

# On the stability of domestic financial market linkages in the presence of time-varying volatility

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## Abstract

We analyze the stability of domestic financial linkages between periods of calm and turbulent market conditions. Our model develops a simultaneous test of shift contagion and bi-directional pure contagion, which is applied to the equity and currency markets of a group of East Asian emerging economies. Our results show a great deal of instability in these markets with widespread evidence of pure contagion in both directions. There is less evidence of shift contagion with the transmission of common shocks unchanged between regimes for the majority of countries.

*Keywords:* Shift contagion; Pure contagion; Financial market crises; Regime switching

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## **1. Introduction**

The financial system has been rocked by a number of severe turbulent periods over the past two decades. In particular, emerging financial markets have been severely affected. These tumultuous episodes have been characterized by large negative asset returns and high volatility and their repercussions have caused problems for the investment community and policymakers alike. Furthermore, these shocks appear to have spread across both national borders and different asset classes. When the spread of shocks occurs in a manner that could not have been anticipated from existing pre-crisis linkages, this is often labeled as ‘contagion’.

Ever since the 1987 stock market crash in the US, a voluminous literature has developed on the identification and causes of financial market contagion. The majority of studies have tended to concentrate on a single event and study the transmission of shocks from the source market to the same asset class in other international markets. For example, studies such as Forbes and Rigobon (2002), Caporale, Cipollini and Spagnolo (2005), Chiang, Jeon and Li (2007) and Flavin and Panopoulou (2007, 2008) have focused on equity markets; while bond markets are analyzed in Favero and Giavazzi (2002) and Dungey, Fry, Gonzalez-Hermosillo and Martin (henceforth DFGM) (2006); with currency markets receiving the attention of Cerra and Saxena (2002) and Dungey, Fry and Martin (2004). More recently, a number of studies have sought to examine channels of contagion between different asset classes across geographical borders. Hartmann, Straetmans and de Vries (2004) focus on the stock and bond markets of the G5 countries, while Dungey and Martin (2007) and DFGM (2008) analyze East Asian and Latin American markets respectively. Ito and Hashimoto (2005) investigate the interactions between currency and equity markets in East Asian markets.

However, less attention has been afforded to contagious effects between different asset types within the same country. This is an important question as policymakers seek to understand the source and evolution of adverse shocks. Likewise, portfolio managers who are exposed to foreign asset risk will want to be familiar with the stability of asset linkages during varying market conditions. If asset returns exhibit increased comovement during a crisis, then this will compound losses on a country-specific portfolio, whereas markets moving in the opposite direction would provide a hedge against losses in one market. We focus on identifying channels of contagion between currency and equity markets in East Asian markets during periods of high-volatility. In particular, we test for both shift and pure contagion within a unified framework. Shift contagion is defined as a change in the normal relationship between pairs of markets during a crisis. Normal levels of market interdependence are often attributed to linkages such as financial flows or exposure to common shocks. Shift contagion implies that the diffusion of common shocks changes between low- and high-volatility regimes; thereby causing the ‘normal’ relationship between market pairs to become unstable during episodes of financial turmoil. On the other hand, pure contagion is suffered during a crisis period when a shock that is normally idiosyncratic spills over to another market (becoming an additional common factor). The transmission of these idiosyncratic shocks occurs through channels that are not identifiable during normal market conditions.<sup>1</sup> The main innovation of this paper is that we build an empirical model that allows us to simultaneously capture shift and bi-directional pure contagion.<sup>2</sup> Accounting for these bi-directional effects is very important as it allows us to fully assess the extent and

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<sup>1</sup> There is great debate in the literature on the definition of contagion and for an overview the reader is referred to Pericoli and Sbracia (2003).

<sup>2</sup> Dungey, Milunovich and Throp (2008) capture bi-directional pure contagious effects between Asian equity markets after controlling for common external shocks.

impact of market interactions. The correct identification of the type of contagion operating between markets and the stability of market linkages is vital to prescribe appropriate policy.

There is strong theoretical and empirical evidence to suggest that equity and foreign exchange markets are interlinked. Pavlova and Rigobon (2007) develop a theoretical model of stock, bond and exchange rate co-movements, where the sign of the correlation between stock prices and the exchange rate depends upon the relative importance of supply and demand shocks in the economy. Pan, Fok and Liu (2007) find significant evidence of causal relationships between stock and currency markets, though the direction of causality differs across the sampled countries. Likewise, Granger, Huang and Yang (2000) provide evidence of feedback effects between many East Asian stock and FX markets. While, these studies provide evidence of dynamic linkages between markets, our focus is on the transmission of contemporaneous shocks between market pairs.

Our results show strong evidence of bi-directional pure contagion between equity and currency markets. In particular, shocks that are normally specific to the foreign exchange market tend to be transmitted to the equity market for all countries. Similarly, high-volatility equity-specific shocks generate contagious effects in the currency market of all countries except Taiwan. On the other hand, there is less evidence of shift contagion. Only Korea and the Philippines exhibit any statistical evidence of instability in the transmission of common shocks between calm and turbulent market conditions. An analysis of the conditional variance shows that common shocks play a greater role in equity markets than in currency markets. Pure contagion is present in all markets but its overall contribution to risk varies across countries.

The paper is organized as follows. Section 2 presents our empirical model. Section 3 describes the data and discusses the filters applied to the asset returns. Section 4 reports our empirical findings for the contagion tests, while our concluding remarks are contained in section 5.

## **2. Empirical model and econometric methodology**

We extend the methodology of Gravelle, Kichian and Morley (2006) and Flavin and Panopoulou (2008) to test for both shift and bi-directional pure contagion within a unified framework. Gravelle, Kichian and Morley (2006) develop a test for shift contagion. Flavin and Panopoulou (2008) extend the model to capture the potential effects of pure contagion. The key enhancement of our model is that we allow for bi-directional pure contagion. In many studies of contagion, it is possible to identify one particular market as the source of the shock and then test for pure contagious effects from this to other markets e.g. in studies of East Asian equity markets, Hong Kong is often identified as the source (see Forbes and Rigobon, 2002; Chiang, Jeon and Li 2007; Flavin and Panopoulou, (2008); amongst others). However, there is little theoretical or consistent empirical evidence to guide us as to the direction of contagion between stock and foreign exchange markets. Therefore it is ultimately an empirical question.

This framework is ideally suited to capturing the different channels of contagion and represents a move away from the more traditional correlation-based tests that have been criticized in the literature (e.g. see Billio and Pelizzon, 2003; Pesaran and Pick, 2007). The model is bivariate in nature and belongs to the family of factor models widely used in financial economics. The factor model is attractive in that we avoid the debate as to what the ‘fundamentals’ should be and it overcomes

problems associated with measuring contagion through changes to correlation coefficients in the presence of unobservable shocks (see Rigobon, 2003b). The model can be summarized as follows. Let  $r_{E,t}$  and  $r_{FX,t}$  represent equity market and currency returns respectively. Returns can be decomposed into an expected,  $\mu_i$ , and an unexpected component,  $u_{it}$ , reflecting the arrival of news to financial markets, i.e.

$$r_{it} = \mu_i + u_{it}, E(u_{it}) = 0, i = E, FX \text{ and } E(u_{E,t}, u_{FX,t}) \neq 0. \quad (1)$$

The forecast errors are allowed to be contemporaneously correlated, implying that common structural shocks may potentially be driving both returns. We decompose the forecast errors of each asset return into an idiosyncratic and a common shock. Let  $z_{ct}$  and  $z_{it}, i = E, FX$  denote the common and idiosyncratic shocks respectively and let their impacts on asset returns be  $\sigma_{cit}$  and  $\sigma_{it}, i = E, FX$ . Then the forecast errors are written as:

$$u_{it} = \sigma_{cit} z_{ct} + \sigma_{it} z_{it}, i = E, FX. \quad (2)$$

Furthermore, the shock variances are normalized to unity, which means the impact coefficients may be interpreted as their standard deviations.

All unobservable shocks are heteroskedastic, which overcomes a shortcoming of some previous work, (e.g. Forbes and Rigobon, 2002), where it is implicitly assumed that any omitted common shocks have a constant variance. Following Gravelle, Kichian and Morley (2006) we allow both the common and the idiosyncratic shocks to switch between two states – high- and low-volatility. The heteroskedasticity of the structural shocks ensures the identification of the system (see also Rigobon, 2003a). As shown by Gravelle, Kichian and Morley (2006), the regime switching behavior of the common shock is sufficient to identify the parameters associated with shift contagion, while the additional parameters introduced by the introduction of pure

contagion are identified through the regime-switching behavior of the idiosyncratic shocks. With this structure, each asset return can move between four distinct regimes.

The structural impact coefficients  $\sigma_{it}, \sigma_{cit}, i = E, FX$  are given by the following:

$$\begin{aligned}\sigma_{it} &= \sigma_i(1 - S_{it}) + \sigma_i^* S_{it}, \quad i = E, FX \\ \sigma_{cit} &= \sigma_{ci}(1 - S_{ct}) + \sigma_{ci}^* S_{ct}, \quad i = E, FX\end{aligned}\tag{3}$$

where  $S_{it} = (0,1), i = E, FX, c$  are state variables that take the value of zero in normal and unity in turbulent times. Variables with an asterisk belong to the high-volatility regime. To complete the model, we need to specify the evolution of regimes over time. Following the regime-switching literature, the regime paths are Markov switching and are endogenously determined. Specifically, the conditional probabilities of remaining in the same state, i.e. not changing regime are defined as follows:

$$\begin{aligned}\Pr[S_{it} = 0 | S_{it} = 0] &= q_i, \quad i = E, FX, c \\ \Pr[S_{it} = 1 | S_{it} = 1] &= p_i, \quad i = E, FX, c\end{aligned}\tag{4}$$

Furthermore, we relax the assumption of expected constant returns in (1). These are allowed to be time varying and depend on the state of the common shock. In this respect, our model suggests that part of the asset return represents a risk premium that changes with the level of volatility.<sup>3</sup> In particular, expected returns are modeled as follows:

$$\mu_{it} = \mu_i(1 - S_{ct}) + \mu_i^* S_{ct}, \quad i = E, FX\tag{5}$$

Given that idiosyncratic shocks are uncorrelated with common shocks and mainly associated with diversifiable risk, expected returns are not allowed to vary with the volatility state of these shocks.

To extend the framework beyond a test of shift contagion, we include channels

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<sup>3</sup> Gravelle, Kichian and Morley (2006) and Flavin and Panopoulou (2007, 2008) also relax this assumption when modeling the interdependence of bond and equity returns respectively.

through which the idiosyncratic shock of one market may potentially exert an influence on the other market during turbulent periods, over and above that captured by the common shock. This captures pure contagion. It is modeled by augmenting the return equation of market  $i$  with the idiosyncratic shock of market  $j$  ( $i \neq j$ ) during the crisis period (see DFGM, 2006 for a similar approach to capturing pure contagion).

To illustrate the channels through which contagion may be transmitted, we present a simplified example. Though, the entire model is estimated in a single step, it implies different features of the model in each of the eight possible regimes. For example, if we take the extreme states, the characteristics of the model during tranquil periods (all shocks in the low-volatility states) are given as follows:

$$\begin{aligned} r_{E,t} &= \mu_E + \sigma_{cE} z_{ct} + \sigma_E z_{Et} \\ r_{FX,t} &= \mu_{FX} + \sigma_{cFX} z_{ct} + \sigma_{FX} z_{FXt} \end{aligned} \quad (6)$$

The two idiosyncratic shocks are assumed to be independent, so co-movements in returns are solely determined by the common shock (factor). Thus, the variance-covariance matrix of returns is given by:

$$\Sigma_1 = \begin{bmatrix} \sigma_E^2 + \sigma_{cE}^2 & \sigma_{cE} \sigma_{cFX} \\ \sigma_{cE} \sigma_{cFX} & \sigma_{FX}^2 + \sigma_{cFX}^2 \end{bmatrix}.$$

On the other hand, during crisis periods (all shocks in high-volatility states), the corresponding return generating process during periods of turbulence is given by

$$\begin{aligned} r_{E,t} &= \mu_E^* + \sigma_{cE}^* z_{ct} + \sigma_E^* z_{Et} + \delta_E \sigma_{FX}^* z_{FXt} \\ r_{FX,t} &= \mu_{FX}^* + \sigma_{cFX}^* z_{ct} + \sigma_{FX}^* z_{FXt} + \delta_{FX} \sigma_E^* z_{Et} \end{aligned} \quad (7)$$

The variance covariance matrix of returns is:

$$\Sigma_8 = \begin{bmatrix} \sigma_E^{*2} + \sigma_{cE}^{*2} + \delta_E^2 \sigma_{FX}^{*2} & \sigma_{cE}^* \sigma_{cFX}^* + \delta_{FX} \sigma_E^{*2} + \delta_E \sigma_{FX}^{*2} \\ \sigma_{cE}^* \sigma_{cFX}^* + \delta_{FX} \sigma_E^{*2} + \delta_E \sigma_{FX}^{*2} & \sigma_{FX}^{*2} + \sigma_{cFX}^{*2} + \delta_{FX}^2 \sigma_E^{*2} \end{bmatrix}.$$

Comparing equations (6) and (7), the additional term in the return generating process of market  $i$  ( $\delta_i \sigma_j^* z_j$ ) detects and measures the importance of pure contagion



during episodes of high-volatility in the idiosyncratic shock of market  $j$ .

An extra assumption of normality of the structural shocks enables us to estimate the model, given by equations (1)-(7), via maximum likelihood employing the methodology for Markov-switching models developed in Hamilton (1989).

### 2.1 Testing for shift contagion.

Our rationale behind testing for shift contagion lies on the assumption, that in its absence, a large unexpected shock that affects both countries does not change their interdependence. In other words, the observed increase in the variance and correlation of returns during crisis periods is due to increased impulses stemming from the common shocks and not from changes in the propagation mechanism of shocks. Our test for shift contagion is based on a likelihood ratio test, where the null and alternative hypotheses are specified as follows:

$$H_0 : \frac{\sigma_{cE}^*}{\sigma_{cFX}^*} = \frac{\sigma_{cE}}{\sigma_{cFX}} \text{ versus } H_1 : \frac{\sigma_{cE}^*}{\sigma_{cFX}^*} \neq \frac{\sigma_{cE}}{\sigma_{cFX}} \quad (8)$$

The null hypothesis postulates that in the absence of shift contagion, the impact coefficients in both calm and crisis periods should move proportionately. This likelihood ratio test is the common test for testing restrictions among nested models and follows a  $\chi^2$  distribution with one degree of freedom corresponding to the restriction of equality of the ratio of coefficients between the two regimes.

### 2.2. Testing for pure contagion.

When the idiosyncratic shock of market  $i$  enters the high-volatility regime, it potentially exerts an influence in market  $j$ , thereby giving rise to pure contagion. This channel of transmission is only active during periods of high idiosyncratic volatility.

Our test for pure contagion from market  $j$  to market  $i$  is a simple t-test on the coefficient  $\delta_i$ , where under the null  $\delta_i = 0$  and there is no pure contagion. We also conduct a likelihood ratio test that both channels are jointly inactive to assess the importance of bi-directional effects.

### **3. Data and Filters**

#### *3.1. Data*

Our analysis is conducted on the equity and foreign exchange markets of a group of East Asian emerging markets. In particular, we focus on Korea, Indonesia, the Philippines, Singapore, Taiwan and Thailand. These countries are chosen as they have a sufficient time series of floating exchange rates to undertake the analysis.<sup>4</sup> As our test of shift contagion involves measuring the reaction of markets to a common shock, we require that the full reaction can be measured and not offset by government intervention. Therefore including ‘non-floating’ exchange rates would bias our results towards finding shift contagion. We work with weekly returns for both markets with currency returns computed as the log change in the US dollar exchange rate, where the exchange rate is expressed in terms of US dollars per 1 unit of local currency. Likewise, equity returns are computed as the log change in the value of the domestic stock market index. These indices are value-weighted and expressed in local currency. They were obtained from Datastream International; with the Datastream codes having the following structure: TOTMKXX, where XX represents the country code, i.e. KO (Korea), ID (Indonesia), PH (Philippines), SG (Singapore), TA (Taiwan) and TH

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<sup>4</sup> We had to preclude Malaysia and Hong Kong from the analysis, because Hong Kong adopted a currency board system and Malaysia pegged its currency to US dollar throughout most of the available sample.

(Thailand). We omit the data for the period prior to July 1997, because most of the East Asian countries adopted fixed or strict exchange rate regimes until the onset of the crisis. Therefore we have over ten years of data, yielding 556 data points for each series. Asset returns for the sample period, 4 July 1997-22 February 2008, are plotted in Figure 1. Clearly, both equity and foreign exchange returns have been highly volatile with a larger spread of returns being experienced in equity markets.

[FIGURE 1 ABOUT HERE]

Table 1 presents some summary statistics. Panels A and B relate to equity and currency markets respectively, while panel C contains details of the dynamic correlations between markets in each country.

[TABLE 1 ABOUT HERE]

Mean equity returns are larger than foreign exchange returns for all markets. However, they are also more risky. Equity returns, with the exception of Taiwan, are positive over the sample, with Korea recording the highest mean return of 0.214%. However, it is noteworthy that in many instances, the median return is far from the mean, implying that the overall distribution of returns is non-normal. With the exception of Singapore, average currency returns are negative, indicating that the value of the domestic currency has fallen against the dollar over the sample period. Both asset returns exhibit significant skewness and kurtosis, with the Jarque Bera test decisively rejecting normality for all series. For most currencies, there is huge negative skewness present in the distribution of returns, indicating the presence of a number of extreme observations in the data.

### *3.2. Data Filters*

Both Granger, Huang and Yang (2000) and Pan, Fok and Liu (2007) document significant autocorrelation and cross-correlation in equity and currency markets. Panel C of Table 1 confirms the presence of cross-correlation effects in our data also. As we wish to focus on the transmission of contemporaneous shocks, we pre-filter the data to remove any dynamic linkages. This is achieved by estimating a bi-variate VAR model on the equity and currency returns of each country. The order of the VAR is determined using a range of information criteria.<sup>5</sup> A constant term is included so that all residual series have a zero mean. The residuals of the VAR are employed as our dependent variables in the application of the regime-switching methodology outlined above. Panel D of Table 1 shows that the correlations of the VAR residuals match those of the raw data very closely. In general, the correlation coefficients are quite low, suggesting the prevalence of important asset-specific effects.

#### **4. Results**

Firstly, we check the reliability of our estimates by performing a number of diagnostic tests and results are reported in Table 2.

[TABLE 2 ABOUT HERE]

Specifically, we test for the presence of serial correlation, ARCH effects and the Normality of the standardized residuals of the asset pairs examined. Columns 2 and 3 report the LM test for serial correlation. For the majority of country asset pairs, we fail to reject the null of serial independence at both one and four lags. Likewise we find little evidence of ARCH effects (see columns 4 and 5). To test for Normality, we use the Cramer-von Mises test which is based on the overall approximation of the empirical distributions of standardized residuals to the Normal. Our results, reported

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<sup>5</sup> We do not include the VAR analysis here but all details are available from the authors upon request.

in Column 6, suggest that most of the asset residuals are normally distributed. Hence, we argue that our regime-switching model adequately captures the distribution of asset returns as the standardized residuals are well behaved.

Furthermore, the regime qualification performance of our model is assessed by the Regime Classification Measure (RCM) statistic developed by Ang and Bekaert (2002). According to this measure, a good regime-switching model should classify regimes sharply, i.e. the smoothed (ex-post) regime probabilities,  $p_t$  are close to either one or zero. For a model with two regimes, the RCM is given by:

$$RCM = 400 * \frac{1}{T} \sum_{t=1}^T p_t(1 - p_t),$$

where the constant serves to normalize the statistic to be between 0 and 100. The lower the RCM statistic, the better is the performance of the model. A perfect model will have a RCM close to zero; while in contrast, a model that poorly distinguishes between regimes will produce a statistic close to 100. Columns 7-9 of Table 2 report the RCMs for both idiosyncratic shocks and the common volatility shock respectively. In general, the regimes are well-defined. With the exception of Singapore and Taiwan, the common shock regimes are sharply distinguished with statistics less than 30. Likewise the regimes of the asset-specific shocks are sharply defined with the majority having RCM statistics less than 50. Shocks associated with the currency markets tend to be better captured than their counterparts in the equity markets.

#### *4.1. Estimates*

Initially, we focus on the expected component of returns, with estimates presented in Table 3. Specifically, columns 2 and 3 report the expected mean returns during the low-volatility regime with the corresponding figures for turbulent periods reported in columns 4 and 5.

[TABLE 3 ABOUT HERE]

This Table presents us with a number of striking features. Firstly, the low volatility regime is characterized by positive mean equity and foreign exchange returns in virtually all cases, with many being statistically significant at conventional levels. High volatility regimes are associated with lower equity returns in all cases. In fact, these are always negative, though admittedly many of these are not statistically different from zero. For currency returns, this pattern, while present in some countries, is not as clear. Secondly, we test for the equality of expected asset mean returns between regimes. We perform a likelihood ratio test but results vary across countries. The hypothesis of equal means is rejected for Singapore, the Philippines and Thailand but not for the remaining countries. Consequently, we conduct the analysis with and without the restriction of equal expected returns across regimes. The results do not differ qualitatively, so we report results in the subsequent analysis where expected returns are allowed to be regime dependent.<sup>6</sup>

#### *4.2. Tests for shift contagion*

We begin with an analysis of ‘shift’ contagion. In particular, we focus on the stability of the transmission of common shocks between low- and high-volatility regimes. Given that asset pairs belong to the same country, this shock can be thought of as being a ‘country’ shock – at least in the sense that it picks up unanticipated domestic occurrences as well as a common exposure to global events. First, we focus on the prevalence of the high-volatility regime for this ‘country’ shock and Figure 2 presents the filtered probabilities of this state being realized.

[FIGURE 2 ABOUT HERE]

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<sup>6</sup> Guidolin and Timmermann (2005) for UK assets and Flavin and Panopoulou (2007) for G-7 equity markets reject the hypothesis of equal means across regimes.

For Indonesia, Korea, the Philippines and Thailand, there are pronounced and persistent periods of high-volatility in the common shock. These are predominantly in the early part of our sample which coincides with the Asian crisis of 1997-98 and the subsequent turmoil on global markets associated with further crises in Russian bond markets, the near-collapse of the LTCM hedge fund, the Brazilian and Argentinean bond market shocks and the ‘Dot com’ crisis of the early 2000s. For all of these countries, the common shock undergoes a period of low volatility from approximately 2002 onwards, with some evidence of higher volatility returning towards the sample end – probably a reaction to the global credit crisis whose affects have sent ripples throughout global financial markets. On the other hand, the common shocks experienced in Singapore and Taiwan exhibit little persistence in the high-volatility regime. This may be due to the fact that their foreign exchange rates were not fixed against the dollar prior to the Asian crisis and hence did not experience such a large drop as their currencies were unlikely to be as over-valued as those of neighboring countries. Consequently, the country shock may not have resulted in such a huge change in their dollar exchange rates as those suffered by Indonesia and Korea.

[TABLE 4 ABOUT HERE]

Table 4 presents a more detailed description of the behavior of the country shock. The statistics ‘Frequency’ and ‘Duration’ report the prevalence and persistence of the high-volatility regime. Frequency measures the proportion of time that the common shock is in this state, while duration is the length of time (in years) for which a high-volatility common shock persists.<sup>7</sup> They provide numerical evidence similar to that contained in Figure 2. For all countries, the common shock is in the high-volatility regime at least 20% of the time, reaching a high of 55% for Korea. The

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<sup>7</sup> ‘Frequency’ is computed as  $(1-Q) / (2-Q-P)$  while ‘Duration’ is computed as  $1 / (1-P)$ , where P and Q are defined as in equation (4).

Korean shock also displays high persistence with duration of nearly six years. Korea appears to be the most affected by the regional and subsequent financial market crises that characterized global markets from 1997 onwards. At the other extreme, the Taiwanese country shock spends the least proportion of time in the turbulent state and persists for only a few weeks. Averaging across countries, common shocks are in the high-volatility regime about 34% of the time, with persistence of 1.5 years. This gives us sufficient observations in each regime to overcome problems of low power due to small crisis samples inherent in many other tests of contagion (see DFGM, 2007).

The remaining columns of Table 4 present estimates of the impact coefficients of common structural shocks for calm ( $\sigma$ ) and turbulent ( $\sigma^*$ ) times as well as the ratio,  $\gamma$ , upon which our test of shift contagion is based. The impact coefficients reveal a number of interesting facts. Firstly, in both regimes, the equity response to a common shock is greater than that for currency returns. This reflects the relatively high risk associated with this asset class. Secondly, for both assets, the response to the high-volatility shock is larger than its low-volatility counterpart. As expected, both assets display greater sensitivity to larger shocks. Finally, in both regimes the dispersion of estimates is greater for equity returns and is larger in the high-volatility state.

To perform a statistical test for shift contagion, we first construct the following statistic:

$$\gamma = \max \left\{ \left| \frac{\sigma_{cE}^* \sigma_{cFX}}{\sigma_{cFX}^* \sigma_{cE}} \right|, \left| \frac{\sigma_{cFX}^* \sigma_{cE}}{\sigma_{cE}^* \sigma_{cFX}} \right| \right\}.$$

This is simply the ratio of the estimated impact coefficients coefficients in the high volatility regime to the ratio of those in the low volatility regime and allows us to test if these are proportional across regimes. If the transmission mechanism governing the country shock is stable, then we should observe a ratio of unity. Conversely, if this



transmission is altered, i.e. shift contagion, our ratio should be statistically different from one. The computed ratio is large in all cases, suggesting a potential change in the transmission mechanism. To test whether or not it is statistically different from unity, we perform a likelihood ratio test and the results are presented in Table 5.

[TABLE 5 ABOUT HERE]

Despite the magnitude of the ratio, we only find statistically significant evidence of shift contagion for Korea and the Philippines. For Korea, the change in the transmission of the country shock is entirely due to the increased sensitivity of the equity return as the response of the currency return is unchanged between regimes. For the majority of markets, we fail to reject the null hypothesis of no shift contagion. For Indonesia, Singapore, Taiwan and Thailand, there is no evidence that the transmission of the country shock is different between regimes and thus linkages due to the common shock remain stable over different market conditions. The degree of interdependence between equity and currency markets that exists in normal market conditions is likely to also prevail in turbulent states for these four countries.

#### *4.3. Tests for pure contagion*

We next turn our attention to tests of pure contagion. Pure contagion refers to the phenomenon whereby the asset-specific shock of one market spills over to the other through channels that only operate during periods of market turbulence. Without a theory to guide us as to the direction of these contagious effects, our model simultaneously evaluates the importance of bi-directional contagion. We begin by analyzing the behavior of these shocks, with the filtered probabilities of being in the high-volatility states presented in Figures 3 and 4 for equities and foreign exchange

markets respectively. Given that we have controlled for the common factors, these shocks can be thought of as being a pure equity and pure currency shock respectively.

[FIGURES 3 & 4 ABOUT HERE]

For equity markets, and in contrast to the common shock, we find that the idiosyncratic shock for Singapore and Taiwan is quite often in the high-volatility state and is quite persistent. For the other countries, the equity shock is less persistent but nevertheless, spends a large proportion of the time in the turbulent regime. With the exception of Taiwan, the foreign exchange shock is far less frequently in the high-volatility state. Once the Asian crisis of 1997-98 had ended, the currency markets of most countries settled back into a sustained period of tranquility.

[TABLE 6 ABOUT HERE]

Table 6 provides a more in-depth analysis of results pertaining to these asset-specific shocks. Consistent with the graphical evidence, the 'Frequency' statistic shows us that the proportion of time spent in the high-volatility regime is greater for the equity shock than the currency shock. For equity markets, the range of time spent in this regime is 23% for Thailand up to 71.4% for Singapore. In contrast the corresponding range for currency markets is 5% (Korea) to 33% (Taiwan). Likewise the persistence of shocks varies widely across markets and countries. Persistent equity shocks are observed for Singapore and Taiwan, while in Korea and Thailand, these shocks are quickly dissipated. All foreign exchange shocks are relatively short-lived, with a duration measure of less than one year for all countries except Singapore. In summary, equity shocks occur more frequently and show greater persistence than foreign exchange shocks but both are sufficiently widespread to be of concern to investors and policymakers if they spill over into other markets.

As in the case of the common shock, we find large variation in the impact coefficients of the idiosyncratic shocks and much increased sensitivity when moving from the low- to the high-volatility state. However, the key parameters are  $\delta_E$  and  $\delta_{FX}$ , which capture the strength of pure contagion effects transmitted to the equity and foreign exchange markets respectively. The results confirm the importance of simultaneously modeling bi-directional pure contagion. In all but one case, we find strong evidence of such effects. The transmission of the idiosyncratic shock is unstable between regimes. In turbulent periods these shocks spill over to the other market, thus becoming an additional common factor. For all countries, but Thailand, currency shocks influence the equity market. This is consistent with foreign investors fleeing domestic equity markets as they become worried about the depreciation of the domestic currency. For example, the Bank of International Settlements report a sharp reversal in capital flows between 1996 and 1997 for Indonesia, Thailand, Korea, Malaysia and the Philippines. Net capital inflows of US\$95 billion turned to a net capital outflow of US\$12 billion. The reverse contagion channel, i.e. equity to foreign exchange markets, is also operational during periods of turbulent equity markets and, with the exception of Taiwan, we find evidence of statistically significant pure contagion. This channel is particularly strong for Indonesia. For Singapore, we find a negative coefficient for  $\delta_{FX}$ , which may imply a flight-to-quality effect. When equity shocks enter their high-volatility state, investors seek refuge in currency assets. This suggests that investors view the Singaporean dollar as a safer currency than its regional counterparts. It may also reflect the belief that Singapore has become a 'developed' rather than an 'emerging' market.

[TABLE 7 ABOUT HERE]

Finally, Table 7 reports results of a likelihood ratio test for the joint significance of the pure contagion parameters. In all cases, we decisively reject the null hypothesis that these parameters are jointly zero. It confirms the importance of accounting for potential bi-directional pure contagion. Much of the extant literature is incapable of simultaneously picking up these market interactions.

#### *4.4. Conditional correlations*

To ascertain the contribution of pure contagion to overall asset market co-movement, we look at its influence on the time-varying correlations generated by our model. Firstly, we compute the conditional correlation of equity and currency markets in each country and these are depicted in Figure 5.

[FIGURE 5 ABOUT HERE]

There is considerable time variation in the co-movement, which is consistent with much of the extant literature. Using a sample of over 108 years, Bordo and Murshid (2000) show that stock market correlations have exhibited large variation, both in tranquil and crisis periods. Figure 5 shows no clear pattern across countries and only in Singapore, do we find higher than usual correlation during the Asian crisis. It also depicts the difficulty of trying to detect contagion on the basis of looking for changes in correlation around the time of a significant event.

[FIGURE 6 ABOUT HERE]

Figure 6 presents the time-varying contribution of pure contagion to the conditional correlations presented above. We decompose the correlation into a component due to the common shock and another due to pure contagion. We then report the proportion of the total conditional correlation arising from the presence of pure contagion. The graphical evidence suggests that its contribution is considerable

for all markets. For all countries, there is a definite relationship between the conditional correlation and the proportion due to idiosyncratic spillovers. All markets show that up to 30% of co-movement may be attributable to pure contagious effects. The importance of this channel is clear during the Asian crisis for most countries and re-emerges during the recent period of global financial turmoil.

#### *4.5. Conditional Variances*

Finally, we examine the conditional asset variances and investigate the impact of pure contagion on them. For ease of exposition we do this on a state-by-state basis. There are eight possible states of the world, ranging from state 1, where all shocks are in the low-volatility regime, to state 8, where the high-volatility regime prevails for all. Table 8 summarizes the behavior of shocks within each state.

[TABLE 8 ABOUT HERE]

Figure 7 presents the conditional variances for each asset type by country. The conditional variance of the equity return is generally greater than that of the FX return, though Korean and Indonesian currency returns are exceptions in the states with high-volatility FX shocks. It is noteworthy that currency returns in Singapore and Taiwan are generally low across states, which is consistent with results reported earlier. On the other hand, Indonesian asset markets exhibit high conditional variances compared to its regional neighbors. This is a consequence of the intense economic and political unrest that has crippled the country in the aftermath of the Asian crisis.

[FIGURE 7 ABOUT HERE]

However, to appraise the importance of pure contagion, we decompose the conditional variances into their constituent channels. Figures 8 and 9 present these decompositions for equity and currencies respectively.

[FIGURE 8 ABOUT HERE]

Pure contagious effects from the FX to equity markets operate in states 3, 4, 7 and 8. From Figure 8, we see modest contributions from this channel to overall asset risk across all countries. It is most important in Korea and Singapore, especially in state 3 when the FX shock is the only one experiencing high volatility. However, the pure contagion channel is dominated by the influence of the common shock. This contributes the majority of equity risk for most countries. The main exceptions are Taiwan and Singapore who both avoided the worst effects of the Asian crisis (see Flavin and Panopoulou, 2008). The pure equity shock operates in all states but apart from Singapore, it plays a smaller role than the common shock.

[FIGURE 9 ABOUT HERE]

On the other hand, a clearer picture emerges with respect to the conditional variances of FX returns. The most striking feature of Figure 9 is, in contrast to equity markets, the small role played by the common shock in determining currency risk. With the exception of Taiwan (where FX variances are very small anyway), the common shock is unimportant and is dominated by the FX idiosyncratic shock and the pure contagion channel. The majority of risk can be attributed to the asset-specific shock but there is evidence of pure contagion in states 2, 4, 6 and 8 when the equity shock is in the turbulent regime. This channel is most important in Korea, Indonesia, the Philippines and Thailand. All these countries suffered huge currency devaluations during the Asian crisis as they were all forced to abandon their fixed rates with the US dollar. Therefore pure contagion is an important source of risk for both asset classes but has a relatively larger effect on the most recently floated exchange rates.

## **5. Conclusions**

We develop a model that allows us to simultaneously test for the presence of both shift and bi-directional pure contagion. This model is well suited to analyzing the stability of linkages between domestic equity and foreign exchange markets. In particular, we focus on the stability of the transmission mechanism of common shocks across different volatility regimes, i.e. shift contagion, and concurrently we investigate if asset-specific shocks spill over to other assets during periods of high volatility, i.e. pure contagion.

Our analysis concentrates on the emerging financial markets of East Asia over a sample period when their exchange rates were floating against the US dollar. We find widespread evidence of pure contagious effects. Shocks that originate in either equity or currency markets influence the other market during turbulent market conditions. In essence, the once asset-specific shock becomes an additional common factor during episodes of high-volatility. Our results convey the importance of allowing for bi-directional pure contagion, as in practice the source of the adverse shock can be difficult to identify. In contrast, there is relatively little statistical evidence of shift contagion. For the majority of countries, both asset returns respond in a stable manner regardless of the volatility state of the common shock.

We also investigate the economic significance of the pure contagious effects. Pure contagion can account for up to 30% of the asset co-movement observed. While it varies substantially, its contribution to the conditional correlation generated by our model is always positive. Likewise, we decompose conditional variances by state into components due to the common factor, own idiosyncratic factors and pure contagion. The common shock is the dominant factor in determining equity market volatility but its influence on currency risk is negligible. The latter market is most influenced by its

own asset-specific shocks. Pure contagious effects are important for both asset types but particularly for the FX markets of the most recently floated currencies.

In summary, the linkages between equity and currency markets in emerging economies do not appear to be stable. There is little statistical evidence that common shocks cause this instability but rather it appears to emanate from transmission channels that emerge when the asset-specific shock of either market experiences episodes of high volatility. This finding is likely to concern both policymakers and investors alike. Policymakers need to take note that high-volatility asset-specific shocks may not be contained for long and therefore a speedy response is necessary to prevent the spread of turbulence throughout the financial system of the affected country. Non-domestic equity investors will be worried that pure contagious effects will further compound their equity losses as the foreign exchange component of overall return falls simultaneously, while domestic equity investors may find it more difficult to diversify away from home assets in bear markets due to a loss of purchasing power of the proceeds of portfolio liquidation.

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**Table 1.****Panel A. Summary Descriptive Statistics-Equity Returns**

	<i>Korea</i>	<i>Indonesia</i>	<i>Philippines</i>	<i>Singapore</i>	<i>Taiwan</i>	<i>Thailand</i>
Mean	0.214	0.186	0.023	0.109	-0.021	0.086
Median	0.528	0.302	0.108	0.255	0.162	0.064
Maximum	16.95	22.72	14.74	11.74	19.59	25.27
Minimum	-19.57	-20.43	-21.13	-18.28	-14.53	-17.58
Std. Dev.	4.878	4.743	3.417	2.921	3.754	4.598
Skewness	-0.216	0.065	-0.411	-0.508	0.074	0.330
Kurtosis	4.787	6.631	7.801	6.826	5.436	6.068
Jarque Bera	78.3 (0.000)	305.8 (0.000)	549.8 (0.000)	363.1 (0.000)	138.0 (0.000)	228.1 (0.000)

**Panel B. Summary Descriptive Statistics-Foreign Exchange Returns**

	<i>Korea</i>	<i>Indonesia</i>	<i>Philippines</i>	<i>Singapore</i>	<i>Taiwan</i>	<i>Thailand</i>
Mean	-0.012	-0.239	-0.078	0.003	-0.021	-0.040
Median	0.064	-0.017	-0.012	0.016	0.000	0.043
Maximum	13.60	38.62	7.67	7.93	3.55	9.68
Minimum	-33.05	-56.86	-12.78	-4.45	-4.37	-11.88
Std. Dev.	2.215	4.758	1.431	0.858	0.676	1.706
Skewness	-5.848	-3.401	-1.683	1.081	-0.749	-1.001
Kurtosis	97.409	56.654	21.048	18.892	12.798	16.939
Jarque Bera	209656.7 (0.000)	67764.0 (0.000)	7808.6 (0.000)	5959.1 (0.000)	2275.8 (0.000)	4594.0 (0.000)

**Panel C. Dynamic Correlations between Equity and Foreign Exchange Returns**

	<i>Korea</i>	<i>Indonesia</i>	<i>Philippines</i>	<i>Singapore</i>	<i>Taiwan</i>	<i>Thailand</i>
eq(t),fx(t)	0.374	0.200	0.375	0.321	0.298	0.254
eq(t),fx(t-1)	-0.160	-0.088	0.023	0.037	0.019	-0.059
eq(t),fx(t-2)	-0.005	-0.157	0.049	0.059	0.000	0.008
eq(t),fx(t-3)	0.033	0.075	0.009	0.058	0.021	-0.019
eq(t),fx(t-4)	-0.074	-0.067	0.058	0.021	0.005	-0.004
eq(t-1),fx(t)	-0.065	-0.059	0.038	-0.110	0.050	0.051
eq(t-2),fx(t)	0.098	0.204	0.145	0.119	0.043	0.212
eq(t-3),fx(t)	0.022	0.005	0.089	-0.025	0.068	0.011
eq(t-4),fx(t)	0.063	-0.018	0.041	-0.035	0.061	0.054

**Panel D. Correlations between Equity and Foreign Exchange Returns**

	<i>Korea</i>	<i>Indonesia</i>	<i>Philippines</i>	<i>Singapore</i>	<i>Taiwan</i>	<i>Thailand</i>
Original data	0.374	0.200	0.375	0.321	0.298	0.254
VAR residuals	0.375	0.258	0.371	0.332	0.299	0.269

**Table 2. Diagnostic tests on standardized residuals and model specification**

<i>Country</i>	<i>LM(1)</i>	<i>LM(4)</i>	<i>ARCH(1)</i>	<i>ARCH(4)</i>	<i>Normality</i>	<i>RCM<sub>E</sub></i>	<i>RCM<sub>FX</sub></i>	<i>RCM<sub>C</sub></i>
Korea	1.89	2.127	8.682*	27.03*	0.105	65.04	3.04	14.56
	0.194	10.86	26.10*	80.70*	0.089			
Indonesia	0.049	1.043	1.293	1.579	0.178	51.97	12.55	26.16
	1.252	4.571	0.002	2.929	0.095			
Philippines	0.637	0.974	0.564	3.142	0.059	65.07	8.41	20.43
	10.43*	21.39*	0.897	3.358	0.121			
Singapore	0.034	0.743	8.727*	19.65*	0.152	11.41	4.83	77.13
	6.035	6.516	4.77	5.422	0.023			
Taiwan	0.008	1.744	0.656	5.771	0.047	16.85	35.81	43.20
	0.288	3.515	8.712*	52.56*	0.288*			
Thailand	1.784	1.962	1.265	3.823	0.053	50.10	6.01	26.17
	1.894	5.606	0.016	5.793	0.234*			

*Notes:*  $LM(k)$  is the Breusch-Godfrey Lagrange Multiplier test for no serial correlation up to lag  $k$ ,  $ARCH(k)$  is the Lagrange Multiplier test for no ARCH effects of order  $k$ , Normality is the Cramer-von-Mises test for the null of Normality,  $RCM_i$  is the Regime Classification Measure, where  $i=E, FX, C$  for the equity and currency idiosyncratic shock and the common shock, respectively. \* denotes significance at 1% level.  $LM(k)$  and  $ARCH(k)$  have a  $\chi^2(k)$  distribution under the null hypothesis. The Cramer-von-Mises test has a non-standard distribution and the cut-off value for RCM is 50.

**Table 3. Estimates of mean returns across regimes**

<i>Country</i>	$\mu_E$	$\mu_{FX}$	$\mu^*_E$	$\mu^*_{FX}$	<i>LR</i>	<i>p-val</i>
Korea	0.349 (0.184)	0.105 (0.056)	-0.150 (0.339)	0.019 (0.074)	2.25	0.32
Indonesia	0.215 (0.195)	0.071 (0.009)	-0.470 (0.458)	-0.191 (0.278)	1.93	0.38
Philippines	0.051 (0.137)	0.025 (0.027)	-0.056 (0.212)	0.360 (0.110)	6.01**	0.05
Singapore	0.467 (0.108)	0.026 (0.034)	-0.380 (0.235)	0.016 (0.056)	10.10***	0.01
Taiwan	0.543 (0.139)	-0.044 (0.018)	-1.387 (0.526)	0.287 (0.048)	0.73	0.69
Thailand	0.162 (0.222)	0.095 (0.042)	-0.189 (0.372)	-0.078 (0.073)	4.59*	0.10

*Notes:* Standard errors in parentheses below coefficients. Likelihood ratio statistic is for the null of equality of mean returns across the regimes. The test statistic has a  $\chi^2(2)$  distribution under the null hypothesis. \*\*\* denotes significance at 1% level, \*\* denotes significance at 5% level, and \* denotes significance at 10% level.

**Table 4. Estimates of impact coefficients of common shocks**

<i>Country</i>	$\sigma_{cE}$	$\sigma_{cFX}$	$\sigma^*_{cE}$	$\sigma^*_{cFX}$	$\gamma$	<i>Frequency</i>	<i>Duration</i>
Korea	2.384 (0.132)	0.061 (0.080)	4.729 (0.249)	0.062 (0.080)	1.98	54.9%	5.69
Indonesia	3.153 (0.129)	0.272 (0.060)	6.176 (2.054)	0.294 (0.192)	1.81	24.9%	1.37
Philippines	2.290 (0.094)	0.073 (0.028)	5.353 (0.457)	0.533 (0.139)	3.14	20.1%	0.52
Singapore	0.004 (0.097)	0.001 (0.013)	1.873 (0.249)	0.497 (0.072)	3.11	45.5%	0.09
Taiwan	1.206 (0.297)	0.208 (0.048)	3.333 (0.429)	0.311 (0.042)	1.85	20.7%	0.03
Thailand	2.662 (0.138)	0.145 (0.059)	5.689 (0.308)	0.212 (0.082)	1.46	36.2%	1.31

*Notes:* Standard errors in parentheses below coefficients. “Duration” refers to the duration of the high volatility common shock expressed in years. “Frequency.” refers to the unconditional probability of the high volatility regime expressed in percentage.

**Table 5. Likelihood ratio tests for shift contagion**

<i>Country</i>	<i>LR</i>	<i>p-val</i>
Korea	34.81***	0.00
Indonesia	0.46	0.50
Philippines	4.21**	0.04
Singapore	0.01	0.99
Taiwan	0.40	0.53
Thailand	0.62	0.43

*Notes:* Likelihood ratio statistic is for the null of no shift contagion against the alternative of shift contagion between the equity and FX returns of the indicated countries.. The test statistic has a  $\chi^2(1)$  distribution under the null hypothesis. \*\*\* denotes significance at 1% level, \*\* denotes significance at 5% level, and \* denotes significance at 10% level.

**Table 6. Estimates of impact coefficients of idiosyncratic shocks  
Bi-directional pure contagion**

<i>Country</i>	$\sigma_E$	$\sigma_{FX}$	$\sigma^*_E$	$\sigma^*_{FX}$	$\delta_E$	$\delta_{FX}$	<i>Frequency / Duration (E)</i>	<i>Frequency / Duration (FX)</i>
Korea	0.001 (0.021)	0.826 (0.071)	3.752 (0.659)	7.583 (1.085)	0.502 (0.138)	0.301 (0.052)	42.3% 0.19	4.7% 0.21
Indonesia	0.043 (1.720)	0.912 (0.041)	1.073 (0.423)	9.764 (0.827)	0.185 (0.060)	1.923 (0.722)	52.8% 0.50	16.2% 0.28
Philippines	1.023 (0.043)	0.374 (0.028)	1.024 (0.046)	3.244 (0.321)	0.349 (0.160)	0.833 (0.069)	50.1% 0.19	9.6% 0.38
Singapore	0.836 (0.113)	0.482 (0.026)	2.746 (0.153)	1.739 (0.158)	1.415 (0.232)	-0.038 (0.018)	71.4% 6.95	11.2% 1.36
Taiwan	1.589 (0.242)	0.110 (0.079)	4.003 (0.251)	1.053 (0.075)	1.147 (0.246)	0.001 (0.006)	50.9% 5.45	32.9% 0.13
Thailand	0.010 (0.284)	0.589 (0.058)	2.317 (0.881)	3.663 (0.314)	0.215 (0.167)	0.492 (0.138)	23.1% 0.13	8.9% 0.65

*Notes:* Standard errors in parentheses below coefficients. “Duration” refers to the duration of the high volatility regime of the idiosyncratic shock expressed in years. “Frequency” refers to the unconditional probability of the high volatility regime expressed in percentage.



**Table 7. Likelihood ratio tests for pure contagion**

<i>Country</i>	<i>LR</i>	<i>p-val</i>
Korea	46.87***	0.00
Indonesia	25.50***	0.00
Philippines	49.43***	0.00
Singapore	28.80***	0.00
Taiwan	19.47***	0.00
Thailand	10.62***	0.00

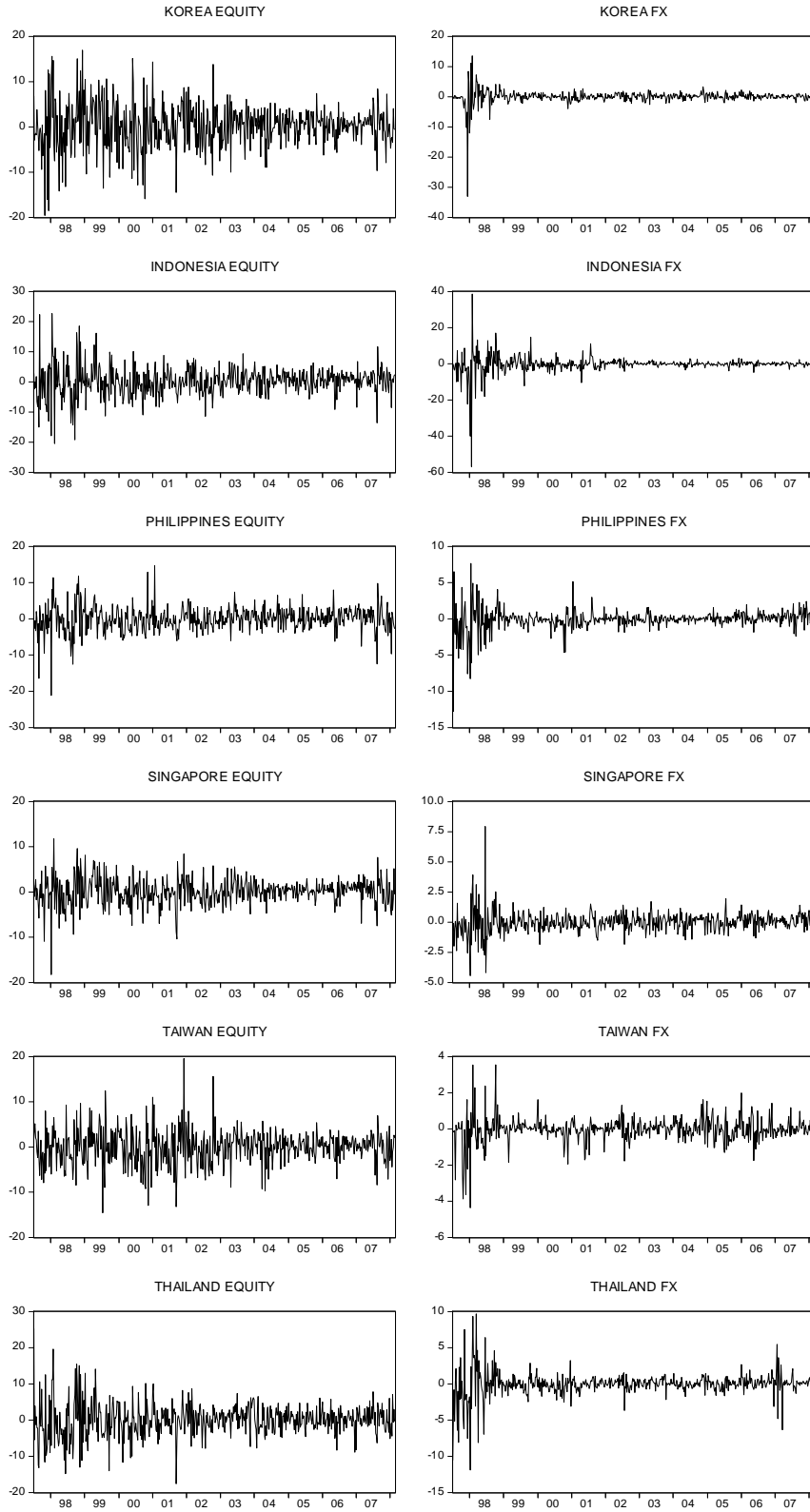
*Notes:* Likelihood ratio statistic is for the null of no pure contagion against the alternative of bi-directional pure contagion between the equity and FX returns of the indicated countries. The test statistic has a  $\chi^2(2)$  distribution under the null hypothesis. \*\*\* denotes significance at 1% level, \*\* denotes significance at 5% level, and \* denotes significance at 10% level.

**Table 8. Summary of shock within each state**

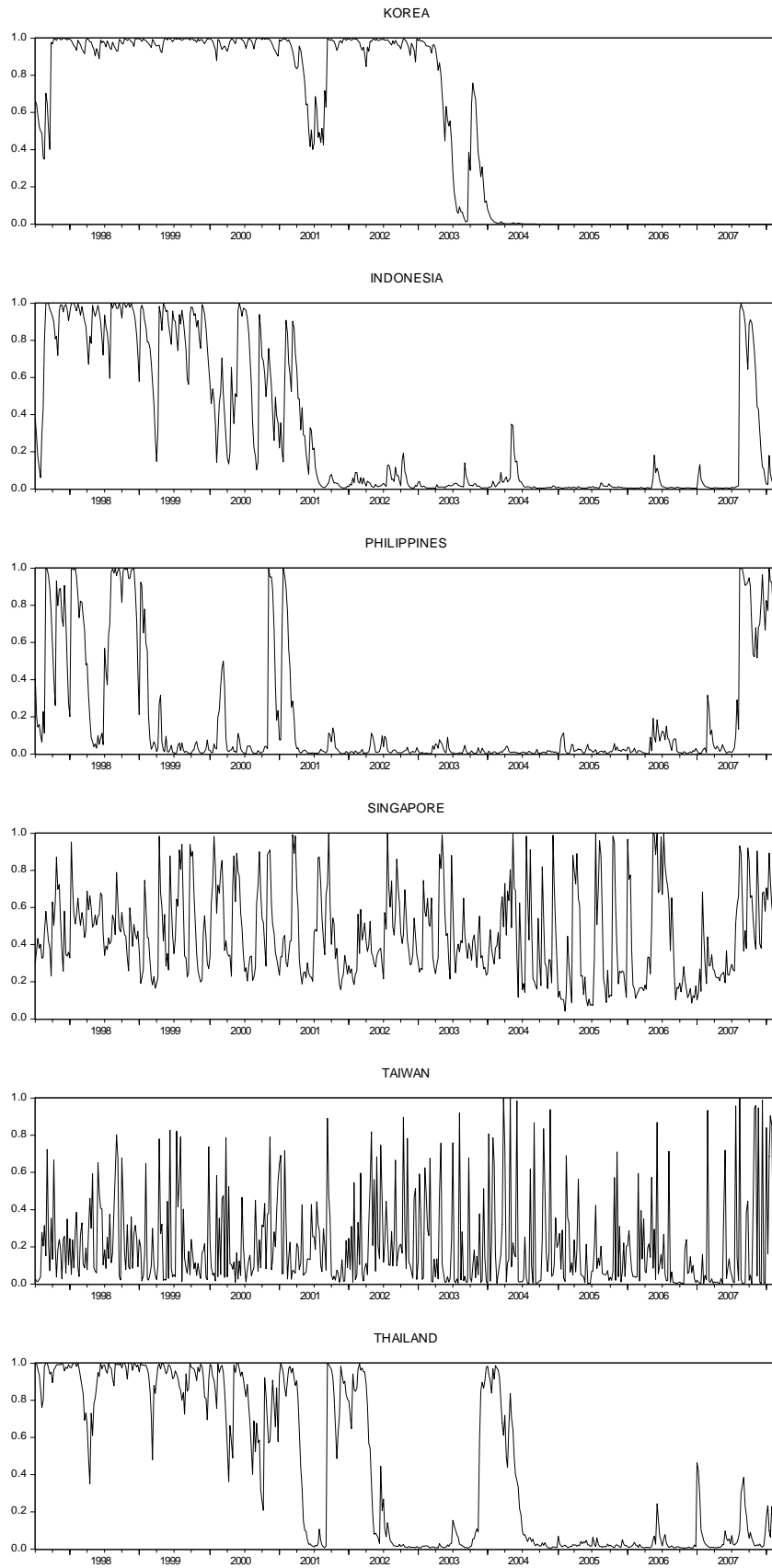
	<i>Equity Shock</i>	<i>FX Shock</i>	<i>Common Shock</i>
State 1	Low	Low	Low
State 2	High	Low	Low
State 3	Low	High	Low
State 4	High	High	Low
State 5	Low	Low	High
State 6	High	Low	High
State 7	Low	High	High
State 8	High	High	High

*Notes:* Low (High) indicates that within that state the shock is in the low- (high-) volatility regime.

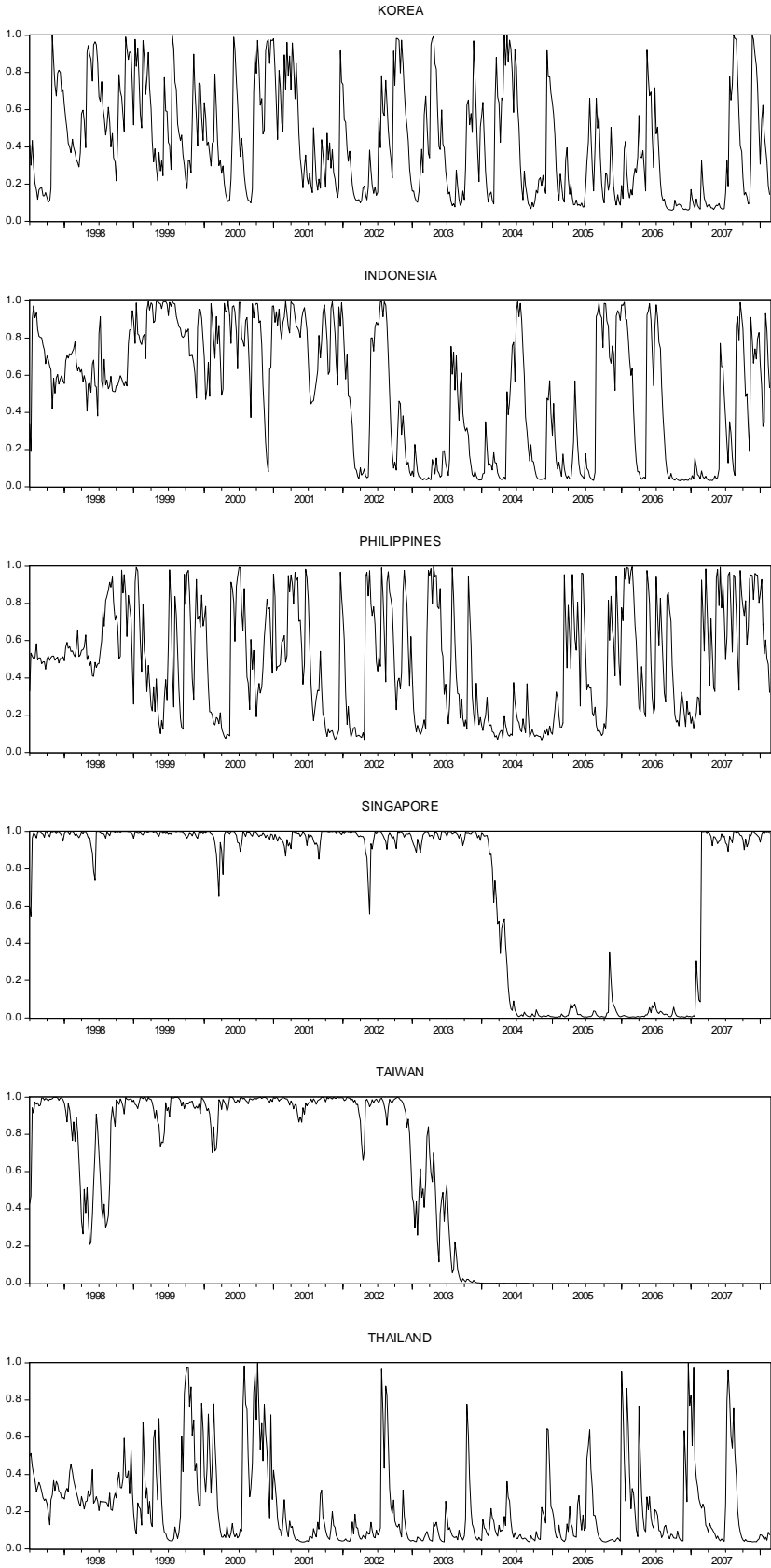
Figure 1. Data



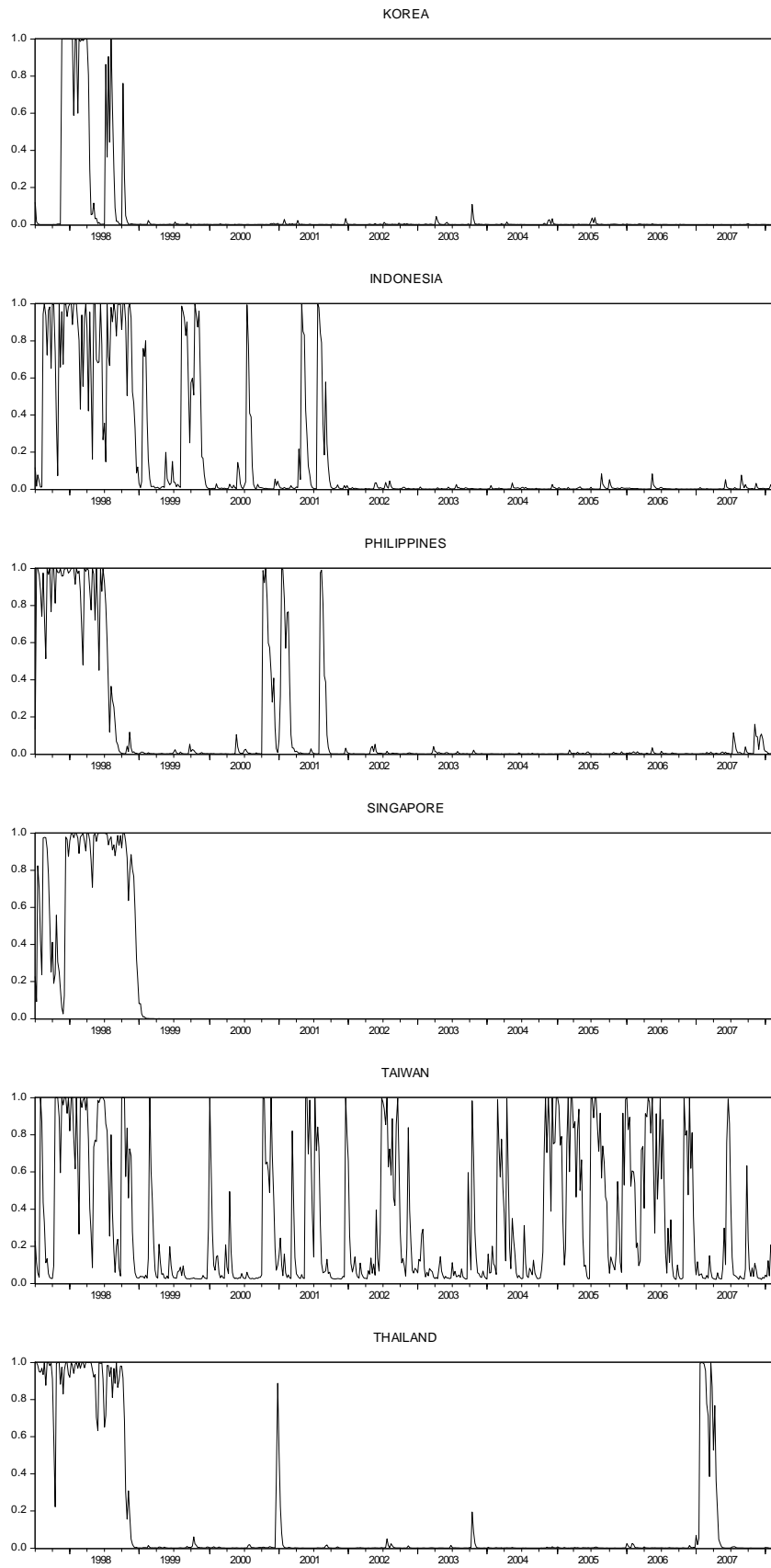
**Figure 2. Filter Probabilities of high volatility common shocks**



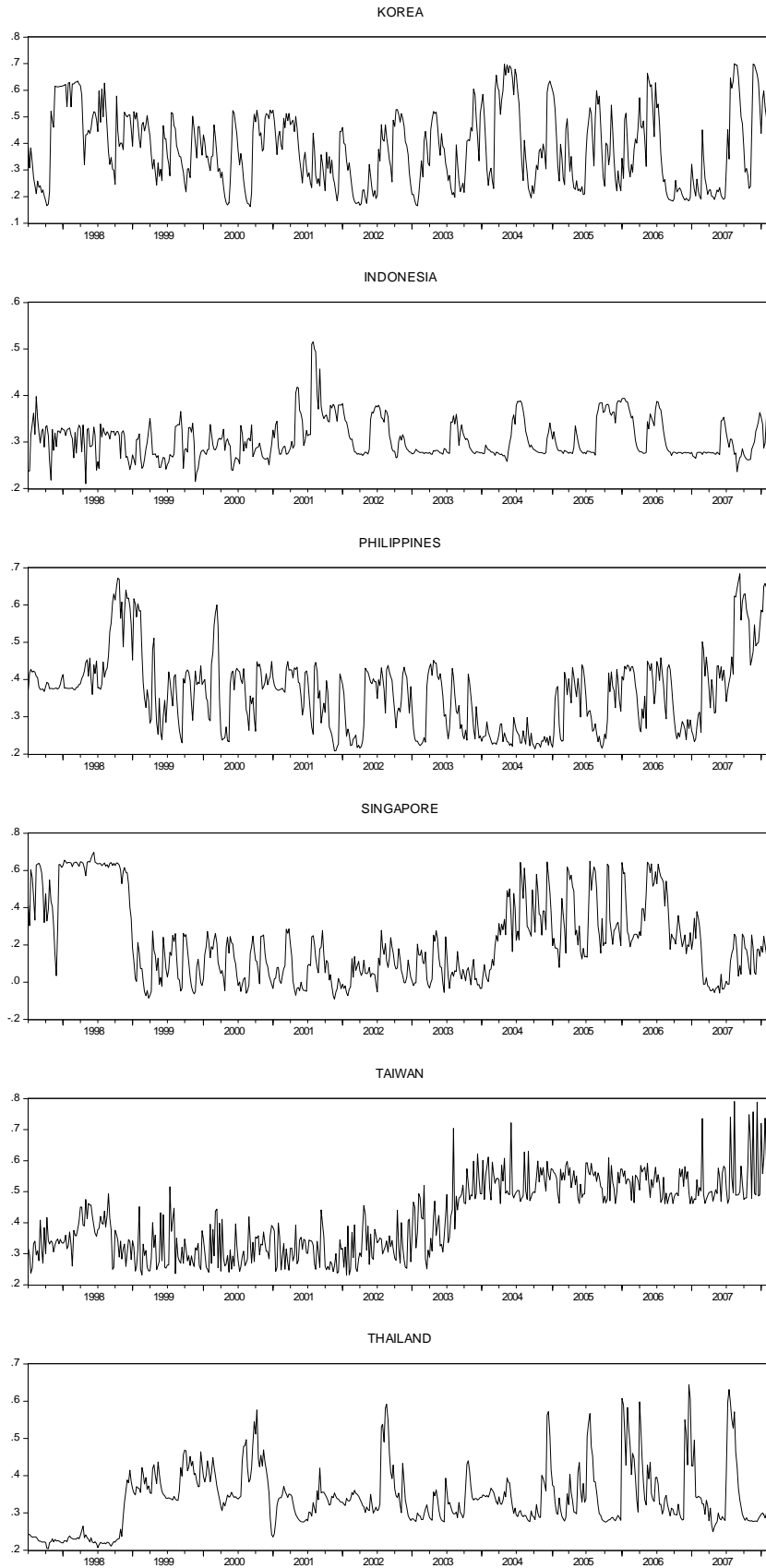
**Figure 3. Filter Probabilities of idiosyncratic shock for the equity market**



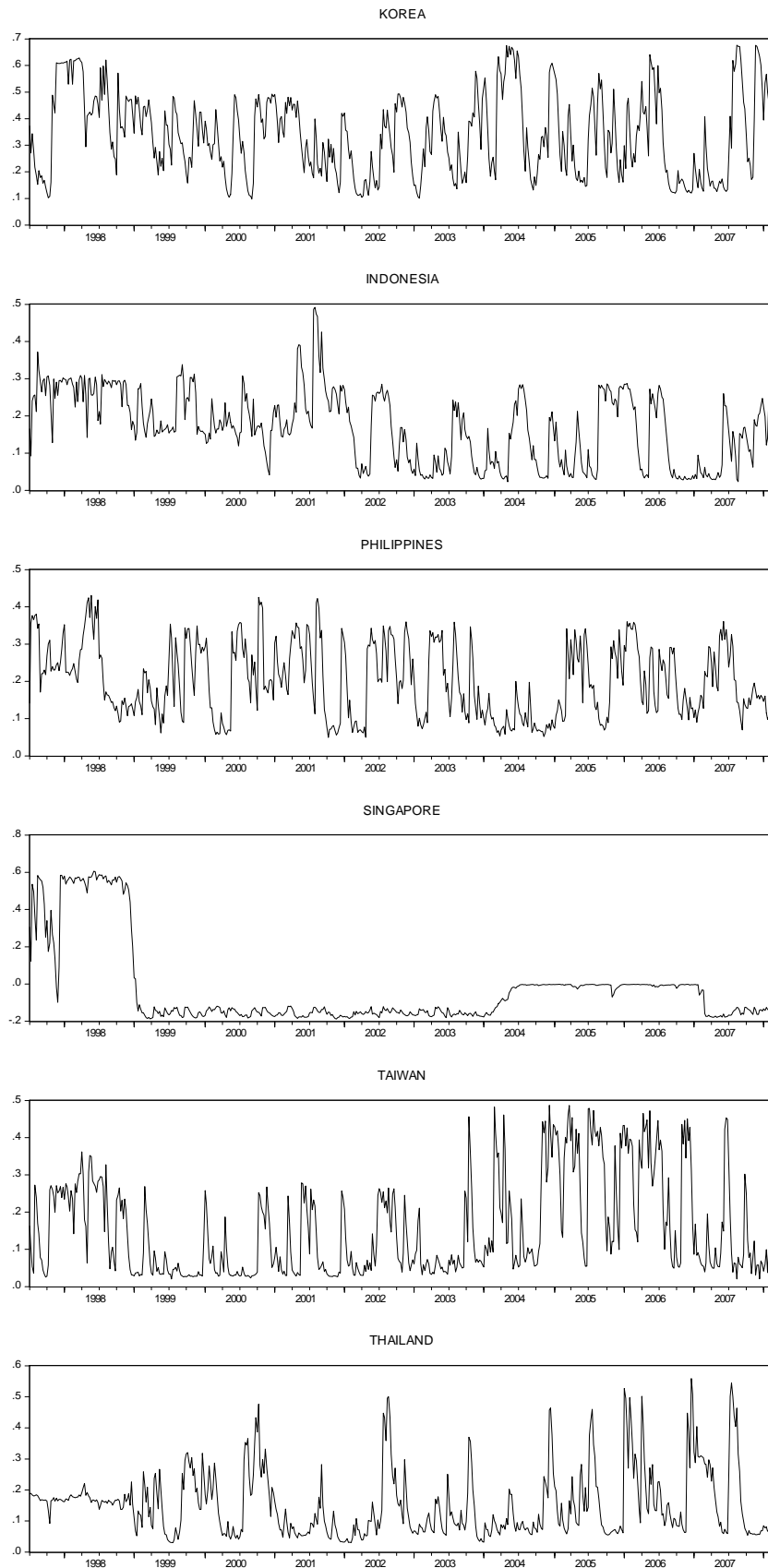
**Figure 4. Filter Probabilities of idiosyncratic shock for the FX market**



**Figure 5. Conditional correlations**

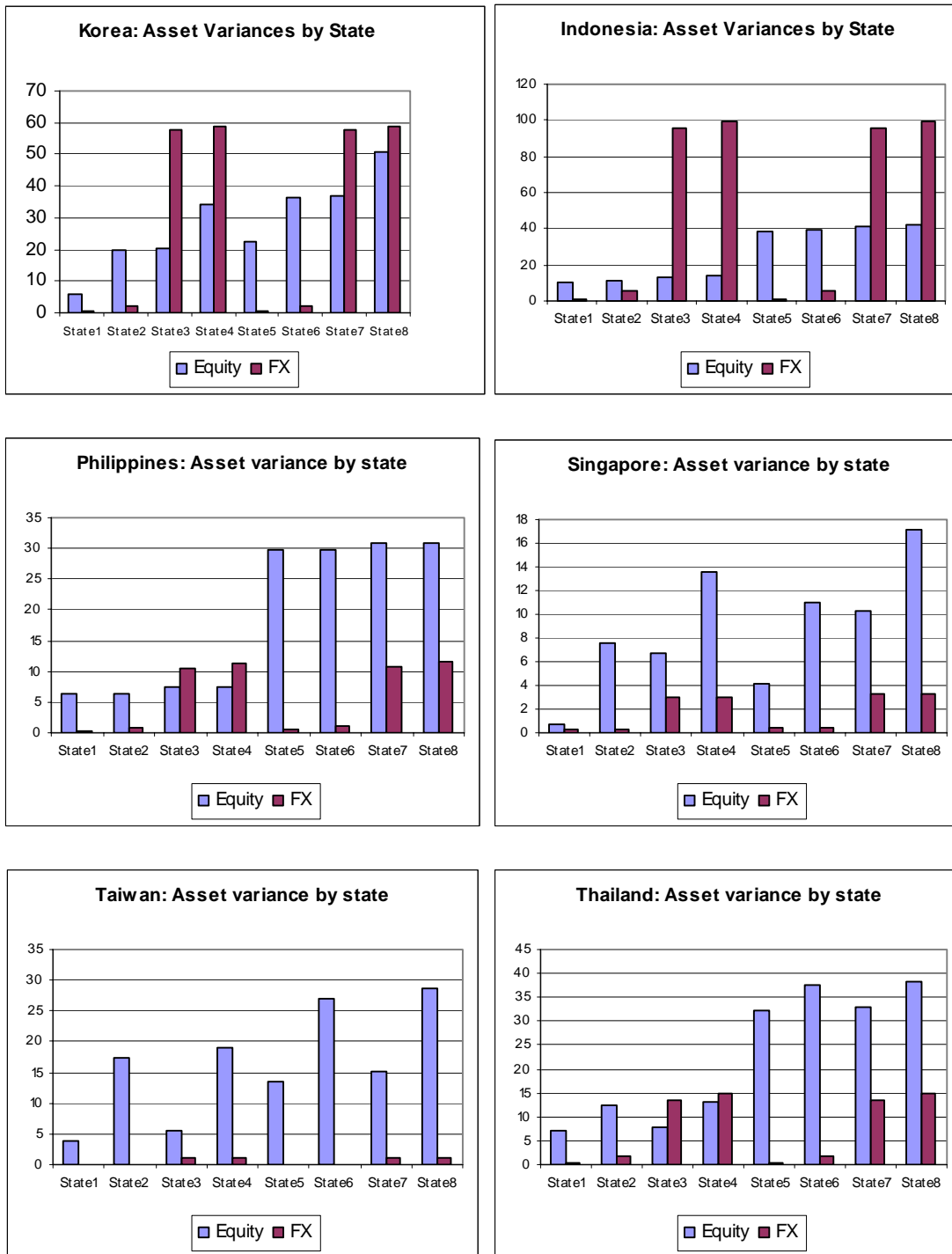


**Figure 6. Contribution of pure contagion to conditional correlations**

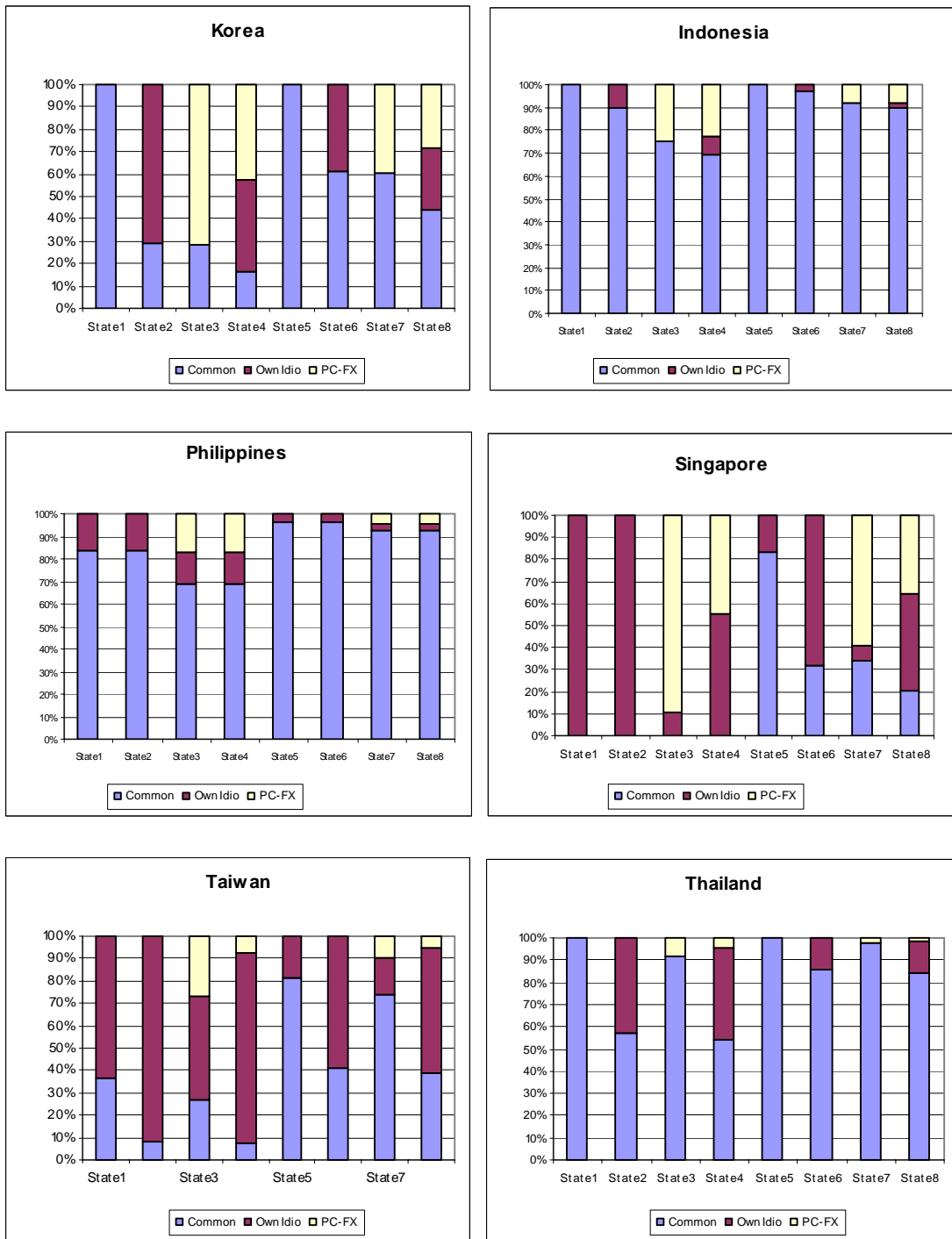




**Figure 7. Conditional Variances by state**



**Figure 8. Decomposition of equity variances by state**



**Figure 9. Decomposition of FX variances by state**

