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Kisswani, Khalid/ M. and Nusair, Salah/ A.

Gulf University for Science and Technology

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# NON-LINEAR CONVERGENCE IN ASIAN INTEREST RATES AND INFLATION RATES

**Khalid M. Kisswani, PhD (corresponding author)**

**Salah A. Nusair, PhD**

Gulf University for Science and Technology

Department of Economics and Finance

P.O. Box 7207

Hawally, 32093

Kuwait

E-mail:

nusair.s@gust.edu.kw

kisswani.k@gust.edu.kw

Tel. (+965) 2530-7339, Fax (+965) 2530-7030

# NON-LINEAR CONVERGENCE IN ASIAN INTEREST RATES AND INFLATION RATES

**Abstract**

We examine the dynamics of convergence of the ASEAN5 plus the big three for nominal interest rates, inflation rates, and real interest rates. We test for convergence relative to the U.S and Japan, using monthly data over the period January 1990 - December 2010, using non-linear unit root tests. The results show strong evidence of stationary inflation and real interest rate differentials in all but China's inflation differential relative to the U.S., and stationary nominal interest differentials in most of the cases. We interpret these results as convergence in inflation rates and real interest rates in all cases, and as nominal interest convergence in most of the cases. Moreover, examining the impact of the Asian crisis shows less number of convergences before the crisis and more convergences after the crisis. This suggests that convergence has increased after the 1997/98 Asian crisis, and that the crisis has pulled the economies together.

*Keywords*: interest rates convergence; inflation convergence; nonlinear unit root tests

*JEL classification*: F15, F36, F41, F42

## 1. Introduction

In recent decades there has been a significant increase in the degree of international financial and goods markets integration, facilitated by the removal of many capital controls and barriers to the international movement of goods and capital across national boundaries (Frankel, 1992). Consequently, interdependence and linkages among national financial and goods markets have gradually strengthened. In terms of the Asian countries, most of them started liberalizing and deregulating their domestic markets in the mid 1970s and early 1980s. For example, Singapore liberalized its financial sector and abolished capital controls in the mid 1970s, while Indonesia, Japan, Malaysia, and the Philippines started liberalization in the early 1980s. On the other hand, Korea and Thailand started their liberalization in the second half of 1980s. In addition, most countries relaxed international capital controls by adopting more flexible exchange rate arrangements. For instance, Japan moved from fixed to flexible exchange rate system in 1973. Other countries, such as Malaysia, Singapore, and Thailand, moved from fixed to managed float or limited flexibility vis-à-vis the U.S dollar or a basket of currencies.

In such integrated markets, interest rates (nominal and real) and inflation across countries should exhibit a long-run convergence trend. On the other hand, financial crises and turmoil were also significant in recent decades, and one would expect them to have affected the degree of international integration and hence, convergence. Whereas the increasing degree of integration is expected to increase convergence among economies, financial crises and turmoil are likely to increase divergence. For the Asian economies, this convergence may have been affected by the 1997/98 Asian financial crisis, which started in Thailand early July 1997 with the collapse of the Thai baht due to severe speculative attacks, forcing Thailand to adopt a managed floating exchange rate regime. The crisis quickly spread to neighboring countries and the currencies of Indonesia, Malaysia, the Philippines, Korea, and Singapore came under speculative attacks.

Convergence is typically taken by policy-makers to mean the reduction of inflation/interest rate differentials between countries (Siklos and Wohar, 1997). Whereas, interest rates convergence serves as an indicator of the degree of financial markets integration, inflation convergence serves as an indicator of the degree of goods markets integration. Therefore, examining convergence in inflation and interest rates has important theoretical, as well as policy implications for the analysis of issues related to monetary policy and open-economy macroeconomic models. For instance, if the real interest rates of the Asian economies converge to either the U.S or Japan's real interest rate, the ability of the domestic monetary authority to conduct independent monetary policies will be severely limited to the extent to which the authority can influence the U.S or Japan's real interest rate. More importantly, finding evidence of nominal interest convergence provides support for uncovered interest parity (UIP), finding evidence of real interest convergence provides support for real interest parity (RIP), and finding evidence of inflation convergence provides support for purchasing power parity (PPP).

In terms of the literature on Asian countries, the bulk of the empirical work has focused on examining the validity of RIP, which is equivalent to testing the joint hypotheses of UIP and PPP. Therefore, this literature has the following drawbacks. First, since the validity of RIP is based on the validity of both UIP and PPP (in addition to Fisher hypothesis), this means that when RIP is rejected, we can't tell which is responsible for the rejection; is it the failure of UIP, or PPP, or both. Second, interest rate movements and inflation performance reflect different behaviors in different markets; namely financial and goods markets. Hence, testing RIP assumes that equilibrium in the two markets is attained equally and at the same rate and time. This assumption may not be correct since equilibrium in financial markets is attained quickly and at a faster rate than in goods markets. Therefore, it is more informative and more appropriate to test the time-series properties of interest rates and inflation rates separately. Third, most of this literature has utilized standard tests, such as the linear Augmented Dickey-Fuller (ADF) unit root test, that have low power since they do not consider nonlinearities in the adjustment process.

Recently, there has been an increasing interest in examining nonlinear adjustment in key economic variables, such as interest rates and inflation rates. This is because if nonlinearity is present but ignored and linear models, such as the ADF test, are used, this may result in a misleading conclusion about the time-series properties of the variables. For example, Pippenger and Goering (1993), Balke and Fomby (1997), Enders and Granger (1998), and Caner and

Hansen (2001) show that linear unit root tests and cointegration tests have low power in the presence of nonlinearity. In particular, Pippenger and Goering (1993) argue that many economic relationships involve economic variables that have implicit transaction costs or arbitrage boundaries where arbitrage is too expensive and, thus, does not take place. They examine the power of unit root tests in detecting mean reversion in economic variables to long-run equilibrium in the presence of transaction costs and find that the power of these tests may fall dramatically under threshold processes. Furthermore, there are empirical studies documenting evidence of nonlinearities in interest rates and inflation rates. Enders and Granger (1998) find evidence of asymmetries in the term structure of the U.S interest rates over the period 1958-1994. Bierens (2000) apply a nonparametric nonlinear co-trending approach to the interest rate and inflation for the U.S using monthly data from 1954 to 1994 and find evidence of nonlinear trends in the two series. Million (2004), Maki (2005), Lanne (2006), and Christopoulos and Leon-Ledesma (2007) provide evidence of nonlinearities in the relationship between interest rates and inflation. Coakley and Fuertes (2002), Kapetanios *et al.* (2003), and Choi and Moh (2007) provide evidence of nonlinear real interest rates.

In terms of the Asian countries, Baharumshah *et al.* (2010a) use quarterly data from 1977 to 2010 to examine the validity of RIP for a sample of 19 OECD and Asian economies utilizing linear and non-linear unit root tests. They find that RIP holds and that the alignments from real interest rate differentials are corrected in a non-linear fashion and that the adjustments are asymmetric in both size and speed. Baharumshah *et al.* (2008) use quarterly data 1977-2002 to examine RIP for the ASEAN-5 with the U.S. and Japan using non-linear unit root tests and find strong evidence of non-linear mean-reversion. Holmes and Maghrebi (2004) use monthly data from 1977 to 2000 to test the real interest differentials of four South East Asian economies with respect to Japan and the U.S., using nonlinear models. They find evidence of smooth transition autoregression (STAR) nonlinearities, and that large shocks to real interest parity are more likely to lead to the reestablishment of parity at a faster rate than small shocks.

In addition to nonlinear models, other techniques have been used. For instance, Kim and Ji (2011) examine mean-reversion of real interest rates for a number of Western and East Asian countries using monthly data from 1987 to 2007. Using panel unit roots, they find strong evidence that real interest rates are mean-reverting, in both major Western and East Asian capital markets, and that the speed of mean-reversion has slowed substantially over the Asian crisis of 1997. Baharumshah *et al.* (2009) use monthly data from 1976 to 2005 to examine RIP for seven East Asian economies with Japan and the U.S. using an array of panel-data tests in the presence of structural breaks and find strong evidence of RIP in all cases.[1] Ji and Kim (2009) utilize impulse response analysis on monthly data from 1980 to 2006 to examine real interest rate linkages for Korea, Singapore, and Thailand with the U.S and Japan and find an increase in the degree of capital market integration after the 1997/98 Asian crisis.

As for inflation convergence, the bulk of literature has focused on testing the validity of PPP, with very limited work on inflation convergence. Baba (2007) examines the price difference between Japan and Korea using city level good-by-good data for the years 1999-2001. Using time-series volatility analysis and cross-sectional difference analysis, Baba finds that the national border has a large effect on price dispersion, that the market between Japan and Korea is less segmented than the European market, and that the source of price dispersion depends on the characteristics of goods. Baharumshah *et al.* (2010b), examine PPP for six East Asian countries with the U.S using quarterly data from 1965 to 2004, and find evidence of stationary real

[1] The panel data approach has been criticized because it tests null hypothesis that all the series in the panel are nonstationary, in which case, the null would be rejected if there is only one series that is stationary (Taylor and Sarno, 1998).

exchange rates in most cases with STAR-type nonlinearity. Zhou (2008) examines the stationarity of Asian-Pacific real exchange rates using quarterly data from 1968 to 2005 relative to the U.S., Australia, Japan, and Singapore. Employing a nonlinear unit root test, Zhou finds evidence of stationarity in most cases, except when Japan is the base country. Holmes (2004) examines U.S. dollar-based Asian real exchange rates from 1973 to 2001, and finds evidence of nonlinearities for India, Singapore, and Sri Lanka.

Similarly, empirical work on nominal interest differentials is rare. Lee and Wu (2004) apply panel unit root tests using monthly data 1998 to 1997 to examine nominal interest rate convergence of Asian countries with the U.S and Japan and find convergence with respect to the U.S, but not with respect to Japan. Tang (2011) examines the empirical validity of UIP for the ASEAN-5 against the U.S using quarterly data from 1978 to 2008. Using heterogeneous panel cointegration tests, Tang finds that the gross domestic return and the uncovered gross domestic return are cointegrated. Moreover, the author finds that UIP only holds for Singapore, which suggests that Singapore's financial market is highly integrated with the US market. As for the other four countries, UIP is strongly rejected, which suggests that their financial markets have not fully liberalized and, therefore, limited the international financial market integration. Moosa and Bhatti (1997) examine the degree of integration between the goods and financial markets of Japan and six Asian countries by testing UIP and *ex-ante* PPP, over the period 1980-1994. They show strong support of the two conditions using residual-based cointegration tests.

The objective of this paper is to examine nominal and real interest rates and inflation rates convergence for the ASEAN 5 (Indonesia, Malaysia, Philippines, Singapore and Thailand) and the big three (China, Japan and Korea) (ASEAN 5 plus 3, hereafter), using Kapetanios, Shin, and Snell (2003) non-linear unit root. To achieve this, we employ monthly data over the period

January 1990 – December 2010, using Japan and the United States as base countries. Moreover, we investigate the effect of the 1997/98 Asian crisis on the convergence process by splitting the sample into pre-crisis period (January 1990 – January 1996) and post-crisis period (May 1998 – December 2010). The data is extracted from the IMF's International Financial Statistics online database and contain the consumer price index (CPI, line 64), and the money market interest rate (line 60B).[2] The measures of interest rate and inflation that we employ are conventional in the literature. Specifically, we use ex-post real interest rates, thus evading the empirical and theoretical issues associated with approximating inflation expectations. The CPI is used to calculate the inflation rate as the percentage change in the logarithm of the CPI. Since the nominal interest rates obtained from the IMF's International Financial Statistics are annualized percents, the monthly inflation rate is annualized as $\Delta \log(CPI) * 1200$.

The rest of the paper is organized as follows. Section two explains the methodology and the rationale of using non-linear unit root tests. Section three provides the empirical results and section four concludes.

## 2. Methodology

Empirically, convergence in interest rates and inflation rates can be examined by means of unit root tests. To this end, we use $i_t$, $i_t^*$, $r_t$, $r_t^*$, $\Pi_t$ and $\Pi_t^*$ to stand for domestic and foreign nominal interest rates, domestic and foreign real interest rates, and domestic and foreign inflation rates, respectively. We, then calculate nominal interest differential $(i_t - i_t^*)$, inflation differential $(\Pi_t - \Pi_t^*)$, and real interest differential $(r_t - r_t^*)$ between the home country and the foreign country (the U.S and Japan). The real interest rate $(r_t)$ is constructed using the ex-post Fisher equation $r_t = i_t - \Pi_t$.

[2] Except for China where the bank rate (line 60) is used for the interest rate, and for the CPI line (64...XZF) is used, which gives the percentage change in the CPI.

Empirically, convergence can be investigated by examining the stationarity of the differentials using linear specifications, such as the ADF unit root test

$$\Delta q_t = \alpha + \rho q_{t-1} + \sum_{j=1}^{P} \lambda_j \Delta q_{t-j} + \varepsilon_t \qquad (1)$$

Where $q_t$ denotes nominal interest rate differentials, inflation rate differentials, and real interest rate differentials at time $t$. The null hypothesis of non-stationary $q_t$ $(H_0: \rho = 0)$ is tested against the stationary linear alternative$(H_A: \rho < 0)$. The parameter $\rho$ represents the speed of adjustment, which is in specification (1), assumed to occur continually and at a constant rate, regardless of the size of the deviation from equilibrium with a half-life deviation of $ln(0.5)/ln(1+\rho)$. However, interest rates and inflation rates may exhibit nonlinearities due to the presence of transaction costs and inflation targeting. Empirically, this nonlinear behavior can be modeled through models that allow the autoregressive parameter $(\rho)$ to vary; such models include the smooth transition autoregression (STAR) model proposed by Granger and Terasvirta (1993). In the STAR model, adjustment takes place in every period but the speed of adjustment varies with the extent of deviations from equilibrium. There are two variants of the STAR model: the exponential STAR (ESTAR) model and the logistic STAR (LSTAR) model. The ESTAR model implies that the behavior of the variable exhibit symmetrical adjustment for deviations above and below the equilibrium level, whereas the LSTAR model implies asymmetrical adjustment. We consider the following representation of the STAR model

$$\Delta q_t = \alpha' + \rho' q_{t-1} + \sum_{j=1}^{P} \lambda_j' \Delta q_{t-j} + \left\{\alpha_0 + \rho_0 q_{t-1} + \sum_{j=1}^{P} \lambda_{0j} \Delta q_{t-j}\right\} F[\theta;\ q_{t-d}] + \varepsilon_t \qquad (2)$$

Where $F[\theta;\ q_{t-d}]$ is the transition function bounded between zero and one, which determines the degree of mean-reversion. The transition function for the ESTAR model is given by $F[\theta;\ q_{t-d}] = 1 - exp[-\theta(q_{t-d} - \mu)^2]$, whereas for the LSTAR model is given by $F[\theta;\ q_{t-d}] = \{1 + exp[-\theta(q_{t-d} - \mu)]\}^{-1}$, where $\mu$ is the equilibrium level of $q_t$, $\theta$ is a transition parameter, which determines the speed of transition between two extreme regimes with lower absolute values implying slower transition, $d$ is a delay parameter suggesting that deviations from the equilibrium level generate increasingly mean reversion with a delay, and $\varepsilon_t$ is a white noise with zero mean and constant variance. In the absence of nonlinearities$(\theta = 0)$, the second term is zero and the model reverts to the linear ADF specification defined in (1). But, if the true behavior of $q_t$ is governed by (2), then the linear ADF model would be misspecified and the estimate of $\rho$ would be inconsistent as it would be estimating $\rho$ as a combination of $\rho'$ and $\rho_0$ in the true model (2). Thus, the crucial parameters are $\rho'$ and $\rho_0$. The speed of convergence to equilibrium would gradually increase as deviations from equilibrium rise in absolute value. This implies that for small deviations, $q_t$ may be characterized by unit root or even explosive behavior; that is, $\rho' \geq 0$ is admissible, but for large deviations, $q_t$ is mean reverting; that is, we must have $\rho_0 < 0$ and $\rho' + \rho_0 < 0$ for global stability.

In carrying out the testing procedure for non-linearities in representation (2), we follow Terasvirta (1994), in which we first, specify a linear autoregressive model to determine the appropriate lag length$(P)$. And second, test the null hypothesis of linearity for different values of the delay parameter$(d)$, and if it is rejected, determine the value of $d$. To this end, testing for nonlinearities is carried out using the following specification (Terasvirta, 1994)

$$q_t = \alpha_0 + \sum_{=1}^{P} \alpha_j q_{t-j} + \sum_{j=1}^{P} \left(\beta_{1j} q_{t-j} q_{t-d} + \beta_{2j} q_{t-j} q_{t-d}^2 + \beta_{3j} q_{t-j} q_{t-d}^3\right) + \varepsilon_t \qquad (3)$$

The null hypothesis of linearity $(H_0\text{: } \beta_{1j} = \beta_{2j} = \beta_{3j} = 0,\ for\ j = 1, \dots, P)$ is tested against the alternative of nonlinearity$(H_A\text{: } at\ least\ one\ \beta \neq 0)$. Rejecting $H_0$ provides evidence in favor of nonlinear STAR model. The null hypothesis may be tested by an ordinary *F-test*. In order to determine the delay parameter $d$, the linearity test in (3) is repeated for the range of values

$1 \leq d \leq D$ (Terasvirta and Anderson, 1992). If the linearity test is rejected for more than one value of $d$, the one that has the smallest *p-value* associated with the linearity test is selected.

Finally, we examine the mean reversion property of the differentials using the nonlinear unit root test developed by Kapetanios, Shin, and Snell (2003, hereafter, KSS). The test is based on the following ESTAR model specification:

$$\Delta q_t = \lambda q_{t-1}[1 - \exp(-\theta q_{t-1}^2)] + \varepsilon_t \tag{4}$$

Where $\theta$ is a parameter determining the speed of mean reversion, and $\varepsilon_t$ is an i.i.d. error term with zero mean and constant variance. The null hypothesis of unit root $(H_0: \theta = 0)$ is tested against the alternative of nonlinear but globally stationary process$(H_A: \theta > 0)$. However, testing this null directly is not feasible, since $\lambda$ is not identified under the null. To overcome this problem, KSS compute a first-order Taylor series approximation to the ESTAR model under the null to obtain the auxiliary regression

$$\Delta q_t = \gamma q_{t-1}^3 + \sum_{j=1}^{P} \beta_j \Delta q_{t-j} + \varepsilon_t \tag{5}$$

Where $P$ is the lag order selected by Akaike information criterion (AIC). The null hypothesis of unit root $H_0: \gamma = 0$ is tested against the alternative $H_A: \gamma < 0$.

### 2.1. The Rationale Behind Non-linearties in Interest Rates and Inflation Rates

Variables such as interest rates and inflation rates may exhibit a nonlinear behavior due to a variety of reasons. Balke and Fomby (1997), for example, argue that the adjustment to the long-run equilibrium may exhibit a discontinuous behavior due to the presence of fixed adjustment costs, or transaction costs, or policy interventions, such as exchange rate management and commodity price stabilization. This may create a band in which prices may diverge and in which arbitrage opportunities exist. They characterize this behavior in terms of a threshold cointegration where the equilibrium error follows a threshold autoregression that is mean-reverting outside the band and has a unit root inside the band.

Other sources of non-linearity include inflation targeting and the opportunistic (approach to disinflation) behavior of central banks. According to Mishkin (2000), inflation targeting is a monetary-policy strategy that involves the public announcement of medium-term numerical targets for inflation and an institutional commitment to price stability as the primary goal of monetary policy. With the adoption of inflation targeting, the reaction of the central bank may vary depending on whether inflation is above or below a particular target. Given that the central bank can influence the short-term interest rate, if the central bank is more worried about high inflation, then it would increase the interest rate more aggressively when the expected rate of inflation is above its target level than when it is close or below the target (Christopoulos and Leon-Ledesma, 2007).

According to the proponents of the opportunistic approach to disinflation (Orphanides and Wilcox, 2002, and Aksoy *et al.,* 2006), when inflation is moderate but still above the long-run objective, the central bank should not take deliberate actions directed at fighting inflation but, rather, should wait for exogenous circumstances –such as favorable supply shocks and unforeseen recessions- to deliver the desired reduction in inflation. Similarly, when inflation is moderate but below the long-run objective, policymakers should not take deliberate countervailing actions but, rather, should wait for inflationary shocks and unforeseen expansions to bring inflation back toward the long-run level. On the other hand, when inflation is running substantially above or below its long-run target, policymakers should respond aggressively to bring inflation toward the long-run level.

Consequently, inflation targeting and the opportunistic behavior of central banks create a *"band of inaction"* around the target inflation level. If inflation is outside the band, policymakers will take deliberate actions to bring inflation toward the target level –inside the band. Once inside the band, policymakers would behave opportunistically (that is; not take deliberate actions) by accommodating shocks that bring inflation towards the target level and should focus on stabilizing output and employment around their potential levels (Orphanides and Wilcox, 2002). This suggests that the behavior of policymakers changes depending on whether inflation is inside or outside the band of inaction and hence, the time-series properties of inflation and interest rates change depending on whether inflation is inside or outside the band. In inside the band, they are divergent and may be characterized by unit root, and outside the band they become mean reverting (Weidmann, 1997). Consequently, interest rates and inflation rates may follow a nonlinear stochastic process that is mean reverting when the variable is outside the band of inaction and has a unit root inside the band.

**2.2 Inflation Targeting in Asian Countries**

Prior to the 1997 Asian financial crisis, exchange rates in most of the crisis-hit countries were pegged to the U.S dollar under managed floating regimes, except the Philippines which operated an independently floating regime. Reports from the IMF (1998) indicated that the pegged exchange rate relative to the U.S dollar was one of the major reasons for the crisis. Because of the crisis, most of the crisis-hit countries announced a shift from an exchange rate-based monetary policy framework to the explicit adoption of inflation targeting (Chow and Kim, 2006). Conventionally, an inflation-targeting regime is accompanied by a flexible exchange rate regime, with the interest rate used as the monetary policy instrument. In particular, Indonesia, Korea, the Philippines and Thailand announced the use of the interest rate as the key monetary policyoperating instrument (Chow and Kim). Since inflation targeting involves an institutional commitment to price stability as the primary goal of monetary policy, these countries have passed legal and institutional legislations to support their inflation targeting arrangements. Table 1 provides highlights of inflation targeting arrangements in these countries. Among the Asian countries, Malaysia is the exception, which shifted to a fixed exchange rate regime relative to the U.S dollar, and imposed capital controls in September 1998 (Chow and Kim).

**[INSERT TABLE 1 HERE]**

## 3. Empirical Results

### 3.1 Preliminary Results

As a preliminary step, we investigate the stationarity of the nominal and real interest rates and inflation rates using the standard ADF unit root test. Because the Asian countries may have experienced structural breaks due to the 1997/98 crisis, we also apply Zivot and Andrews (1992) test, which allows for a single break endogenously determined. The authors propose three models for unit root testing. Model A allows for a one-time change in the mean of the series, model B allows for a one-time change in the slope of the trend function, and model C allows for a one-time change in both the mean and the slope of the trend function. The unit root null under each model is tested against the alternative of a deterministic trend with a change in either the mean, or the slope, or both. The number of lags is determined by AIC with $P_{max} = 12$.

The results from the ADF test, reported in table 2, indicate that we are unable to reject the unit root null in all but Indonesia and Japan. For the inflation rates, the unit root null is rejected in all cases, except for China. Overall, the results suggest that the nominal interest rates are non-stationary and inflation rates are stationary. This raises an obvious question about the time-series properties of the real interest rates. If nominal interest rates and inflation rates are integrated of order one, real interest rates could still be stationary, given that they are cointegrated. On the other hand, if the order of integration is different, as suggested by the results, then real interest rates in these countries could be nonstationary. Applying the ADF test on the real interest rates indicate that we are able to reject the unit root null for Indonesia, Malaysia, the Philippines, Singapore, and the U.S. Applying Zivot-Andrews test suggests that the results are not significantly different from those obtained from the ADF test; however, there are significant breaks in most of the variables either in the intercept, or the slope, or both, with most of the breaks clustered around the 1997/98 Asian crisis.

**[INSERT TABLE 2 HERE]**

Nominal and real interest differentials, and inflation differentials are calculated relative to Japan and the U.S. Visual inspection of the differentials, plotted in figures 1 to 3, shows noticeable movements in the differentials around the 1997/98 Asian crisis, which may suggest the possibility of structural breaks around that period. Discernable spikes notably appear in all the differential series. Moreover, the inflation differential and real interest differential series show immense variability over the sample period. On the other hand, the nominal interest differential series for most of the countries show a limited amount of variability until 1997/98, when a significant upward spike occurs in most of the cases due to the Asian crisis, then followed by a significant reduction and the series became less variable and converging.

**[INSERT FIGURES 1 to 3 HERE]**

Tables 3 and 4 present summary statistics of the series relative to the U.S and Japan. The statistics suggest the followings. The means of nominal interest differentials are significantly different from zero in all cases. The means of inflation differentials are significantly different from zero in all cases except for Malaysia relative to the U.S. On the other hand, the means of real interest differentials for China, Japan, Malaysia, and Singapore relative to the U.S. do not significantly differ from zero. In addition, the means of real interest differentials for China and Singapore relative to Japan are not significantly different from zero. The Jarque-Bera (JB) normality test rejects the null hypothesis of normality in most cases. For nominal interest differentials relative to the U.S, the JB test rejects normality for China, Malaysia, and Singapore. As for inflation differentials and real interest differentials relative to the U.S, normality is rejected in all cases. Relative to Japan, the JB test rejects the null of normality in all cases except for Singapore's nominal and real interest differentials and inflation differentials.

**[INSERT TABLES 3 and 4 HERE]**

### 3.2 Unit Root Tests and Convergence

Finding evidence of stationary differentials implies convergence. Conversely, failing to find evidence of stationarity implies divergence. Tables 5 and 6 provide the results of the linear ADF test and Zivot-Andrews test relative to the U.S and Japan. At the 1 and 5 percent significance levels, the linear ADF test reveals evidence of nominal interest convergence for only Indonesia and Malaysia relative to the U.S, and for only Indonesia relative to Japan. On the other hand, the test suggests inflation convergence in all cases, except China and Singapore relative to the U.S and Japan. While we reject real interest rate convergence for Japan and Korea relative to the U.S, we reject it in all cases relative to Japan, except for Indonesia and the Philippines.

**[INSERT TABLES 5 and 6 HERE]**

Applying Zivot-Andrews test shows evidence of nominal interest convergence for Korea, Malaysia, the Philippines, and Thailand relative to the U.S, and for Korea, Malaysia, and for Thailand vis-à-vis Japan, with structural breaks around the 1997/98 Asian crisis. Conversely, inflation convergence is found in all cases, except for Japan relative to the U.S., and for all cases, except for Singapore relative to Japan, with most of the breaks around the 1997/98 crisis. Real interest convergence is detected for China, Korea, the Philippines, and Thailand relative to the U.S., and for China and Korea relative to Japan.

Thus, including endogenously determined structural breaks in the data generating process of the differentials using Zivot-Andrews test leads to slight improvement in nominal interest and inflation convergence, and no improvement in real interest convergence. Overall, we find evidence of inflation convergence, but limited evidence of nominal and real interest convergence, particularly when Japan is the reference country.

Although the Zivot-Andrews test is more powerful than the linear ADF test in the presence of structural breaks, neither accounts for nonlinearities. If nonlinearity is present, applying the ADF test, or Zivot-Andrews test might be misleading. Therefore, in the next section we test for the presence of nonlinearities in the behavior of $q_t$.

**3.3 Linearity Test**

The results of conducting the linearity test are presented in table 7 over the range for the delay lag length $d \in \{1, \dots, 12\}$. In most cases, the optimum $d$ order is between one and four months indicating a rather fast response to shocks, and that market participants react to deviations with a delay of one to four months. The longest delay is 12 months observed for Japan's inflation differential relative to the U.S., and for China' nominal and real interest differentials, the Philippines' inflation differential, and the Philippines' real interest differential relative to Japan. The optimum autoregressive order $(P)$ is determined by AIC.

**[INSERT TABLE 7 HERE]**

The table reports the p-values for test statistics for the null hypothesis of linearity ($H_0: \beta_{1j} = \beta_{2j} = \beta_{3j} = 0$) against the alternative of nonlinearity ($H_A$ at least one $\beta \neq 0$). If the linearity test is rejected for more than one value of $d$, the one that has the smallest *p-value* associated with the linearity test is selected. The results decisively reject the linearity null at conventional significance levels in all cases, except for China's nominal interest differentials relative to the U.S and Japan. This suggests that the behavior of nominal and real interest differentials and inflation differentials for these countries is governed by STAR-type nonlinearity.

Having established this type of nonlinearity in all cases, the next section presents the results of testing the stationarity of the differentials using Kapetanios *et al*. (2003).

### 3.4 Nonlinear Unit Root Tests

Table 8 presents the results of testing the stationarity of the differentials using the KSS nonlinear unit root test. The number of lags is selected using AIC with $P_{max} = 12$. The results show evidence of nominal interest rate convergence for all countries except China, Japan, and Singapore relative to the U.S, and except China relative to Japan. Conversely, convergence in real interest rate differentials and inflation differentials is found in all the cases, except for China's inflation differential relative to the U.S. Thus, by using the nonlinear KSS test, we are able to find real interest convergence and inflation convergence in all cases and regardless of the reference country, except for China's inflation differential relative to the U.S. On the other hand, nominal interest convergence is found for the most of the cases.

**[INSERT TABLE 8 HERE]**

The policy implication of these findings of convergences is that the differentials are not persistent and, thus, goods and financial markets are integrated. This convergence makes the national monetary policy a less effective stabilization policy tool, since; in this case, the ability of the domestic monetary authority to influence internal real interest rates and other variables that depend upon them will be severely limited to the extent to which the monetary authority can influence the reference country's real interest rate.

**3.5 The Impact of the Asian Crisis**

In this section we investigate the impact of the 1997/98 Asian financial crisis on the differentials. In particular, we attempt to assess the effect of the crisis on the convergence process, and investigate whether the crisis pulled the Asian economies together or pushed them apart. To this end, the full sample (January 1990 – December 2010) is split into pre-crisis period (January 1990 – December 1996) and post-crisis period (December 1998 – December 2010), and then the nonlinear KSS test is applied to the differentials. The results, reported in table 8, for the pre-crisis period reveal no evidence of nominal interest convergence in all cases and regardless of the reference country, except for Indonesia against the U.S. On the other hand, the results for the post-crisis period indicate evidence of nominal interest convergence in all cases relative to Japan, except for Thailand. This suggests that nominal interest convergence has been affected by Asian crisis; in particular, the crisis pulled the countries' nominal interest rates together relative to Japan. The results for the post-crisis period against the U.S show nominal interest convergence for Malaysia, the Philippines, and Thailand. This, again suggests that the crisis has affected nominal interest convergence for these countries and pulled them together relative to the U.S. The results for Indonesia relative to the U.S suggest that nominal interest convergence has not been affected by the crisis, since the unit root null is rejected for the full sample as well as for the pre and post-crisis periods.

Turning to inflation differentials convergence, the pre-crisis period results relative to the U.S show convergence for all cases, except for China and Korea. The test results for Korea suggest the possibility that inflation differentials follow an explosive process. Conversely, for the post-crisis period, the results show convergence in all the cases. Again, these findings of inflation convergences for the post-crisis period suggest that the crisis pulled these countries together relative to the U.S. Interestingly, China's inflation convergence relative to the U.S is detected only for the post-crisis period, as no evidence of convergence is found for the full sample as well as for the pre-crisis period. Inflation convergence relative to Japan is confirmed in all the cases in the pre-crisis period, except for China, which is confirmed only for the post-crisis period.

Real interest convergence relative to the U.S is found for all the countries for the full sample as well as the post-crisis period. For the pre-crisis period, convergence could not be established for China, Indonesia, and Thailand. This suggests that, once again, the crisis pulled these countries together. The results relative to Japan show real interest convergence in all cases for the full sample and for the post-crisis period as well. However, no evidence of convergence is found for China and Indonesia for the pre-crisis period.

Overall, the Asian crisis has affected the convergence process. In particular, the crisis has increased the number of convergences in nominal and real interest rates and inflation differentials. These findings support previous studies that found that the degree of markets integration has increased in the Asian countries after the crisis. For instance, Ji and Kim (2009) find that the degree of capital market integration of the Pacific-Basin countries has increased after the Asian crisis. Nusair (2008) finds evidence of stronger stability in the PPP relationship for Asian countries after the Asian crisis. Choudhry (2005) finds evidence of generalized-PPP for Asian countries during and after the crisis period, but not for the pre-crisis period.

## 4. Summary and Conclusion

We examine the dynamics of convergence of the ASEAN5 (Indonesia, Malaysia, Philippines, Singapore and Thailand) and the big three (China, Japan and Korea) for nominal and real interest rates, and inflation rates. We test for convergence relative to the U.S and Japan, using monthly data over the period January 1990 - December 2010. Convergence is investigated by examining the stationarity of nominal interest differentials, inflation differentials, and real interest differentials, non-linear unit root tests, in addition to using linear tests and tests with structural breaks. Finding evidence of stationary differentials is taken as evidence of convergence.

The linear tests and tests that endogenously determine structural breaks provide only limited evidence of stationary differentials and hence, limited evidence of convergence. On the other hand, the nonlinear test provides strong evidence of stationarity and hence, convergence. In particular, the results show strong evidence of stationary inflation and real interest rate differentials in all but China's inflation differential relative to the U.S., and stationary nominal interest differentials in most of the cases. We interpret these results as convergence in inflation rates and real interest rates in all cases, and as nominal interest convergence in most of the cases.

The policy implication of these findings of convergences is that the differentials are not persistent and, thus, goods and financial markets are integrated. This convergence makes the national monetary policy a less effective stabilization policy tool, since; in this case, the ability of the domestic monetary authority to influence internal real interest rates and other variables that depend upon them will be severely limited to the extent to which the monetary authority can influence the reference country's real interest rate.

Moreover, examining the impact of the Asian crisis shows less number of convergences before the crisis and more convergences after the crisis. This suggests that convergence has increased after the 1997/98 Asian crisis, and that the crisis has pulled the economies together.

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Table 1: highlights of inflation targeting arrangements in some Asian countries (as of July 2005)

| Country | Date of initiation of inflation targeting | Target price index | Target rate | Target horizon |
|---|---|---|---|---|
| Indonesia | May 1999 | Headline CPI | 5 - 6% | 3 years |
| Korea | January 1998 | Core CPI (excluding non-cereal agricultural product and petroleum products | 2.5 – 3.5% | 1 year indefinite |
| Philippines | December 2001 | Headline CPI. Also monitors core CPI (excluding agricultural product and petroleum products) | 4 – 6% | 2 years |
| Thailand | April 2000 | Core CPI (excluding fresh food and energy) | 0 – 3.5% | indefinite |

Source: Cavoli and Rajan (2006).

Table 2: Unit root tests of interest rates and inflation rates

| | ADF test | | Zivot-Andrews tests | | | | | |
|---|---|---|---|---|---|---|---|---|
| China | Level | First diff | Model A | BD | Model B | BD | Model C | BD |
| $i$ | -1.07(0) | -9.92(1)* | -5.28(0)** | Mar-98 | -1.67(0) | Sep-01 | -5.34(0)** | Mar-98 |
| $\Pi$ | -1.71(12) | -11.91(11)* | -4.08(12) | Jul-96 | -2.78(12) | Apr-00 | -4.61(12) | Dec-94 |
| $r$ | -2.35(12) | | -4.44(12) | Jul-96 | -3.06(12) | Jan-99 | -4.99(12) | Dec-94 |
| Indonesia | | | | | | | | |
| $i$ | -3.28(8)** | -14.06(1) | -4.63(8) | Apr-97 | -4.23(8) | Sep-97 | -4.83(8) | Jul-97 |
| $\Pi$ | -5.05(7)* | -6.67(9)* | -5.74(7)* | Jul-97 | -5.45(7)* | Mar-98 | -5.91(7)* | Feb-99 |
| $r$ | -3.51(10)* | | -4.56(10) | Feb-96 | -4.25(10) | Nov-98 | -5.10(10)** | Apr-00 |
| Japan | | | | | | | | |
| $i$ | -4.24(8)* | -3.90(1)* | -3.97(8) | Jan-95 | -5.30(8)* | Jun-95 | -5.87(8)* | Apr-95 |
| $\Pi$ | -3.66(11)* | -11.98(10)* | -4.18(11) | Apr-98 | -3.93(11) | Oct.00 | -4.15(11) | Mar-02 |
| $r$ | -2.28(11) | | -3.46(11) | Apr-95 | -4.33(11) | Jun-96 | -4.97(11) | Apr-98 |
| Korea | | | | | | | | |
| $i$ | -1.38(7) | -7.98(6)* | -5.29(9)** | Dec-98 | -3.76(9) | Oct-02 | -5.26(9)** | Aug-98 |
| $\Pi$ | -3.58(11)* | -11.18(10)* | -4.78(11) | Nov-98 | -4.10(11) | Jul-99 | -4.79(11) | Nov-98 |
| $r$ | -1.01(11) | | -5.29(11)** | Mar-99 | -3.58(11) | Feb-03 | -5.24(11)** | Mar-99 |
| Malaysia | | | | | | | | |
| $i$ | -1.55(4) | -8.54(3) | -4.99(4)** | Sep-98 | -2.77(4) | Apr-02 | -5.02(4) | Sep-98 |
| $\Pi$ | -12.05(0)* | -9.22(10)* | -12.35(0)* | Feb-99 | -12.20(0)* | Aug-02 | -12.33(0)* | Feb-99 |
| $r$ | -11.66(0)* | | -8.54(4)* | Apr-99 | -8.39(4)* | Apr-97 | -8.62(4)* | Apr-99 |
| Philippines | | | | | | | | |
| $i$ | -1.33(8) | -7.77(9)* | -5.38(7)* | Apr-99 | -4.95(7)* | Oct-03 | -5.42(7)** | Apr-99 |
| $\Pi$ | -10.62(0)* | -8.47(10)* | -11.57(0)* | Jan-04 | -11.53(0)* | Apr-93 | -11.58(0)* | Jun-93 |
| $r$ | -11.38(0)* | | -12.06(0)* | Dec-02 | -12.16(0)* | Apr-93 | -12.22(0)* | Apr-93 |
| Singapore | | | | | | | | |
| $i$ | -2.57(2) | -11.76(1)* | -3.60(1) | Jul-07 | -3.23(1) | Aug-07 | -3.83(1) | Apr-93 |
| $\Pi$ | -3.87(12)* | -7.10(10)* | -5.21(12)** | Jul-07 | -4.71(12)** | Jan-02 | -5.69(12)* | Jul-07 |
| $r$ | -2.91(11)** | | -4.64(12) | Jul-07 | -4.24(12) | May-98 | -4.69(12) | Jul-07 |
| Thailand | | | | | | | | |
| $i$ | -2.27(1) | -18.76(0)* | -5.16(1)** | Jul-98 | -2.95(1) | Jun-02 | -5.47(1)** | Jul-98 |
| $\Pi$ | -11.45(0)* | -10.26(10)* | -12.08(0)* | Jul-98 | -11.65(0)* | Nov-01 | -12.07(0)* | Jul-98 |
| $r$ | -2.61(11) | | -11.86(0)* | Jun-99 | -11.45(0)* | Apr-5 | -11.86(0)* | Jun-99 |
| U.S. | | | | | | | | |
| $i$ | -2.10(3) | -5.45(2)* | -3.54(3) | Jan-01 | -2.93(3) | May-97 | -3.71(3) | Dec-00 |
| $\Pi$ | -4.81(10)* | -8.64(12)* | -5.27(10)** | Jan-04 | -5.32(10)* | Dec-07 | -5.66(10)* | Jan-05 |
| $r$ | -3.03(10)** | | -4.68(10) | Jan-02 | -3.93(10) | Jun-97 | -4.67(10) | Jan-02 |

* and ** denotes rejection of the null hypothesis of a unit root at the 1% and 5%,significance level. The number of lags in parentheses is selected by AIC with a maximum lag length of 12. $i$ is the nominal interest rate, $\Pi$ is the inflation rate, and $r$ is the real interest rate. The 1% and 5% critical values are -3.48 and -2.88 for the ADF test. The tests are conducted on an intercept only. The 1% and 5% critical values for Zivot and Andrews test are -5.34 and -4.80 for Model A, -4.93 and -4.42, for Model B, and -5.57 and -5.08 for Model C (source: Zivot and Andrews, 1992). BD stands for the break date.

Table 3: Descriptive statistics: relative to the U.S.

| | Mean | Std. Dev. | Skewness | Kurtosis | Maximum | Minimum | JB Stat. |
|---|---|---|---|---|---|---|---|
| **Nominal interest differentials** | | | | | | | |
| China | 1.515 | 2.420 | -0.000 | 2.497 | 6.920 | -3.330 | 2.657 |
| | (0.000)* | | | | Aug-93 | May-00 | [0.265] |
| Indonesia | 10.168 | 12.983 | 3.137 | 12.582 | 75.530 | -0.310 | 1377.426 |
| | (0.000)* | | | | Aug-98 | Aug-07 | [0.000] |
| Japan | -2.587 | 2.328 | 0.149 | 1.729 | 2.164 | -6.549 | 17.889 |
| | (0.000)* | | | | Apr-91 | Jun-00 | [0.000] |
| Korea | 4.185 | 4.357 | 0.889 | 3.364 | 20.210 | -1.430 | 34.563 |
| | (0.000)* | | | | Jan-98 | May-00 | [0.000] |
| Malaysia | 0.585 | 2.172 | -0.072 | 2.458 | 5.873 | -4.039 | 3.305 |
| | (0.000)* | | | | Jul-97 | May-00 | [0.192] |
| Philippines | 6.447 | 4.169 | 2.057 | 9.205 | 28.410 | 0.237 | 574.938 |
| | (0.000)* | | | | Dec-90 | Jun-90 | [0.000] |
| Singapore | -1.313 | 1.232 | -0.344 | 2.596 | 2.330 | -4.750 | 6.676 |
| | (0.000)* | | | | Jan-98 | May-95 | [0.036] |
| Thailand | 1.772 | 4.142 | 1.300 | 5.283 | 18.390 | -4.830 | 125.776 |
| | (0.000)* | | | | Sep-97 | Aug-00 | [0.000] |
| **Inflation differentials** | | | | | | | |
| China | 2.148 | 7.555 | 1.127 | 4.141 | 26.895 | -13.664 | 66.722 |
| | (0.000)* | | | | Oct-94 | Sep-05 | [0.000] |
| Indonesia | 7.673 | 17.299 | 3.787 | 23.589 | 141.886 | -16.255 | 5033.231 |
| | (0.000)* | | | | Feb-98 | Jul-99 | [0.000] |
| Japan | -2.240 | 4.989 | 0.843 | 5.281 | 23.224 | -12.805 | 84.196 |
| | (0.000)* | | | | Apr-97 | Feb-03 | [0.000] |
| Korea | 1.594 | 5.932 | 1.118 | 6.298 | 31.462 | -11.333 | 166.033 |
| | (0.000)* | | | | Dec-97 | Jun-09 | [0.000] |
| Malaysia | 0.231 | 5.480 | 0.992 | 8.191 | 34.353 | -12.181 | 322.938 |
| | (0.504) | | | | Jun-08 | Mar-07 | [0.000] |
| Philippines | 3.826 | 7.896 | -0.339 | 12.548 | 40.171 | -49.680 | 958.161 |
| | (0.000)* | | | | Dec-90 | Jan-00 | [0.000] |
| Singapore | -0.873 | 6.223 | 0.449 | 4.833 | 24.763 | -16.311 | 43.589 |
| | (0.027)** | | | | Jul-07 | Jun-09 | [0.000] |
| Thailand | 0.941 | 5.810 | -0.039 | 8.344 | 29.258 | -31.910 | 297.621 |
| | (0.011)** | | | | Aug-97 | Aug-08 | [0.000] |
| **Real interest differentials** | | | | | | | |
| China | -0.631 | 6.359 | -1.077 | 4.523 | 14.798 | -23.966 | 72.799 |
| | (0.117) | | | | Jun-09 | Nov-11 | [0.000] |
| Indonesia | 2.525 | 14.660 | -1.119 | 15.780 | 60.488 | -93.946 | 1760.379 |
| | (0.007)* | | | | Oct-98 | Oct-05 | [0.000] |
| Japan | -0.351 | 5.356 | -0.723 | 5.394 | 12.500 | -28.438 | 81.822 |
| | (0.300) | | | | Jun-09 | Apr-97 | [0.000] |
| Korea | 2.592 | 6.330 | -0.104 | 3.486 | 21.414 | -17.408 | 2.925 |
| | (0.000)* | | | | Mar-98 | Nov-08 | [0.232] |
| Malaysia | 0.370 | 5.538 | -0.968 | 7.594 | 12.113 | -33.063 | 259.916 |
| | (0.291) | | | | Oct-92 | Jun-08 | [0.000] |
| Philippines | 2.629 | 8.281 | 0.374 | 8.216 | 52.640 | -25.252 | 286.934 |
| | (0.000)* | | | | Jan-00 | Jan-91 | [0.000] |
| Singapore | -0.439 | 6.309 | -0.362 | 4.841 | 16.741 | -27.423 | 40.929 |
| | (0.272) | | | | Jun-09 | Jul-07 | [0.000] |
| Thailand | 0.818 | 6.044 | 0.506 | 6.080 | 33.280 | -19.388 | 109.898 |
| | (0.033)** | | | | Aug-08 | Aug-97 | [0.000] |

Numbers in parentheses are t-statistics testing the hypothesis that the mean is equal to zero. Numbers in brackets are *p*-values testing the hypothesis of normality using the Jarque and Bera (JB) (1980) test. *, **, and *** mean significantly different from zero at the 1%, 5%, and 10% significance levels.

Table 4: Descriptive statistics: relative to Japan

| | Mean | Std. Dev. | Skewness | Kurtosis | Maximum | Minimum | JB Stat. |
|---|---|---|---|---|---|---|---|
| **Nominal interest differentials** | | | | | | | |
| China | 4.102 | 2.578 | 0.798 | 2.786 | 9.985 | -1.034 | 27.223 |
| | (0.000)* | | | | Nov-95 | Apr-91 | [0.000] |
| Indonesia | 12.755 | 13.735 | 3.065 | 12.102 | 80.583 | 2.551 | 1264.418 |
| | (0.000)* | | | | Aug-98 | Aug-93 | [0.000] |
| Korea | 6.773 | 4.157 | 1.399 | 5.509 | 25.195 | 1.670 | 148.260 |
| | (0.000)* | | | | Jan-98 | Mar-09 | [0.000] |
| Malaysia | 3.173 | 2.207 | 0.587 | 4.890 | 10.950 | -2.076 | 51.999 |
| | (0.000)* | | | | Jul-97 | Feb-90 | [0.000] |
| Philippines | 9.064 | 4.226 | 1.715 | 8.723 | 33.390 | 1.012 | 461.881 |
| | (0.000)* | | | | Oct-97 | Jun-90 | [0.000] |
| Singapore | 1.274 | 1.823 | -0.201 | 3.831 | 7.315 | -3.648 | 8.963 |
| | (0.000)* | | | | Jan-98 | Mar-91 | [0.011] |
| Thailand | 4.359 | 4.456 | 2.036 | 7.191 | 23.372 | -1.795 | 358.541 |
| | (0.000)* | | | | Sep-97 | Mar-92 | [0.000] |
| **Inflation differentials** | | | | | | | |
| China | 4.389 | 7.637 | 0.926 | 4.714 | 31.053 | -21.524 | 66.560 |
| | (0.000)* | | | | Nov-94 | Apr-97 | [0.000] |
| Indonesia | 9.914 | 17.559 | 3.761 | 23.509 | 145.279 | -19.883 | 4990.871 |
| | (0.000)* | | | | Feb-98 | Apr-97 | [0.000] |
| Korea | 3.835 | 6.304 | 0.543 | 5.499 | 32.304 | -19.194 | 77.671 |
| | (0.000)* | | | | Dec-97 | Apr-97 | [0.000] |
| Malaysia | 2.472 | 6.273 | 0.678 | 8.953 | 40.501 | -26.920 | 389.916 |
| | (0.000)* | | | | Jun-08 | Apr-97 | [0.000] |
| Philippines | 6.066 | 8.654 | -0.142 | 8.813 | 41.426 | -44.949 | 354.273 |
| | (0.000)* | | | | Dec-90 | Jan-00 | [0.000] |
| Singapore | 1.367 | 6.659 | 0.280 | 3.433 | 25.646 | -19.176 | 5.243 |
| | (0.001)* | | | | Jul-07 | Apr-97 | [0.073] |
| Thailand | 3.181 | 6.950 | -0.991 | 9.679 | 30.331 | -40.225 | 507.621 |
| | (0.000)* | | | | Aug-98 | Aug-08 | [0.000] |
| **Real interest differentials** | | | | | | | |
| China | -0.280 | 6.717 | -0.337 | 5.169 | 30.028 | -23.241 | 53.957 |
| | (0.510) | | | | Apr-97 | Nov-94 | [0.000] |
| Indonesia | 2.876 | 15.420 | -0.599 | 13.882 | 70.459 | -92.352 | 1253.388 |
| | (0.003)* | | | | Oct-98 | Oct-05 | [0.000] |
| Korea | 2.944 | 7.0677 | 0.638 | 4.587 | 31.698 | -15.012 | 43.403 |
| | (0.000)* | | | | Apr-97 | Sep-00 | [0.000] |
| Malaysia | 0.721 | 6.414 | -0.467 | 9.434 | 33.686 | -37.510 | 442.120 |
| | (0.076)*** | | | | Apr-97 | Jun-08 | [0.000] |
| Philippines | 3.009 | 9.338 | 0.321 | 6.787 | 53.628 | -25.853 | 152.465 |
| | (0.000)* | | | | Jan-00 | Jan-91 | [0.000] |
| Singapore | -0.087 | 6.932 | -0.274 | 3.481 | 22.180 | -23.585 | 5.572 |
| | (0.842) | | | | Apr-97 | Jul-07 | [0.062] |
| Thailand | 1.169 | 7.453 | 1.107 | 7.607 | 43.171 | -19.173 | 273.312 |
| | (0.014)** | | | | Aug-08 | Apr-08 | [0.000] |

Numbers in parentheses are t-statistics testing the hypothesis that the mean is equal to zero. Numbers in brackets are *p*-values testing the hypothesis of normality using the Jarque and Bera (JB) (1980) test. *, **, and *** mean significantly different from zero at the 1%, 5%, and 10% significance levels.

Table 5: Unit root tests of differentials relative to the U.S

| | ADF test | Zivot-Andrews | | | | | |
|---|---|---|---|---|---|---|---|
| Nominal interest differentials | | Model A | BD | Model B | BD | Model C | BD |
| China | -1.86(4) | -3.65(4) | Mar-98 | -2.73(4) | May-06 | -3.44(4) | Mar-98 |
| Indonesia | -3.50(8)* | -4.78(4) | Apr-97 | -4.27(8) | Sep-97 | -4.91(8) | Jul-97 |
| Japan | -2.57(7) | -3.81(7) | Feb-94 | -3.89(7) | May-95 | -4.03(7) | Jun-00 |
| Korea | -1.75(7) | -4.87(7)** | May-98 | -3.59(7) | Sep-00 | -4.87(7) | May-98 |
| Malaysia | -3.72(9)* | -5.01(9)** | Jul-98 | -4.26(9) | Nov-06 | -5.02(9) | Jul-98 |
| Philippines | -2.08(8) | -5.13(7)** | Jul-94 | -4.84(7)** | Sep-07 | -5.51(7)** | Jun-94 |
| Singapore | -2.69(0) | -3.69(0) | May-94 | -3.29(0) | Apr-99 | -3.73(0) | Mar-01 |
| Thailand | -2.72(1) | -5.99(1)* | Jul-98 | -3.24(1) | Nov-00 | -6.11(1)* | Jul-98 |
| Inflation differentials | | | | | | | |
| China | -2.36(5) | -3.78(5) | Jan-96 | -2.99(5) | Oct-00 | -5.08(5)** | Aug-95 |
| Indonesia | -5.08(7)* | -5.73(7)* | Jul-97 | -5.44(7)* | Mar-98 | -5.98(7)* | Feb-99 |
| Japan | -3.69(11)* | -4.58(11) | Jan-99 | -4.23(11) | Aug-05 | -4.63(11) | Jan-99 |
| Korea | -10.11(1)* | -10.84(1)* | Mar-98 | -10.58(1)* | May-06 | -10.83(1)* | May-98 |
| Malaysia | -3.84(11)* | -5.21(11)** | Mar-99 | -4.38(11) | Sep-03 | -5.17(11)** | Mar-99 |
| Philippines | -11.12(0)* | -11.82(0)* | Feb-99 | -11.65(0)* | Feb-00 | -11.89(0)* | Feb-99 |
| Singapore | -2.81(12) | -6.01(12)* | Jul-07 | -4.74(12)** | Jul-05 | -5.98(12)* | Jul-07 |
| Thailand | -13.47(0)* | -14.67(0)* | Sep-98 | -13.58(0)* | Apr-02 | -14.74(0)* | Jul-98 |
| Real interest differentials | | | | | | | |
| China | -3.72(3)* | -4.71(3) | Jan-96 | -4.20(3) | Jul-93 | -6.69(3)* | Aug-95 |
| Indonesia | -3.80(10)* | -4.55(10) | Feb-96 | -4.27(10) | Mar-99 | -4.97(10) | Apr-00 |
| Japan | -2.09(11) | -3.35(11) | Aug-94 | -3.40(11) | Jun-96 | -3.78(11) | Dec-98 |
| Korea | -1.92(11) | -10.30(1)* | Aug-99 | 9.88(1)* | May-93 | -10.27(1)* | Aug-99 |
| Malaysia | -3.12(11)** | -3.50(11) | Apr-02 | -3.31(11) | Jan-08 | -3.72(11) | Oct-05 |
| Philippines | -11.66(0)* | -11.96(0)* | Jun-04 | -12.05(0)* | Apr-93 | -12.28(0)* | Apr-93 |
| Singapore | -3.39(12)** | -4.57(12) | Jul-97 | -3.93(12) | Feb-05 | -5.01(12) | Jul-07 |
| Thailand | -5.17(4)* | -14.47(0)* | Jun-99 | -14.07(0)* | Aug-08 | -14.45(0)* | Jun-99 |

* and ** denotes rejection of the null hypothesis of a unit root at the 1% and 5%,significance level. The number of lags in parentheses is selected by AIC a maximum lag length of 12. $i$ is the nominal interest rate, $\Pi$ is the inflation rate, and $r$ is the real interest rate. The 5% and 1% critical values for Zivot and Andrews test are -4.80 and -5.34 for Model A, -4.42, and -4.93 for Model B, and -5.08, and -5.57 for Model C (source: Zivot and Andrews, 1992). BD stands for the break date. The 1% and 5% critical values for the ADF test are -3.48 and -2.88.

Table 6: Unit root tests of differentials relative to Japan

| | ADF test | Zivot-Andrews | | | | | |
|---|---|---|---|---|---|---|---|
| Nominal interest differentials | | Model A | BD | Model B | BD | Model C | BD |
| China | -1.99(5) | -3.26(5) | Mar-98 | -3.79(5) | Jul-93 | -4.07(5) | Mar-98 |
| Indonesia | -3.21(8)** | -4.46(8) | Apr-97 | -4.30(8) | Sep-97 | -4.91(8) | Dec-98 |
| Korea | -1.53(7) | -4.58(7) | Dec-98 | -2.94(7) | Jan-95 | -6.17(7)* | Dec-98 |
| Malaysia | -2.78(7) | -3.64(4) | Sep-98 | -2.73(4) | Sep-95 | -5.62(4)* | Sep-98 |
| Philippines | -1.82(8) | -4.13(8) | Sep-95 | -4.29(8) | Aug-97 | -4.91(8) | Apr-99 |
| Singapore | -1.96(0) | -3.76(0) | Apr-93 | -3.82(0) | Jul-96 | -4.74(0) | Jul-98 |
| Thailand | -2.46(1) | -4.56(1) | Jul-98 | -3.06(1) | Mar-95 | -6.41(1)* | Jul-98 |
| Inflation differentials | | | | | | | |
| China | -1.78(12) | -3.60(12) | Aug-95 | -2.48(12) | Sep-99 | -5.48(12)** | Apr-95 |
| Indonesia | -4.21(12)* | -5.20(12)** | Jul-97 | -4.76(12)** | Mar-98 | -5.24(12)** | Oct-97 |
| Korea | -4.41(11)* | -5.10(11)** | Sep-98 | -4.92(11)** | Nov-06 | -5.09(11)** | Nov-98 |
| Malaysia | -4.79(11)* | -4.99(11)** | Jan-00 | -4.78(11)** | Sep-03 | -4.98(11) | Dec-04 |
| Philippines | -4.69(11)* | -5.19(11)** | Mar-99 | -4.86(11)** | Feb-00 | -5.08(11)** | Apr-04 |
| Singapore | -2.79(11) | -4.34(11) | Jul-07 | -3.75(11) | Feb-05 | -4.47(11) | Jul-07 |
| Thailand | -4.14(12)* | -5.12(12)** | Sep-98 | -4.44(12)** | Feb-95 | -5.60(12)* | Aug-98 |
| Real interest differentials | | | | | | | |
| China | -1.84(12) | -4.47(12) | Jan-96 | -2.65(12) | Feb-98 | -5.69(12)* | Apr-95 |
| Indonesia | -3.00(11)** | -4.19(11) | Feb-96 | -3.87(11) | Sep-97 | -4.91(11) | Apr-00 |
| Korea | -1.29(12) | -4.77(12) | Feb-99 | -2.97(12) | Nov-04 | -5.36(12)** | Feb-99 |
| Malaysia | -2.87(11) | -3.83(11) | Jun-95 | -3.82(11) | Nov-96 | -4.51(11) | Nov-98 |
| Philippines | -3.72(11)* | -4.82(11) | Feb-96 | -4.41(11) | Jun-97 | -4.67(11) | Jun-00 |
| Singapore | -1.84(11) | -3.14(11) | Aug-94 | -3.62(11) | Jun-97 | -4.18(11) | Jan-99 |
| Thailand | -2.47(11) | -3.60(11) | Jun-99 | -3.26(11) | Jan-97 | -4.79(11) | Dec-98 |

* and ** denotes rejection of the null hypothesis of a unit root at the 1% and 5%,significance level. The number of lags in parentheses is selected by AIC a maximum lag length of 12. $i$ is the nominal interest rate, $\Pi$ is the inflation rate, and $r$ is the real interest rate. The 5% and 1% critical values for Zivot and Andrews test are -4.80 and -5.34 for Model A, -4.42, and -4.93 for Model B, and -5.08, and -5.57 for Model C (source: Zivot and Andrews, 1992). BD stands for the break date. The 1% and 5% critical values for the ADF test are -3.48 and -2.88.

Table 7: Linearity test

| | Relative to the U.S. | | | Relative to Japan | | |
|---|---|---|---|---|---|---|
| | Nominal interest differentials | | | Nominal interest differentials | | |
| | $P$ | $d$ | $F-Stat$ | $P$ | $d$ | $F-Stat$ |
| China | 5 | 10 | 1.088[0.3684] | 6 | 12 | 1.300[0.1893] |
| Indonesia | 19 | 1 | 2.144[0.0001] | 19 | 1 | 2.776[0.0000] |
| Japan | 8 | 6 | 2.189[0.0017] | n.a. | n.a. | n.a. |
| Korea | 8 | 1 | 3.059[0.0000] | 8 | 1 | 5.344[0.0000] |
| Malaysia | 14 | 2 | 3.588[0.0000] | 3 | 2 | 14.814[0.0000] |
| Philippines | 9 | 2 | 11.073[0.0000] | 9 | 1 | 9.211[0.0000] |
| Singapore | 1 | 1 | 6.743[0.0002] | 1 | 4 | 6.111[0.0005] |
| Thailand | 2 | 10 | 4.894[0.0001] | 2 | 10 | 7.479[0.0000] |
| | Inflation differentials | | | Inflation differentials | | |
| China | 25 | 1 | 2.026[0.0002] | 25 | 6 | 1.580[0.0119] |
| Indonesia | 8 | 1 | 5.423[0.0000] | 13 | 1 | 5.472[0.0000] |
| Japan | 12 | 12 | 1.971[0.0019] | n.a. | n.a. | n.a. |
| Korea | 2 | 1 | 2.889[0.0098] | 15 | 5 | 2.123[0.0003] |
| Malaysia | 16 | 4 | 1.680[0.0085] | 14 | 3 | 1.329[0.1050] |
| Philippines | 1 | 1 | 2.401[0.0684] | 14 | 12 | 3.376[0.0000] |
| Singapore | 25 | 4 | 2.057[0.0002] | 24 | 11 | 1.606[0.0097] |
| Thailand | 1 | 3 | 2.059[0.1063] | 14 | 4 | 2.417[0.0000] |
| | Real interest differentials | | | Real interest differentials | | |
| China | 25 | 1 | 2.257[0.0000] | 16 | 12 | 1.765[0.0044] |
| Indonesia | 11 | 5 | 2.784[0.0000] | 12 | 5 | 3.041[0.0000] |
| Japan | 12 | 4 | 1.642[0.0183] | n.a. | n.a. | n.a. |
| Korea | 12 | 1 | 1.641[0.0219] | 12 | 11 | 1.488[0.0476] |
| Malaysia | 16 | 3 | 1.636[0.0119] | 14 | 11 | 1.347[0.0948] |
| Philippines | 1 | 3 | 2.333[0.0747] | 12 | 12 | 3.068[0.0000] |
| Singapore | 25 | 4 | 2.368[0.0000] | 24 | 11 | 1.774[0.0023] |
| Thailand | 5 | 4 | 3.732[0.0000] | 12 | 4 | 3.453[0.0000] |

The appropriate lag length ($P$) in the AR model is determined by AIC. The optimal $d$ is selected by minimizing the p-value associated with the linearity test over the range $\{1, \ldots, 12\}$.The $F-Stat$ tests the null hypothesis of linearity against the alternative of nonlinearity. The numbers in square brackets are the p-values associated with the linearity test.

Table 8: The non-linear KSS test of differentials

| Full sample: January 1990 – December 2010 | | | | | | |
|---|---|---|---|---|---|---|
| | Relative to the U.S. | | | Relative to Japan | | |
| Country | Nominal interest diff | Inflation diff | Real interest diff | Nominal interest diff | Inflation diff | Real interest diff |
| China | -1.72(4) | -2.17(0) | -3.02(1)* | -1.42(5) | -2.34(0)** | -5.02(0)* |
| Indonesia | -2.59(4)** | -5.89(1)* | -7.16(1)* | -3.54(0)* | -6.48(1)* | -8.22(0)* |
| Japan | -1.92(7) | -6.53(0)* | -5.40(0)* | n.a. | n.a. | n.a. |
| Korea | -3.94(7)* | -3.70(0)* | -5.70(0)* | -2.97(7)* | -4.43(0)* | -4.05(2)* |
| Malaysia | -5.31(9)* | -5.44(0)* | -5.84(0)* | -3.84(7)* | -5.99(0)* | -6.11(0)* |
| Philippines | -10.77(0)* | -7.28(0)* | -6.50(0)* | -9.01(0)* | -8.16(0)* | -7.30(0)* |
| Singapore | -2.09(0) | -7.28(0)* | -6.30(0)* | -3.01(0)* | -9.59(0)* | -9.87(0)* |
| Thailand | -3.14(12)* | -8.18(0)* | -7.69(0)* | -2.70(12)** | -8.28(0)* | -7.22(0)* |
| Pre-crisis period: January 1990 – December 1996 | | | | | | |
| China | -1.11(2) | -1.32(12) | -1.17(12) | -0.33(3) | -1.17(1) | -1.55(1) |
| Indonesia | -2.89(12)* | -4.36(0)* | -2.20(7) | -1.08(12) | -3.51(1)* | -0.91(9) |
| Japan | -0.60(7) | -4.79(1)* | -3.31(3)* | n.a. | n.a. | n.a. |
| Korea | -0.76(11) | 0.01(6) | -2.21(6) | 0.24(12) | -3.26(2)* | -3.57(2)* |
| Malaysia | -1.31(4) | -2.37(3)** | -6.09(0)* | -0.31(5) | -3.06(3)* | -3.35(3)* |
| Philippines | -1.97(12) | -3.12(12)* | -2.70(9)* | -1.23(12) | -2.78(2)** | -4.02(2)* |
| Singapore | -0.70(6) | -4.63(1)* | -5.00(2)* | -1.69(0) | -4.70(1)* | -3.81(2)* |
| Thailand | -1.54(12) | -3.76(1)* | -0.60(9) | -0.13(12) | -3.60(1)* | -4.08(1)* |
| Post-crisis period: December 1998 – December 2010 | | | | | | |
| China | -1.67(11) | -3.64(1)* | -4.15(1)* | -7.01(0)* | -6.39(0)* | -3.83(0)* |
| Indonesia | -5.36(6)* | -6.21(1)* | -6.83(1)* | -5.50(6)* | -6.96(1)* | -7.77(1)* |
| Japan | -2.01(7) | -5.95(0)* | -5.92(0)* | n.a. | n.a. | n.a. |
| Korea | -1.35(9) | -5.46(1)* | -3.80(0)* | -10.87(3)* | -5.37(2)* | -1.80(2) |
| Malaysia | -3.96(7)* | -4.93(0)* | -5.14(0)* | -2.47(10)** | -4.71(0)* | -4.53(0)* |
| Philippines | -2.85(1)* | -6.37(0)* | -5.81(0)* | -2.65(3)** | -7.90(0)* | -6.16(0)* |
| Singapore | -1.12(0) | -5.97(0)* | -5.18(0)* | -7.31(0)* | -7.27(0)* | -7.89(0)* |
| Thailand | -2.35(8)** | -6.58(0)* | -6.41(0)* | -1.98(8) | -6.49(0)* | -6.31(0)* |

*, ** denote rejection of the null hypothesis of unit root at the 1% and 5% significance levels The numbers in parentheses represent the number of lags selected by Akaike Information Criterion (AIC). The 1% and 5% critical values are -2.82 and -2.22. Source: Kapetanios et al. (2003).

Figure 1: Inflation differential

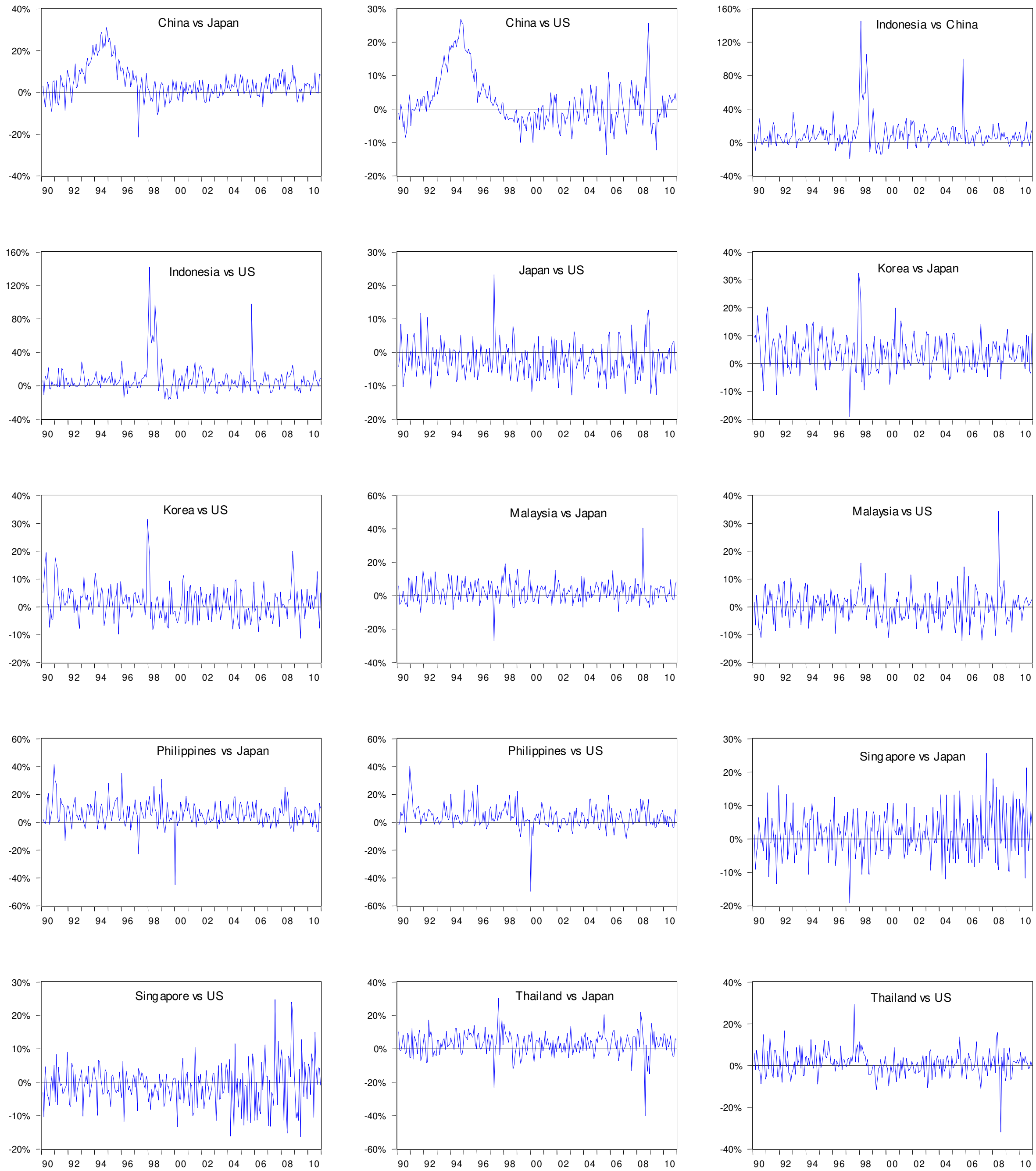

Figure 2: Nominal interest differentials

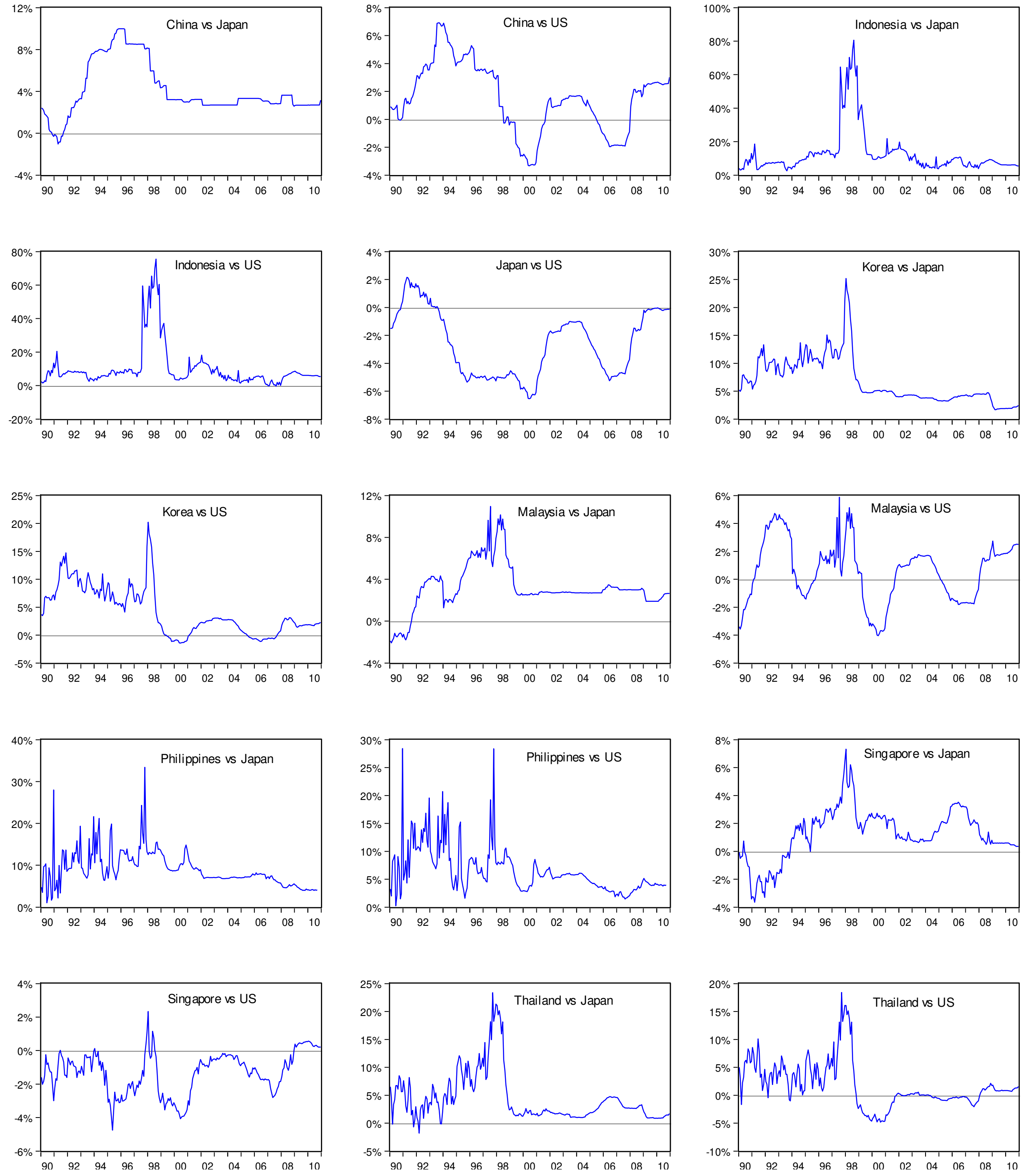

Figure 3: Real interest differentials