China	1.719	82.125	1.962	4.364	2.587	1.226	2.943	2.062	1.012	17.875
Hong Kong	9.537	1.205	58.559	1.836	1.080	1.967	7.245	3.129	15.443	41.441
India	7.904	4.897	2.769	72.310	1.221	2.366	2.866	4.298	1.368	27.690
Indonesia	2.342	2.634	3.242	0.767	79.425	0.534	2.914	6.413	1.729	20.575
Japan	3.449	1.241	2.986	5.440	1.551	75.724	2.493	1.761	5.354	24.276
Korea	8.975	3.155	5.942	2.495	2.687	1.441	60.083	7.296	7.927	39.917
Malaysia	4.557	2.276	3.951	2.123	8.136	3.018	9.952	60.706	5.282	39.294
Singapore	8.442	1.074	12.973	1.638	0.867	4.922	10.074	2.559	57.451	42.549
Contribution TO others	46.925	17.654	43.365	19.733	19.983	17.727	47.264	30.368	47.041	TCI
Net spillovers	10.481	-0.220	1.923	-7.956	-0.592	-6.549	7.347	-8.926	4.492	32.229

Notes: Values reported are variance decompositions based on a 36-months-ahead forecasts.
In both periods, a TVP-VAR(0.99,0.99) lag length of order 1 is selected by the BIC.

Figure 1: Foreign Holdings in LCY Government Bonds

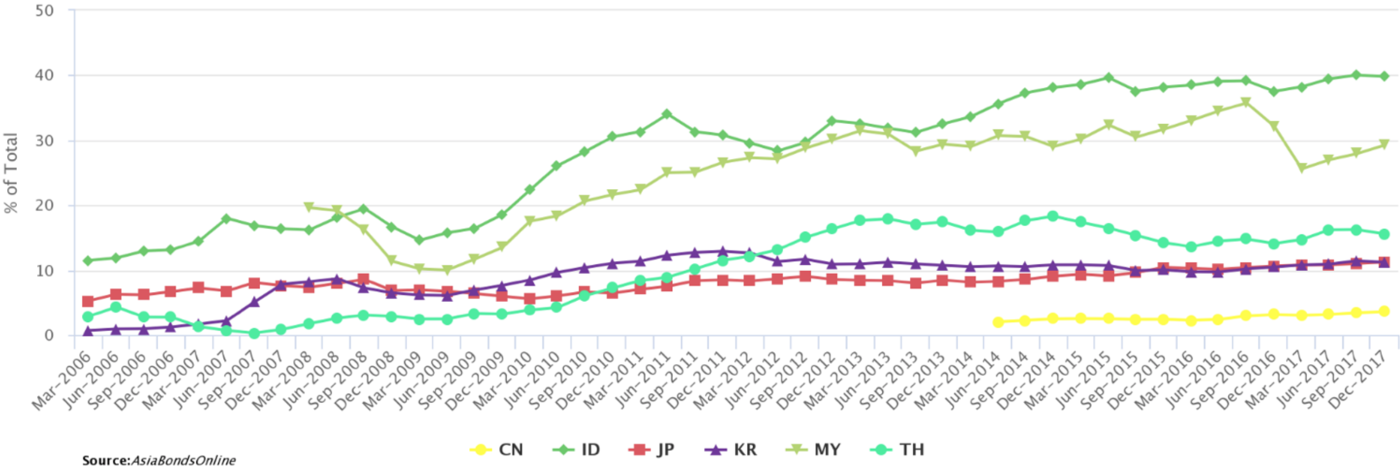


Figure 2: Raw and First Differenced Series

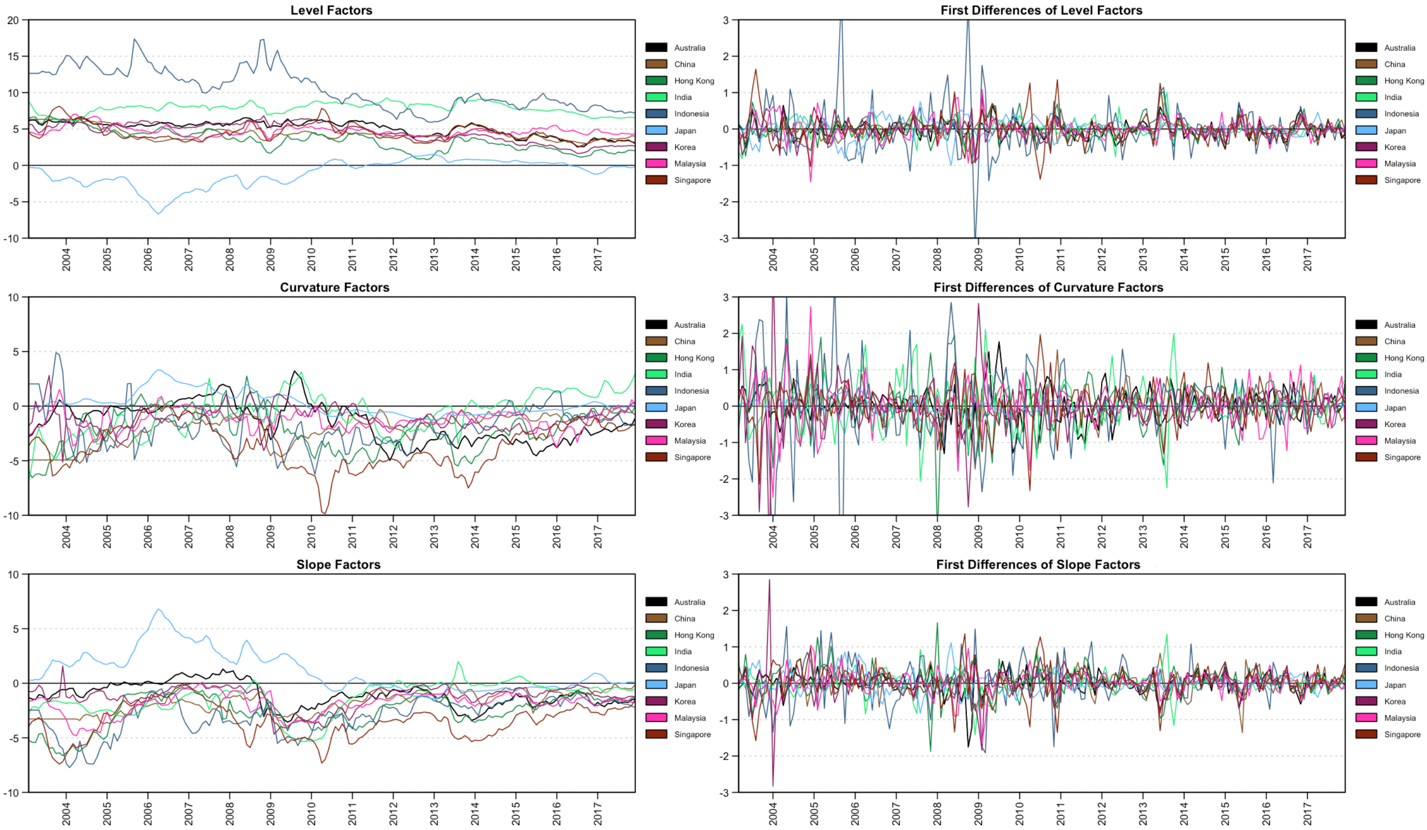
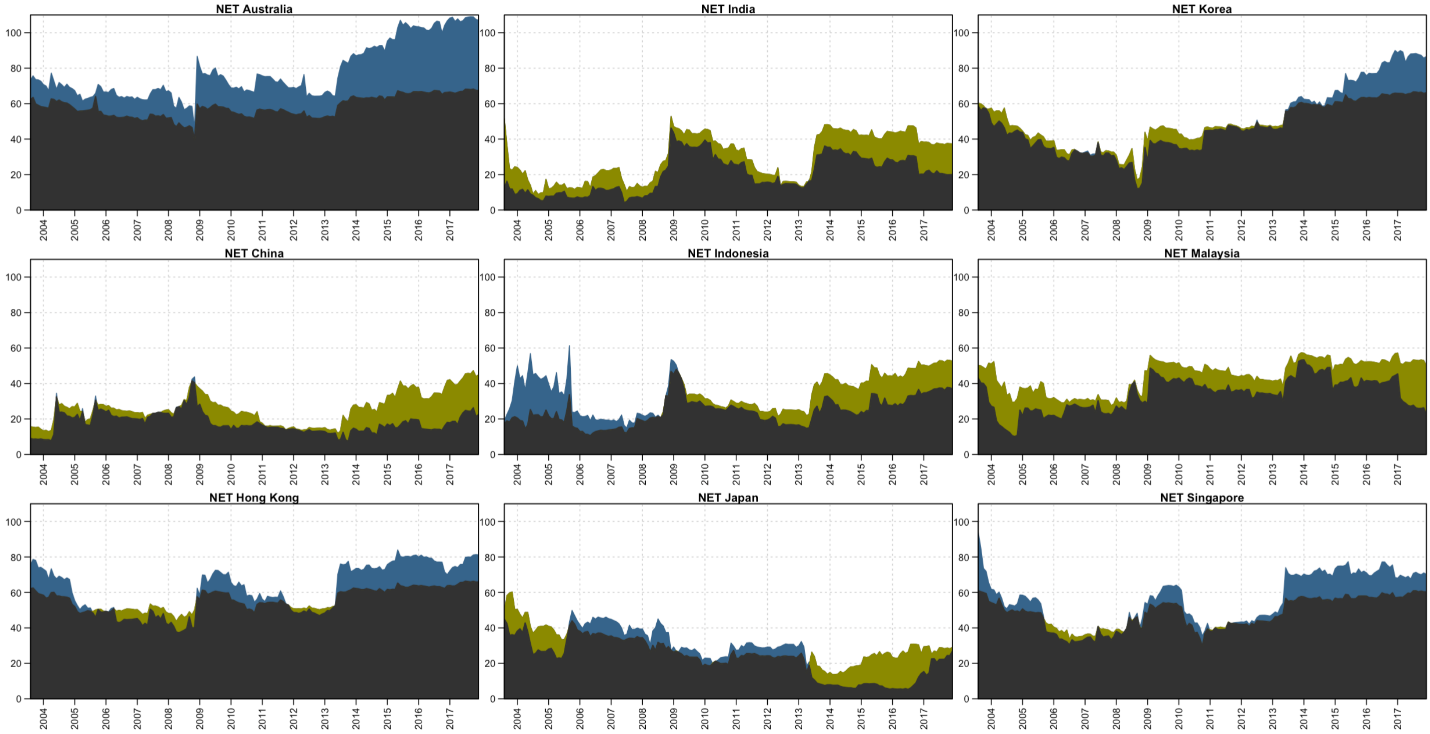
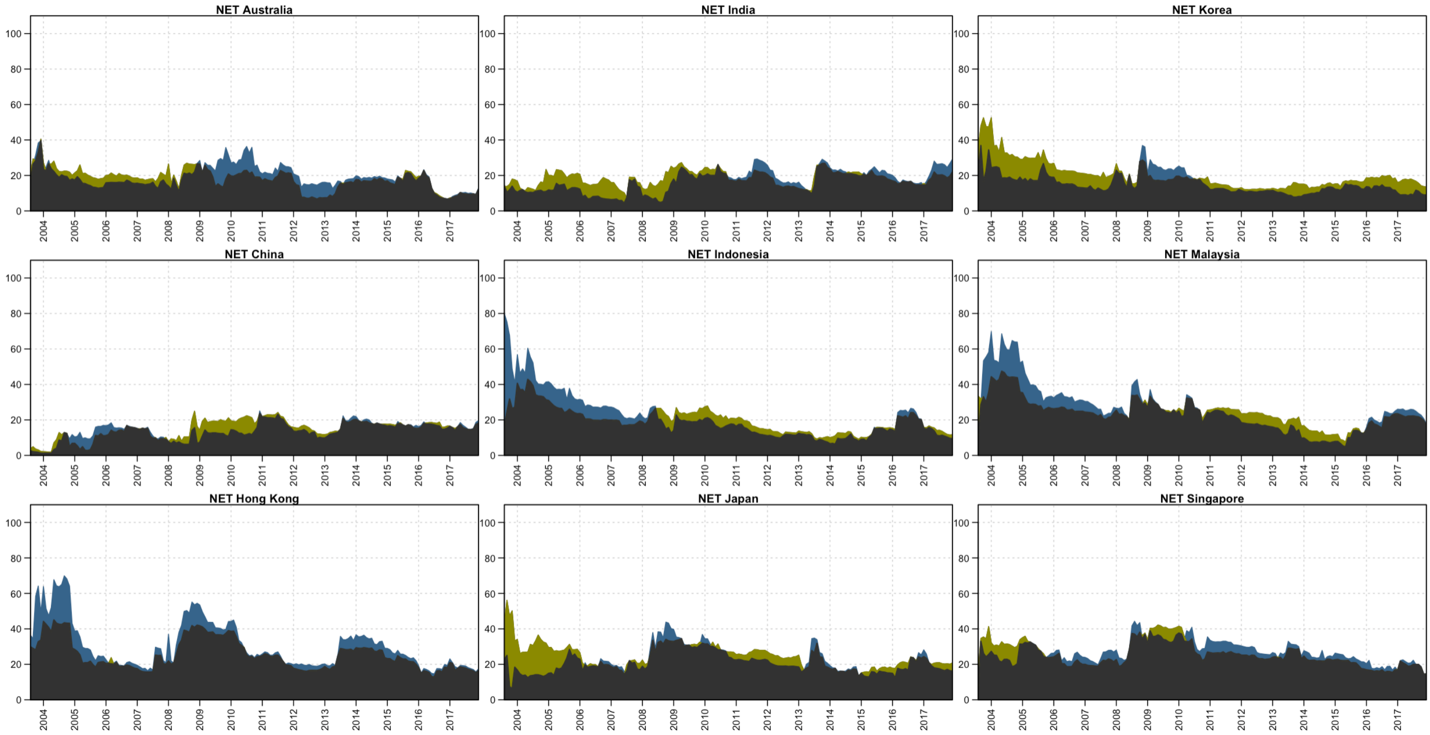


Figure 3: Level Factor Net Total Directional Connectedness



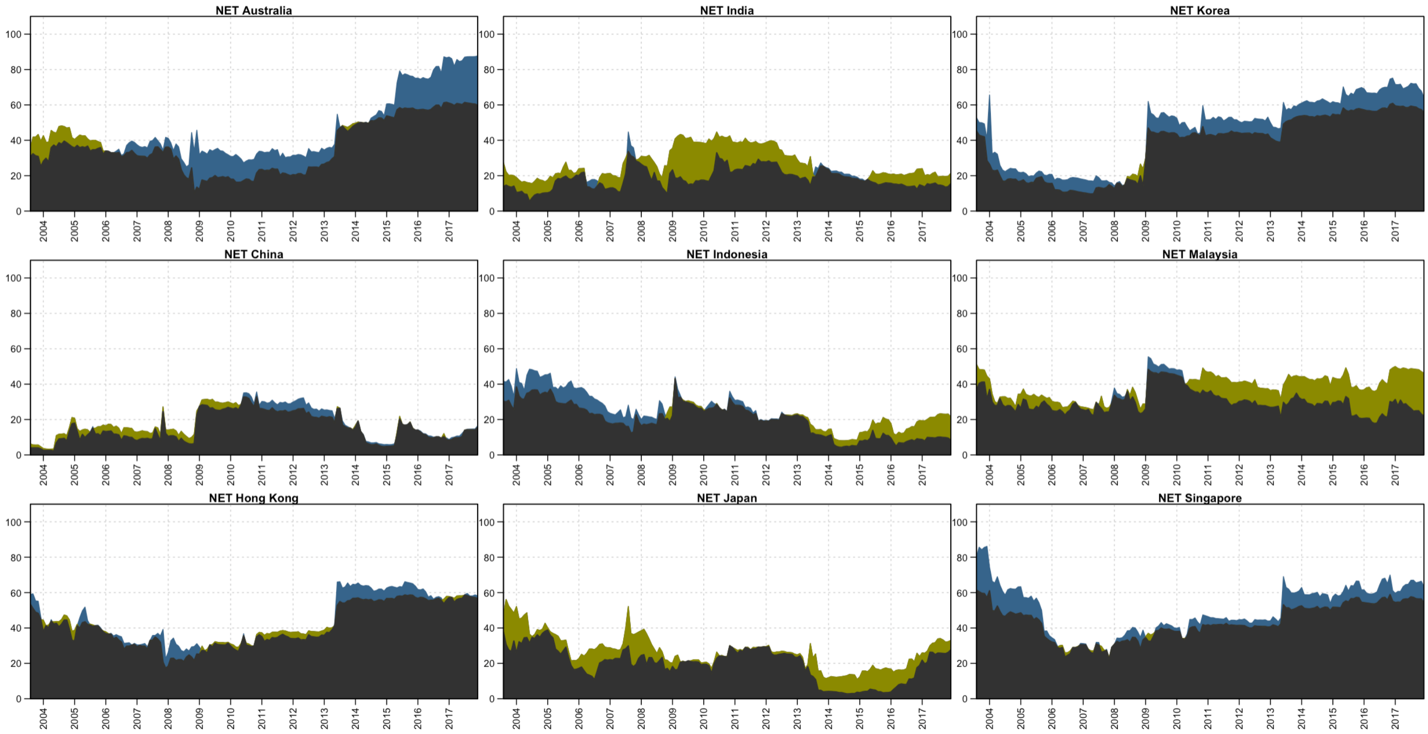
Notes: Black areas represent the overlap of the dynamic total directional connectedness TO and FROM others. Hence, positive (negative) net total directional connectedness measures are represented in blue (yellow). Results are based on a TVP-VAR(0.99,0.99) with one lag.

Figure 4: Curvature Factor Net Total Directional Connectedness



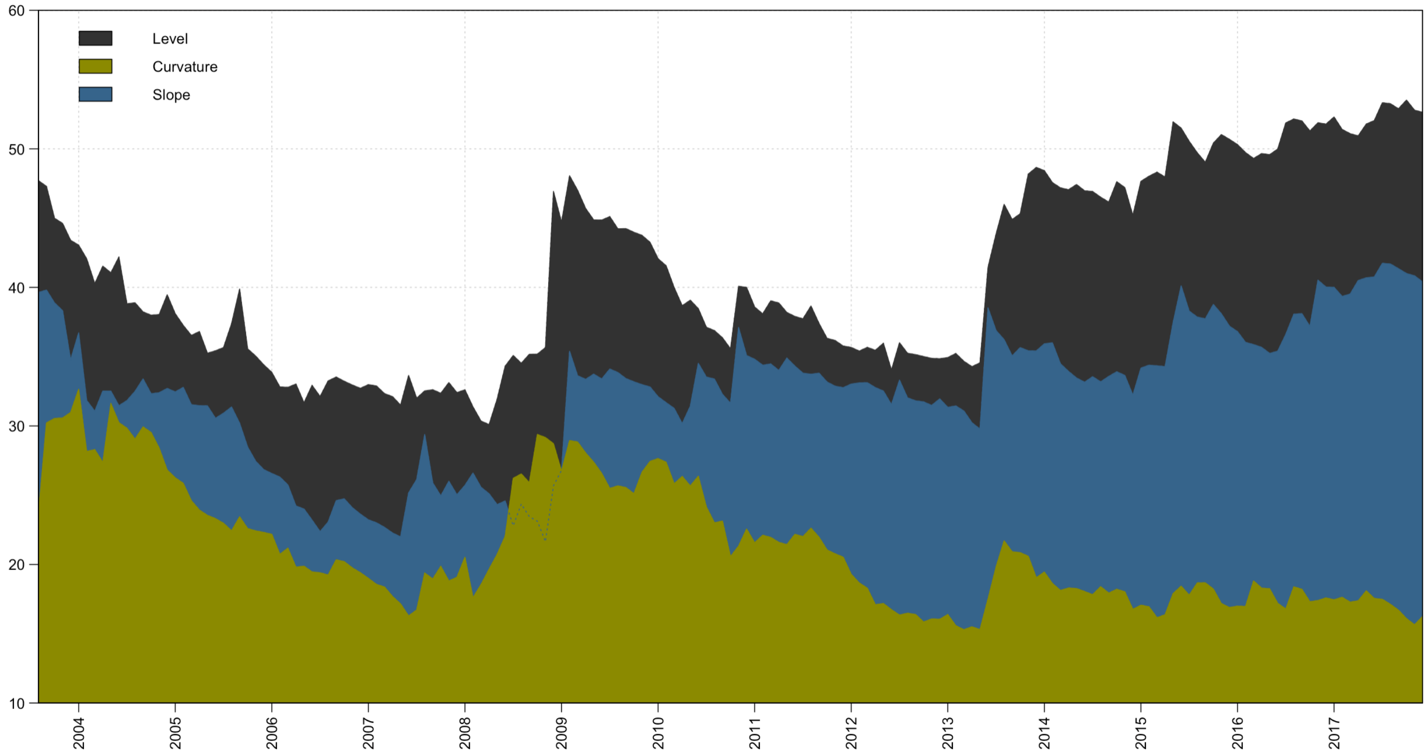
Notes: Black areas represent the overlap of the dynamic total directional connectedness TO and FROM others. Hence, positive (negative) net total directional connectedness measures are represented in blue (yellow). Results are based on a TVP-VAR(0.99,0.99) with one lag.

Figure 5: Slope Factor Net Total Directional Connectedness



Notes: Black areas represent the overlap of the dynamic total directional connectedness TO and FROM others. Hence, positive (negative) net total directional connectedness measures are represented in blue (yellow). Results are based on a TVP-VAR(0.99,0.99) with one lag.

Figure 6: Dynamic Total Connectedness



A Online Appendix

Figure A.1: Zero-coupon yield curves

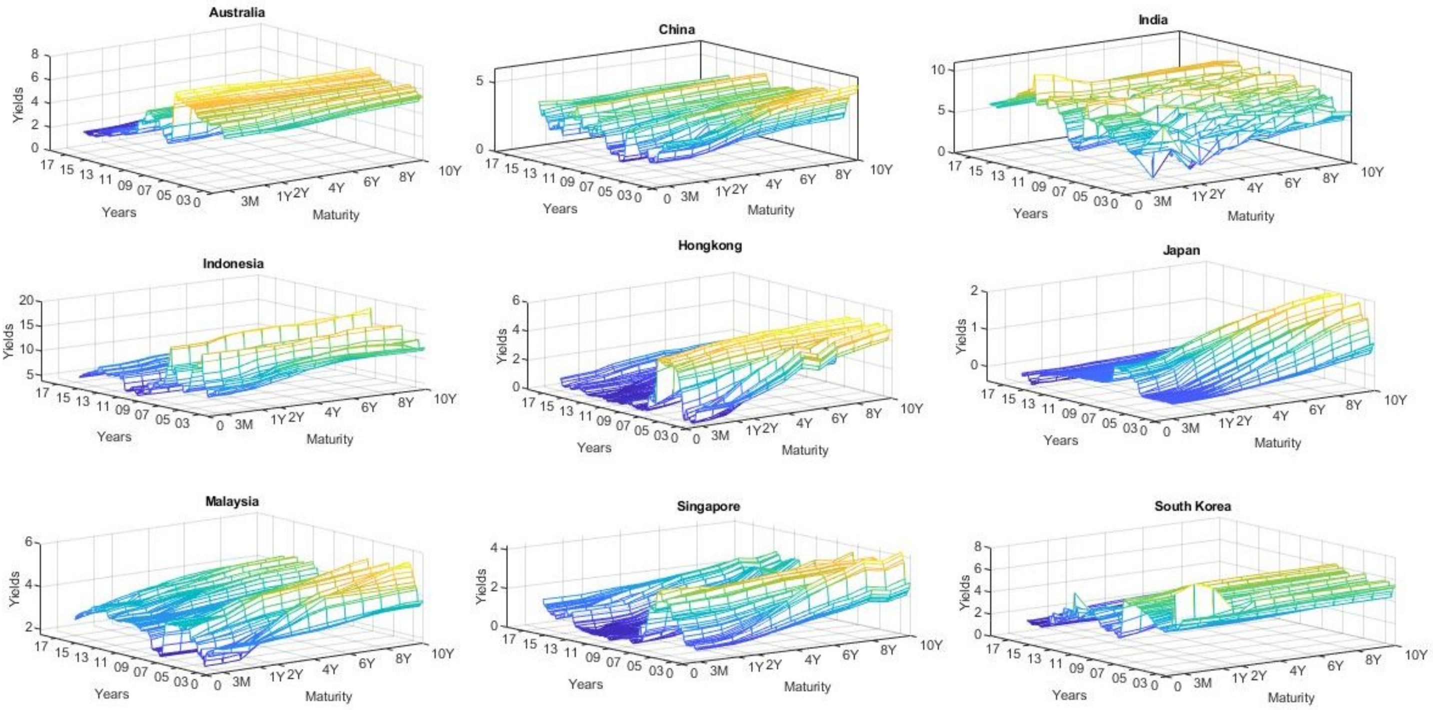
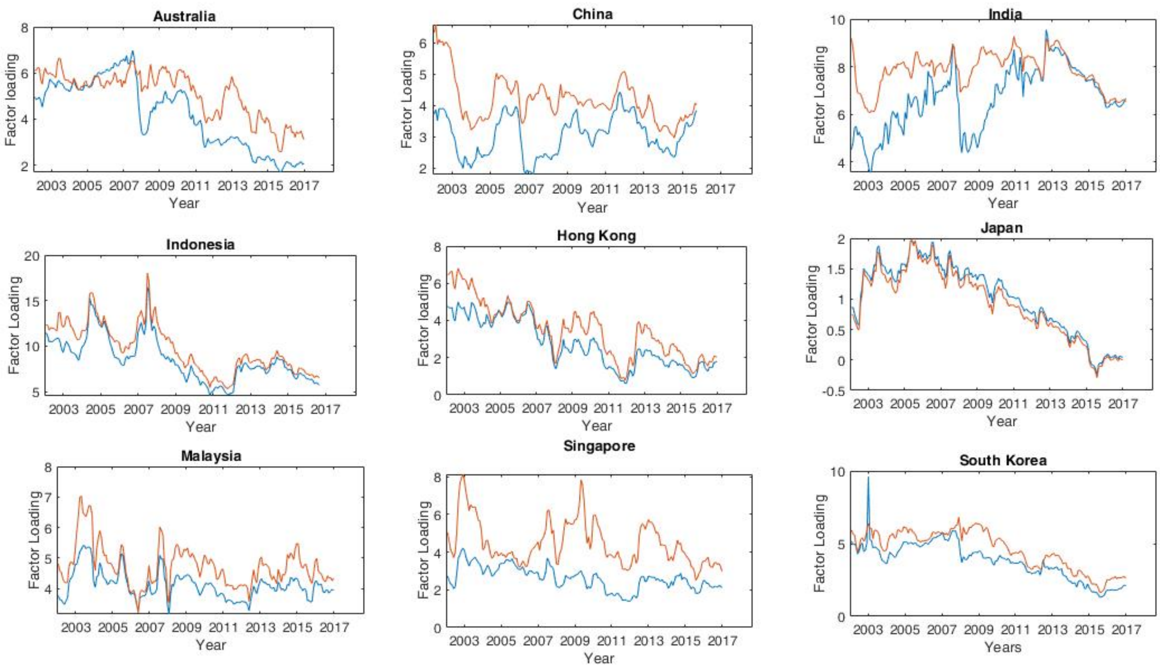
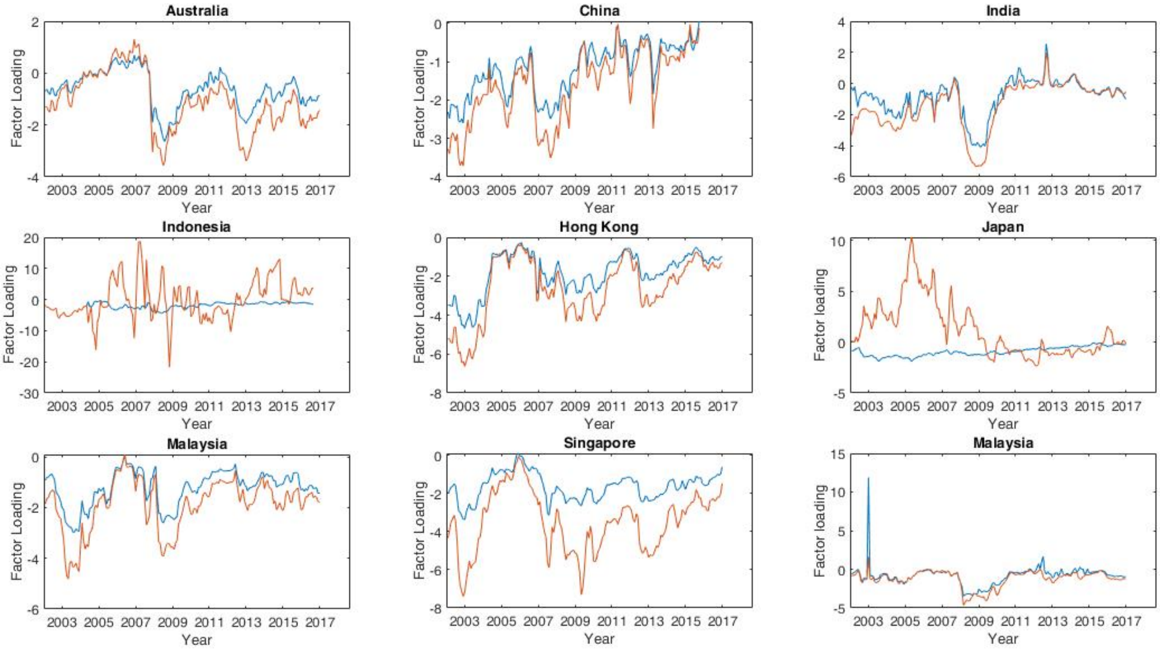


Figure A.2: Comparison of Extracted level factor with the empirical proxy



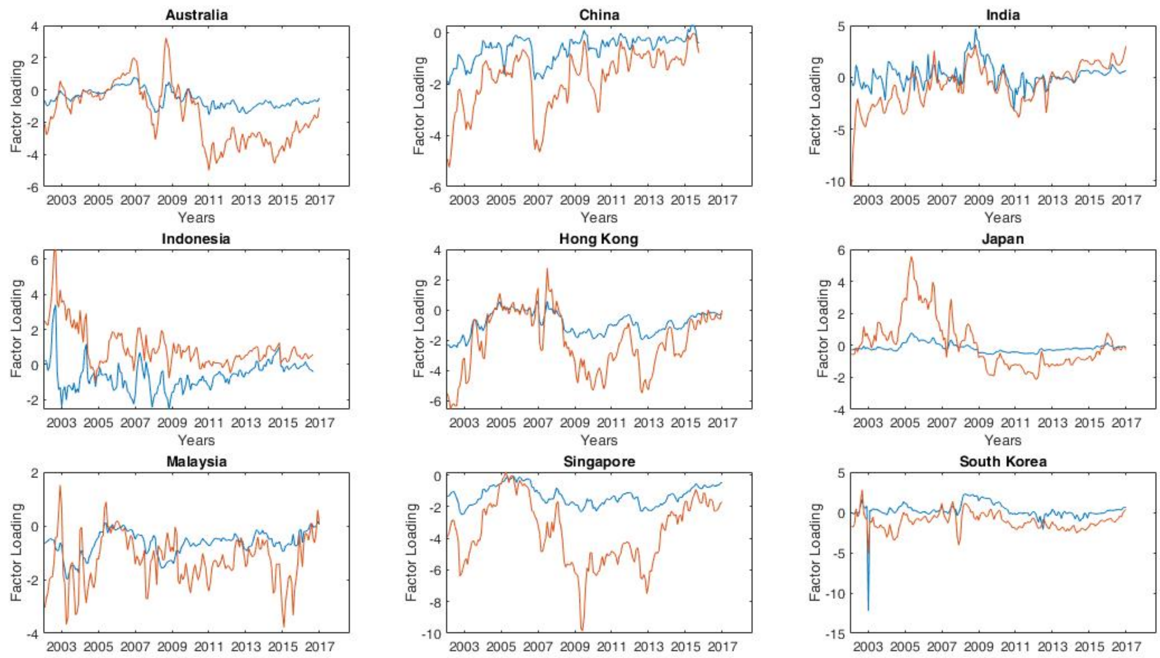
Notes : Red lines represents the extracted level factor using Dynamic Nelson Siegel model. Blue line represents the empirical level factor. The empirical level factor is estimated as average of 3,60 and 120 months yield rate.

Figure A.3: Comparison of Extracted slope factor with the empirical proxy



Notes: Red lines represents the extracted slope factor using Dynamic Nelson Siegel model. Blue line represents the empirical slope factor. The empirical slope factor is estimated as difference between the 3month and 12 months yield rate

Figure A.4: Comparison of Extracted curvature factor with the empirical proxy



Notes: Red lines represents the extracted curvature factor using Dynamic Nelson Siegel model. Blue line represents the empirical curvature factor. The empirical curvature factor is estimated as, 2 (yield rate of 60 months - yield rate of 3 months – yield rate of 120 months)