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Roberta Colavecchio and Michael Funke

Volatility transmissions between renminbi and Asia-Pacific on-shore and off-shore U.S. dollar futures

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Roberta Colavecchio* and Michael Funke**

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Abstract

This paper uses multivariate GARCH techniques to study volatility spillovers between the Chinese non-deliverable forward market and seven of its Asia-Pacific counterparts over the period January 1998 to March 2005. To account for the time-variability of conditional correlation, a dynamic correlation structure is included in the volatility model specification. The empirical results demonstrate that the renminbi non-deliverable forward (NDF) has been a driver of various Asian currency markets but that such co-movements exhibit a substantial degree of heterogeneity. As to the determinants of the magnitude of these co-movements, we test the relevance of potential factors and find that it is the degree of real and financial integration, in particular, that exerts the largest influence on volatility transmission.

Keywords: China, renminbi, Asia, forward exchange rates, non-deliverable forward market, multivariate GARCH models
JEL-Classification: C22, F31, F36

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Roberta Colavecchio and Michael Funke

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Tiivistelmä

Tässä työssä tutkitaan volatiliteetin leviämistä Kiinan termiinimarkkinoiden (ns. non-deliverable forwards) ja seitsemän muun Aasian maan termiinimarkkinoiden välillä. Usean muuttujan GARCH-menetelmiä käyttävä tutkimus kattaa ajanjakson tammikuusta 1998 maaliskuuhun 2005. Koska ehdollinen korrelaatio muuttuu ajan myötä, volatiliteetti-mallissa käytetään dynaamista korrelaatiorakennetta. Tulosten mukaan Kiinan termiini-markkinat vaikuttavat selvästi muiden Aasian maiden markkinoihin, mutta vaikutusten suuruus vaihtelee maittain. Tulosten mukaan reaalinen ja finanssi-integraatio näyttävät vaikuttavan siihen, miten volatiliteetti välittyy yksiltä markkinoilta toisille.

Asiasanat: Kiina, juan, Aasia, termiinikurssit, non-deliverable forwards, usean muuttujan GARCH-mallit

1 Introduction

The financial turmoil in the Asia-Pacific region in the 1990s has sparked intense interest in the degree of international financial integration and in co-movements between foreign exchange markets. The removal of capital controls in emerging markets and the subsequent vast capital inflows seeking higher returns in these developing economies provide ample proof that financial markets became increasingly integrated during the recent decade. In tandem with these financial developments, a seemingly unstoppable Chinese export drive has redrawn the lines of international trade.[1] Following more than two decades of market-oriented reforms, China has become an international production hub which combines a vast supply of cheap labour with an economy that is unusually open by international standards. The sum of exports and imports amounted to about 75 percent of China's GDP in 2004, compared to around 25-30 percent in Brazil and India. Thus China has an impact upon the world economy that amounts to a substantial supply shock. This has raised the world's potential GDP growth rate, helped to hold down inflation, and triggered significant changes in relative prices of labour, capital, and goods. Furthermore, China as a potential market far exceeds Europe, and it is hard to dispute that China has the potential to be a principal engine of world economic growth in the twenty-first century. World trade patterns and production structures in the rest of the world will have to adjust to accommodate China's emergence as a global economic player.

Since China is especially open to trade, it is not merely a driver of global growth, but also has a highly pervasive impact on other economies. Whereas ten years ago a downturn in the Chinese economy may not have had far-reaching repercussions for the rest of the world, today the consequences of such would be far more perilous for global economic growth . In light of this, the Chinese currency regime has become one of the most intensely debated issues in international economics.[2]

On July 21, 2005, after more than a decade of pegging the renminbi to the U.S. dollar at an exchange rate of 8.28, the People´s Bank of China (PBOC) announced a revalua-

[1] See Rodrik (2006) for a comprehensive analysis of China´s export success.
[2] Chinese reform of the exchange rate regime is watched with unprecedented interest: a *Google* search for „China currency regime change" yielded 3.7 million hits.

tion of the currency, together with a reform of the exchange rate regime.[3] Under the reform, the PBOC manages the renminbi against an undisclosed basket of currencies of China's main trading partners. The initial revaluation put the renminbi at 8.11 against the dollar, which amounts to an appreciation of 2.1 percent. In spite of this, many economists argue that the present situation does not represent an equilibrium and that the small renminbi revaluation merely marks the beginning of a more significant evolution of the currency regime.[4] Greater flexibility in China's exchange rate is viewed as an essential element of a global response to the large macroeconomic imbalances in the world economy. The United States has been joined by the international community, including the G-7, IMF, and Asian Development Bank, in vigorously encouraging China to implement greater exchange rate flexibility, which would be associated with a larger renminbi appreciation.

Arising of this, the Chinese currency's future path, as well as in co-movements across Asian currencies, continues to demand the attention of policymakers and academics alike. This stems from the fact that, while China's Asian trading partners are weighted significantly in its trade-weighted index, China is also an important trade partner for them. As a consequence, PBOC´s exchange rate policy is likely to influence the path of many Asian currencies. Indeed, McKinnon (2005) has recently argued that a number of China's main Asian trading partners have smoothed their dollar exchange rates in an effort to retain competitiveness against China.

Despite the great interest in the topic, no papers have addressed the issue of interdependence among Asian exchange rate markets via temporal volatility (or conditional variances) so far. The lack of research dedicated to this is quite surprising.[5] The objective of this study is twofold. We first scrutinize the nature of co-movements between Chinese and other Asian forward exchange rates in order to shed some light on how, and to what extent, the volatility of Asian currencies is affected by renminbi exchange rate developments. We then explore whether the interaction between China and other Asia-Pacific countries have changed since the 1997-98 crisis. To state it more intuitively, this paper aims to provide answers to questions such as: are there volatility spill-

[3] The terms "renminbi" and "yuan" are generally used interchangeably to refer to China´s currency. The renminbi is the currency, while the yuan is the unit of account.

[4] This poses a problem in that the announcement and subsequent clarifications leave the Chinese central bank with considerable discretion over its renminbi target. Funke and Rahn (2005) have recently estimated that the renminbi exchange rate against the U.S. dollar is undervalued by 10-15 percent compared to the equilibrium rate. A survey of the literature is provided by Li and Dunaway (2005).

[5] Co-movements between markets occur as rational agents try to infer information from price changes in other markets. A number of papers have demonstrated that the nature of such financial market linkages is time-varying [see Bekaert and Harvey (1995, 1997)]. Park (2001) is the sole paper to date analysing interrelations and information flows across NDF and spot markets for the Korean won.

overs between Chinese and other Asian forward exchange rates? Have the correlations between those markets changed over time, and in particular after the Asian crisis? Which are the potential determinants of co-movements across countries? As is now standard in the literature, volatilities and international correlations are modeled as estimated variance and correlation parameters of the conditional joint distributions of returns using a multivariate Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model.

The reminder of the paper is organized as follows. Section 2 outlines the characteristics of the Asian Non-Deliverable Forward (NDF) market, as well as describing the dataset used in this study. Section 3 discusses the methodology employed and presents the bivariate GARCH models used to model volatility spillovers, together with the dynamic correlation structure. Section 4 analyses the empirical results and Section 5 investigates a variety of potential determinants of the magnitude of co-movements across countries. Section 6 summarizes the findings and concludes with some general remarks.

2 Data description

The aim of this section is twofold. We first present the dataset used in our study, highlighting the main features of markets for NDF in Asian currencies. We then present a set of scatter plots for the analysed variables in order to provide some preliminary evidence for volatility clustering in the data.

The evolution of forward exchange rate markets, which are considered a gauge of the anticipated direction of a change of a currency's value, is closely monitored by a diverse range of economic agents. However, a number of emerging market economies restrict the access of foreign firms and international investors to on-shore financial markets and, as a consequence, forward markets either do not exist or are underdeveloped. Since the early 1990s, however, some international banks have been providing an offshore, over-the-counter, market in non-deliverable forwards (NDFs) for many emerging-market currencies, one of which includes the Chinese renminbi.

In order to analyse of co-movements in Chinese and Asian forward exchange rates, we use daily observations of NDF rates relative to spot exchange rates for eight Asian countries. These eight countries can be classified as (1) Greater China (China and Hong Kong), (2) the NIE´s (Korea, Singapore and Taiwan), and (3) three ASEAN countries (Indonesia, Malaysia, Philippines). Our dataset includes on-shore and off-shore forward ex-

change rates with maturities of one month to eighteen months. Contracts with maturities longer than twelve months, however, are too thinly traded to serve as reliable market indicators. As the NDF markets only began full scale trading in 1996-97, our sample commences in 1998 and spans the period 1 January 1998 to 23 March 2005. All data were obtained from Citibank in Hong Kong. The country coverage is detailed in Table 1.

Table 1: Country coverage and forward exchange rates against the U.S. dollar

COUNTRY	LOCAL CURRENCY	FX FORWARD CONTRACTS	NDF CONTRACTS
China	Renminbi		√
Hong Kong	Hong Kong Dollar	√	
Indonesia	Rupiah		√
Malaysia	Ringgit		√
Philippines	Peso	√	
Singapore	Singapore Dollar	√	
South Korea	Won		√
Taiwan	Taiwan Dollar		√

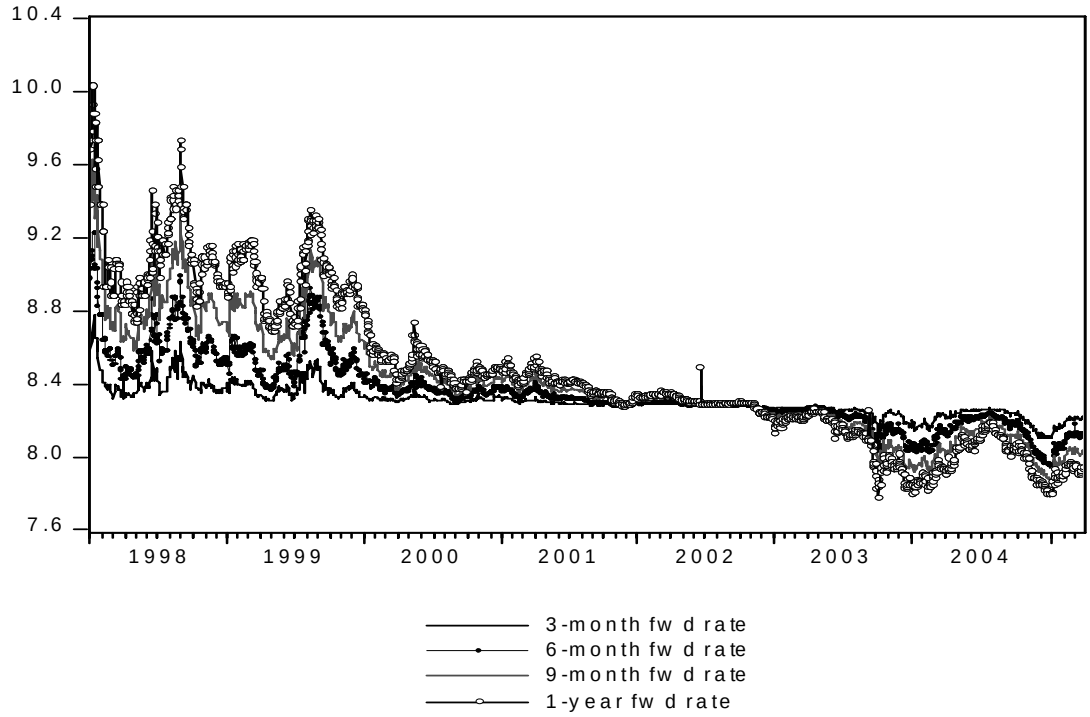
Notes: The table shows the data availability for all countries in the sample. √ indicates data availability. All daily data are currency option quotes in Hong Kong provided by Citibank, the observations being recorded at the close of business (average of closing bid and offered rates).

As is the case with standard forward contracts, NDF exchange rates for conversion are fixed for a future date. Unlike forward contracts, however, there is no delivery of underlying foreign currency. Instead, the net U.S. dollar is settled with a compensating payment based on the difference between NDF contract rate and the exchange rate prevailing at maturity. Effectively, the NDF user is financially protected from exchange rate fluctuations by the compensating U.S. dollar payment paid or received, based on the NDF fixed rate, even though foreign currency is exchanged. In contrast to standard deliverable forwards, NDFs are traded offshore, i.e. outside the jurisdiction of the authorities of the corresponding currency.

Active and growing NDF markets exist for several Asian currencies. These offshore markets offer international investors an otherwise unavailable hedging tool against local currency exposure. An analysis of Asian NDF markets as a whole, together with a discussion of the basic institutional features of the renminbi NDF market, is provided by Fung et al. (2004) and Ma et al. (2004). Ma et al. (2004) discuss the deepening of the Asian NDF markets in recent years. Turnover has been highest on the Korean won, Taiwan dollar, and Chinese renminbi markets, though the remaining, shallower markets have also deepened in

recent years. Renminbi NDFs with the U.S. dollar, for example, have a daily trading volume ranging from approximately US$150 million to US$600 million, with increasing participation from international hedge funds.[6] This suggests that the level of market liquidity is sufficient for fluctuations in NDF prices to serve as a meaningful indicator of the market's belief about the future path of the renminbi against the U.S dollar. The one-, three-, six-, and twelve-month renminbi NDF exchange rates are plotted in Figure 1.

Figure 1 Movements of renminbi NDF against U.S. Dollar
Period: 1/1/1998 to 23/3/2005



Given that it is centered on the pre-reform peg of 8.28 renminbi per dollar, the chart indicates that prior to mid-2002 the NDF market expected a depreciation of the renminbi (NDF rates were constantly higher than the target rate), which never materialized. Since late 2002 or early 2003, the NDF market has consistently expected – and missed - an appreciation of

[6]The PBOC has recently announced that it will allow more domestic banks to participate in its forward exchange market. The goal is to develop on-shore markets in which firms can hedge their foreign exchange exposuress. Eventually, it is envisaged that such markets will supplant the NDF market. Once a currency is fully convertible, NDF markets tend to disappear. In this way, NDF markets can be seen as an intermediate step in the process of market integration from limited to full capital convertibility.

the Chinese currency relative to the U.S. dollar.[7] Moreover, at the end of July 21, 2005, the day of the PBOC announcement, three-month NDF rates dropped below 8 renminbi per dollar, anticipating further appreciation of the renminbi-dollar exchange rate. While it would be misleading to regard NDF rates as predictions of a currency's future path, they do provide valuable information about the sentiment of market participants.[8] An NDF is a zero-sum game in which setting the NDF contract's exchange rate equal to the expected future spot rate minimizes one participant's loss (and the other's gain). Hence, the parties will use all available information in forming their expectations.

In our study we analyse the continuously compounded daily returns on one-year NDFs of the forementioned eight Asian countries. All the series appear to have fat-tailed distributions relative to the normal distribution, with significant linear and non-linear serial correlations. With respect to non-linear serial correlations, it is often observed that large changes tend to be followed by large changes, and small changes tend to follow small changes. This regularity, known as volatility clustering, is even more evident in high-frequency financial data and our dataset is no exception. The daily returns oon one-year NDF contracts for our set of countries are plotted in Figure 2: the existence of volatility clustering is clearly evident.

To shed further light on the extent of linkages among Asian forward exchange rate markets, Figure 3 displays a set of scatter diagrams, each plotting the Chinese return series on the vertical axis and the return series of one of the remaining Asian countries on the horizontal axis together with a regression fit line. As one would expect, the diagrams highlight the fact that the observations for all country pairs are concentrated near a line of positive slope and falling in the symmetric quadrants (+,+) and (-,-), indicating a tendency to have unusually large values of the two series simultaneously. In particular, this evidence implies that the information revealed in one market is factored into the behavior of other market.[9]

[7] Even when a substantial revaluation of the renminbi is not the most likely prediction for the foreseeable future, the market price will nevertheless include compensation for the small probability of a substantial renminbi appreciation. This risk premium for the small probability of a large adjustment, i.e. the so-called peso problem, causes the NDF rate to deviate on one side of the pegged exchange rate since the beginning of 2003.

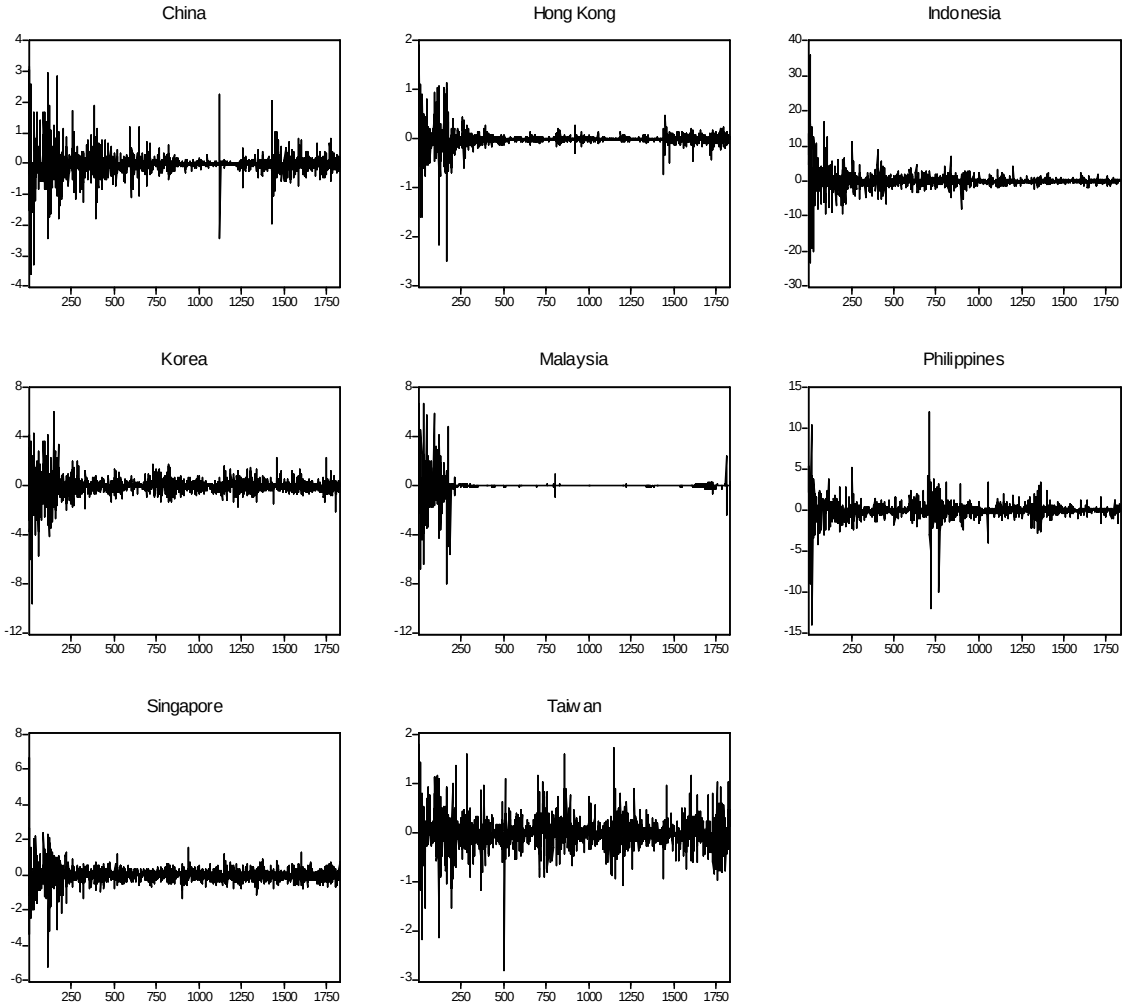
[8] The forward rate primarily reflects exchange rate risk, and incorporates both expectations about the expected future spot rate and a currency risk premium.

[9] This may be called the Chinese dominance hypothesis, by which financial markets perceive different exchange rates to be the same, and therefore a new piece of information arriving to the market causes them to move in the same direction.

The key insight to emerge from this analysis is that clear links can be observed between daily returns on one-year NDF contracts between China and its Asian counterparts. This link manifests itself most visibly in the cases of Korea, Taiwan, and Philippines, as it is these countries that appear to exhibit the strongest interdependence with China.[10] Given this preliminary data analysis, it is now pertinent to undertake an assessment of volatility spillovers across Asian countries.[11] The methodology of this step is that of a multivariate GARCH model.

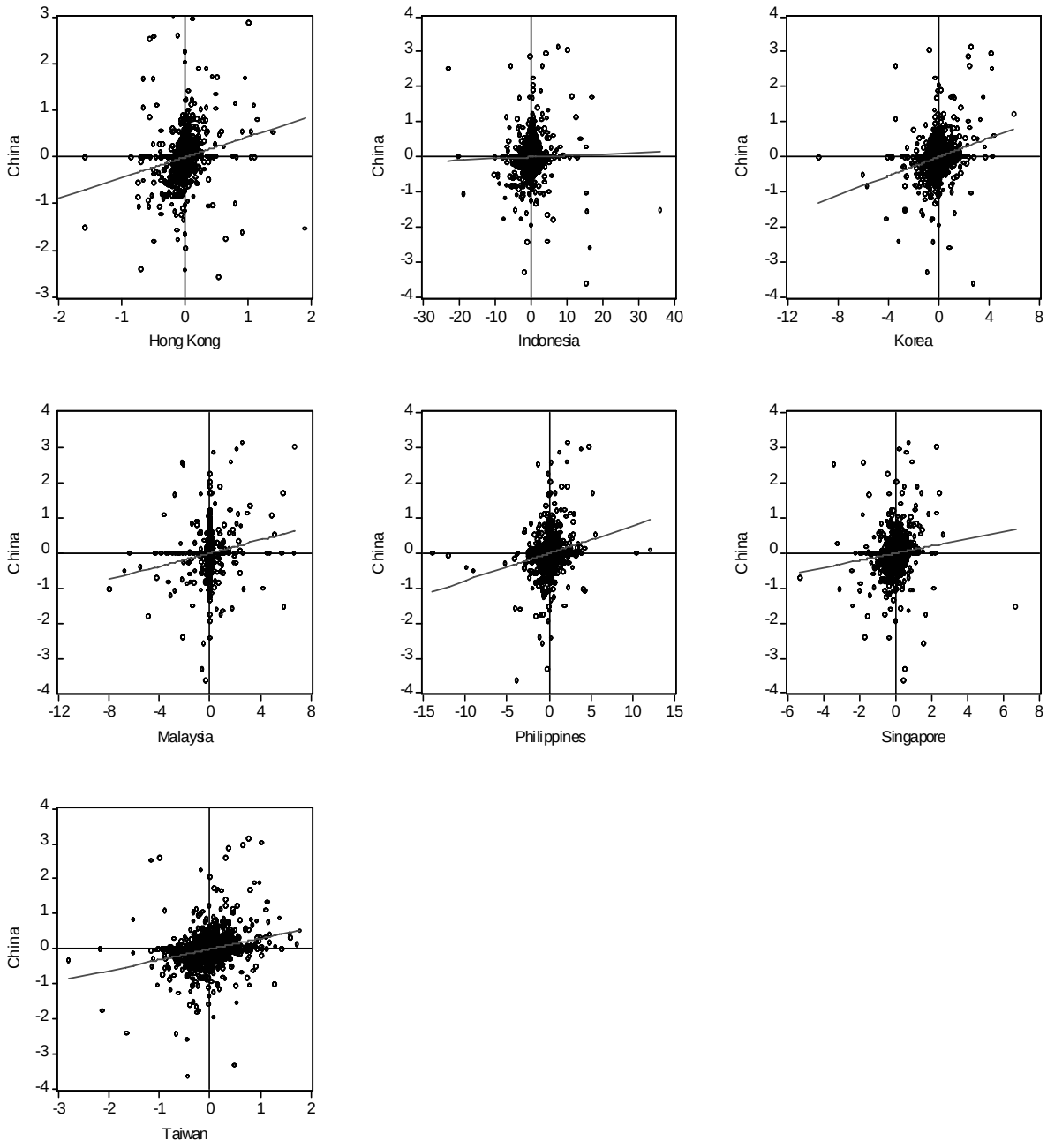
Figure 2 Daily returns on 1-year NDFs by country

Period: 1/1/1998 to 23/3/2005



[10] In the case of Malaysia, the scatter plot turns out to be less representative due to a scaling problem.
[11] The linkages between markets are an important element from the point of view of investors, as these estimates provide the necessary inputs for models used to construct efficient hedging and diversification portfolio strategies.

Figure 3 Daily returns on 1-year forward exchange rates across countries



3 Multivariate GARCH framework

A topic at the forefront of the research agenda in financial econometrics is the construction and analysis of models capable of summarising the volatility properties of two or more asset returns. A striking empirical regularity that emerges from numerous empirical studies using high-frequency financial data is the finding of GARCH behavior.[12] We therefore address the topic of cross-country volatility spillovers in a multivariate GARCH model framework.[13] In the multivariate GARCH literature one of the most prominent problems is the "curse of dimensionality", due to the large number of parameters. To make computation more tractable, Bollerslev (1990) and Engle (2002) have suggested the Constant Conditional Correlation (CCC) and its extension, the Dynamic Conditional Correlation (DCC) model which probably is the most popular multivariate GARCH parameterization. Both frameworks combine flexibility and a parsimonious specification with appropriate restrictions ensuring positive definite variance-covariance matrices.

Introducing some notation, let r_t denote an N dimensional time series of returns of length T. Returns are calculated as continuously compounded returns using log differences of prices. Suppose for simplicity that the mean of r_t is zero. The objective then is to find a suitable model for the conditional covariance matrix H_t of r_t defined by $H_t = \mathrm{Cov}(\varepsilon_t|\Omega_{t-1})$. The CCC model imposes the following structure:

(1) $$H_t = \begin{bmatrix} \sigma_{1,t}^2 & \sigma_{12,t} & \cdots & \sigma_{1n,t} \\ \sigma_{12,t} & \sigma_{2,t}^2 & \cdots & \sigma_{2n,t} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{1n,t} & \sigma_{2n,t} & \cdots & \sigma_{n,t}^2 \end{bmatrix}$$

(2) $$\sigma_{i,t}^2 = \delta_i + \sum_{j=1}^{p} \beta_{i,j}\, \sigma_{i,t-j}^2 + \sum_{j=1}^{q} \alpha_{i,j}\, \varepsilon_{i,t-j}^2 \qquad i = 1, ..., n$$

(3) $$\sigma_{ij,t} = \rho_{ij}\, \sigma_{i,t}\, \sigma_{j,t}$$

$$i,j = 1, ..., n,\ i \neq j$$

[12] A large number of previous papers have documented the persistence of volatility in nominal exchange rates; see, for example, Baillie and Bollerslev (1987), Bollerslev (1987, 1990), Hsieh (1989) and McCurdy and Morgan (1988).

[13] It would be impossible, and it is not our intention here, to provide an overview of the multitude of GARCH models recently developed. See Bauwens et al. (2003), Brooks (2003), Lütkepohl (2005), pp. 557-584 and Tsay (2005), pp. 443-489 for comprehensive surveys of the multivariate GARCH literature.

The main feature of this formulation is the assumption of constant correlation among variables. In most practical applications, relatively simple first-order models have been found to provide good representations of the conditional variance process. For the bivariate case (N = 2) and first-order specification p=q=1, the total number of parameters is $(p+q+1)n+n(n+1)/2=7$. Positive definiteness is guaranteed, since we can rewrite as follows:

$$H_t = D_t R D_t = \begin{bmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \sigma_{2,t} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_{n,t} \end{bmatrix} \begin{bmatrix} 1 & \rho_{12} & \cdots & \rho_{1n} \\ \rho_{21} & 1 & \cdots & \rho_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{n1} & 0 & \cdots & 1 \end{bmatrix} \begin{bmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \sigma_{2,t} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_{n,t} \end{bmatrix}. \tag{4}$$

Although this simple transformation involving diagonal matrices is elegant, the assumption of constant conditional correlations may be too restrictive. Engle (2002) has therefore generalised the CCC model to the DCC model, which adds a limited GARCH-type dynamic structure to the correlations. This augmented model is

$$H_t = D_t R_t D_t \tag{5}$$

$$R_t = diag\left(Q_t\right)^{-1/2} Q_t \, diag\left(Q_t\right)^{-1/2} \tag{6}$$

$$Q_t = S\left(1-\alpha-\beta\right) + \alpha\varepsilon_{t-1}\varepsilon'_{t-1} + \beta Q_{t-1} \tag{7}$$

where α and β are parameters and ε_t are the standardised, but correlated, residuals. That is, the conditional variances of the components of ε_t are equal to 1, but the conditional correlations are given by R_t. The notation diag(Q_t) represents a diagonal matrix with the same diagonal elements as Q_t. S is the sample correlation matrix of ε_t. If α and β are zero, one obtains the above CCC model. If they are different from zero, one gets an ARMA-type structure for all correlations. Note, however, that all correlations follow the same dynamics, since the ARMA parameters are the same for all correlations.[14] This DCC(1,1) model , in the bivariate case, contains eight parameters.

Estimation of the dynamic correlation models can be carried out using Quasi-Maximum-Likelihood (QML), following the suggestion of Engle (2002) and Bollerslev

[14] Engle and Sheppard (2001) demonstrated that this restriction of an identical ARMA-type structure leads to some bias in the case of many financial assets because employing this a priori restriction violates the data. This assumption may be more easily satisfied by a small number of exchange rates, but it becomes increas-

and Wooldridge (1992). The CCC and DCC frameworks allow one to "break" the log-likelihood into two parts, one part for the parameters determining univariate volatilities and the other for the parameters determining the correlations (two-step estimation technique). The associated asymptotic standard errors calculated from the QML method are consistent and robust to the density function underlying the residuals.

A crucial assumption of the standard CCC and DCC models is that standardized residuals are normally distributed. The normality assumption allows QML to provide feasible and consistent DCC coefficients of conditional correlations. Financial time series, however, rarely support this assumption. QML estimation under misspecification of the (non-Gaussian) conditional distribution, however, may yield inconsistent parameter estimates [Newey and Steigerwald (1997)]. Furthermore, if excess kurtosis is ignored then the probability of extreme events will almost surely be underestimated with possible serious repercussions for risk management activities. The standard way to overcome drawbacks of the normality assumption involves the use of tick (non-normal) distributions to achieve efficiency. A commonly used assumption is the multivariate *t*-distribution for the errors.[15]

The nonlinearity in the arguments of the likelihood function necessitates a numerical maximisation technique. As in all numerical search procedures, it is crucial to obtain good starting values. Since the simplex algorithm is more robust to initial parameter starting values than the Broyden, Fletcher, Goldfarb, Shanno (BFGS) algorithm, we use the simplex algorithm to provide initial parameter estimates for the BFGS algorithm, which in turn provides the final parameter estimates along with the corresponding variance-covariance matrix. We thereby ensure that the algorithm does not get stuck at a local – as opposed to global – optimum.

In the GARCH family of models, exogenous variables can be included in the mean equation. In our modeling exercise we include the bid-ask spread as an explanatory variable for future exchange rate changes only when it turns out to be significant, as bid-ask spreads are a proxy for market liquidity. Because shocks to the mean equation are the main actors in the multivariate framework, it is important that the mean equation not be misspecified. We have therefore estimated various models and tested the individual and joint significance of the coefficients. The final specification of the mean equation and the lag structure was chosen using likelihood ratio tests and in-

ingly more unlikely with many returns. Therefore, we have estimated several bivariate (pairwise) models to allow for country-specific dynamics.

[15] Bauwens et al. (2003) review various multivariate asymmetric distributions. However, the majority of these distributions are either too complicated to be estimated for GARCH purposes or present undesirable properties such as infinite variances.

formation criteria. Furthermore, Ljung-Box portmanteau tests were performed on standardized residuals and squared residuals. The final bivariate model specifications are given in Table 2.[16]

Table 2 Bivariate GARCH specifications (1-Year Returns)

PAIR OF COUNTRIES	ORDER OF THE GARCH		CONDITIONAL MEAN EQUATION
	p	*q*	
China, Hong Kong	1	1	Bid-Ask spread
China, Korea	1	1	Bid-Ask spread
China, Philippines	1	1	Bid-Ask spread
China, Taiwan	1	1	Bid-Ask spread
China, Indonesia	1	1	Constant
China, Malaysia	1	1	Bid-Ask spread
China, Singapore	1	1	Constant

Notes: *p* is the number of GARCH (lagged variance) terms; *q* is the number of ARCH (lagged residual squared) terms.

4 Empirical results

Estimation results for the specified models indicate that strong GARCH effects are evident in virtually all of the regressions, with the sum of estimated (statistically significant) coefficients very close to one. This finding is consistent with the literature on high frequency exchange rate dynamics.[17] The estimated daily conditional correlations from the bivariate CCC-GARCH and DCC-GARCH models are plotted in Figure 4.[18]

[16] In most cases, the diagnostic tests fail to detect any serious misspecification of models, thus suggesting that there is little unexplained dependence in the data. In particular, the Ljung-Box tests performed on the squared normalised residuals are reduced substantially compared to the values for the raw squared returns, which indicates that the GARCH(1,1) models do a very good job of tracking the strong temporal dependence in the variance. We have also computed the coefficients of skewness and kurtosis on the standardised residuals, which indicate that strong deviations from normality remain. Standard errors are corrected for non-normality of residuals.

[17] For the sake of brevity, the GARCH estimation results are not presented here, but are available from the authors upon request. Qualitatively similar results arise for maturities of three, six and nine months.

[18] Because of the model's popularity, Tse (2000) has outlined an LM test that evaluates the constant correlation model against the alternative of the DCC dynamic structure. This computationally convenient test examines the restrictions imposed on a model which encompasses the CCC model. We do not pursue the test in our paper because it is based on the normality assumption.

Figure 4 Constant (CCC) and Time-Varying (DCC) Conditional Correlation Coefficients
Period: 1/1 1998 to 25/3 2005

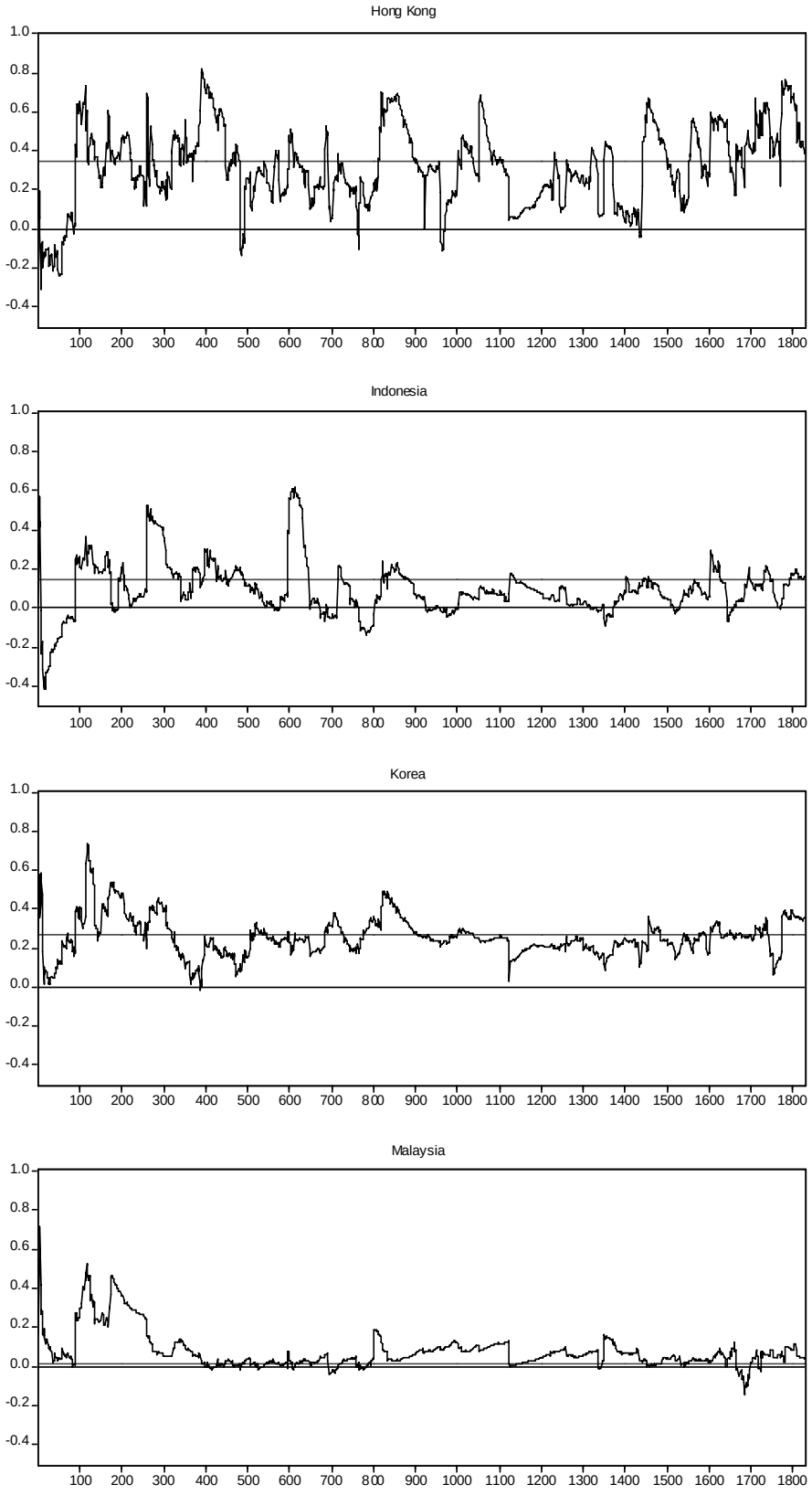
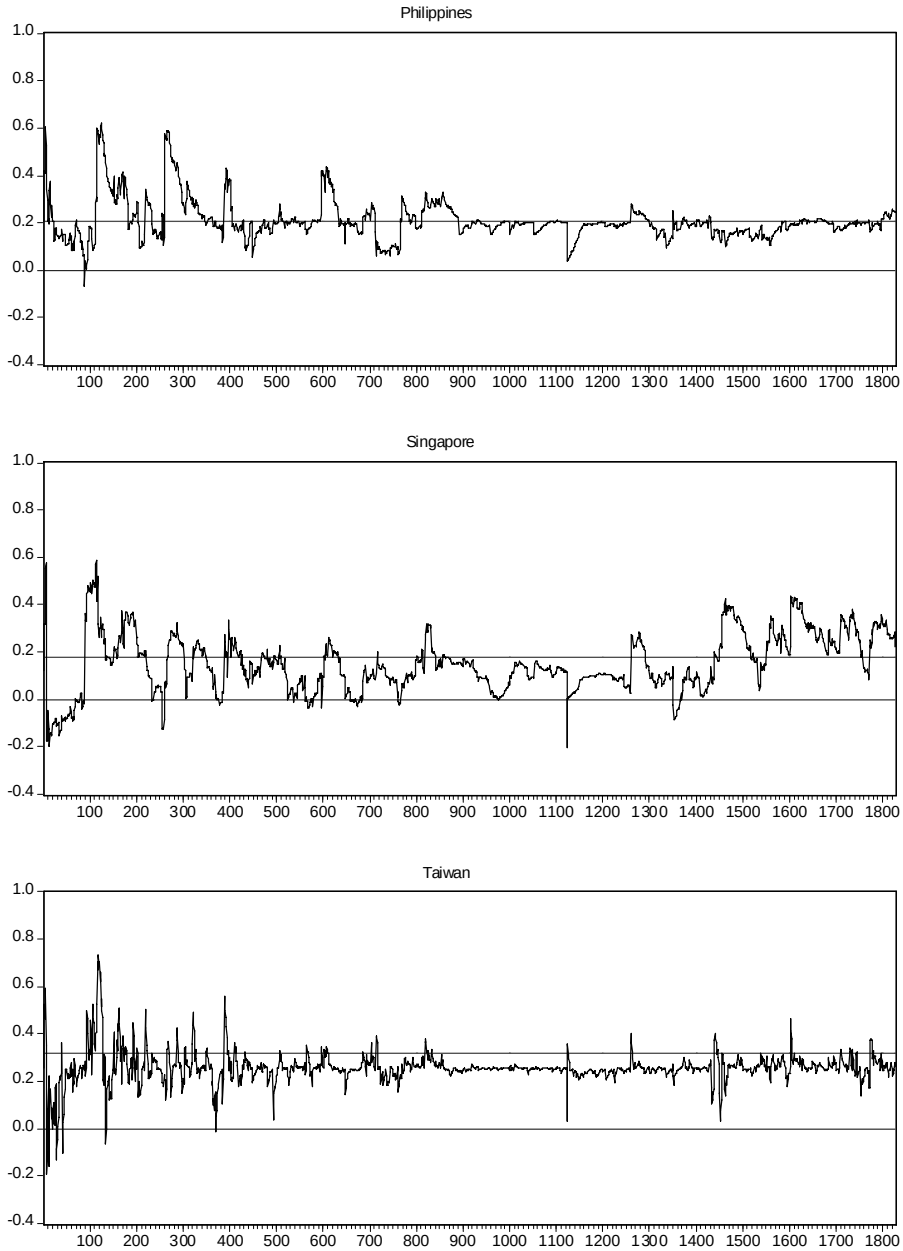


Figure 4 Continued



Note: Estimated bivariate conditional correlations between Asian on-shore and off-shore markets and China. The horizontal line (above the zero axis) is the correlation coefficient estimated within the CCC framework.

The estimates obtained within the CCC framework show that Hong Kong and Taiwan are the two Asian countries whose forward market returns have the strongest interdependence with China: their conditional correlation coefficients are 0.35 and 0.32, respectively. Ma-

laysia and Indonesia show the lowest conditional correlations: 0.03 and 0.14, respectively.[19]

Further insights can be gained by allowing the correlation matrix to vary over time. As is evident from Figure 4, in all cases NDF market return correlations exhibit significant variation, ranging between a maximum of 0.8 and a minimum of –0.4, and have a number of spikes. Apart from a handful of negative values, each of the graphs in Figure 4 displays conditional correlations of the returns with China, which are all positive. Moreover, the observed correlation coefficients display two distinct changes of pattern over the given time span: one at the beginning and one at the end of the sample period. In particular, the correlation coefficients of each ofl the countries display a sudden drop followed by a sharp increase between January and September 1998. The magnitude of such shifts appeared to be particularly relevant for Hong Kong, Indonesia and Singapore, but this evidence is common to all the countries studied. The Asian crisis, in fact, began in Thailand in the late spring of 1997 with substantial speculative attacks on the local currency, and continued with its floatation in summer 1997. Speculators also attacked the Indonesian and Korean currencies. Thus, there is strong evidence that during periods of stress and high volatility both the magnitude and persistence of comovements increased significantly.[20]

Evidence of the second pattern change in conditional correlations between all markets and China is found towards the end of the sample period, when the coefficients trend upwards. Despite this, the timing and magnitudes of the increases differ noticeably from country to country. In the case of Hong Kong and Singapore, the rise in correlation with China occurred at the end of 2003, coinciding with appreciation of the Hong Kong dollar in autumn 2003.[21] Hong Kong's correlation coefficient subsequently increased from near 0 to more than 0.4 in March 2005, while the corresponding figure for Singapore rose to approximately 0.3 over the same period. The bivariate conditional correlations between Malaysia, Philippines and Taiwan have remained relatively stable over the sample period. Ma-

[19] The size of the conditional correlations provides credence to the notion that Chinese financial markets remain partially de-linked due to the absense of full currency convertibility.
[20] The results confirm an observation often reported by market professionals, namely that "during major market events, correlations change dramatically". Testing the hypothesis that conditional correlations increase in volatile times is, however, a difficult exercise due to the potentially spurious relationship between volatility and co-movements [see Longin and Solnik (2001)].
[21] In late September 2003 the Hong Kong dollar appreciated unexpectedly from close to HKD 7.80 per U.S. dollar to HKD 7.70 per U.S. dollar in New York overnight trading. On October 16, Moody´s upgraded Hong Kong´s foreign currency rating to a level above that of Mainland China. This points to an increasing recognition that Hong Kong has successfully contained the outbreak of SARS (Severe Acute Respiratory Syndrome)

laysia has continued to manage its exchange rate in an active manner since September 2, 1998, when the Malaysian authorities quite openly fixed their bilateral U.S. dollar exchange rate, and have defended this parity through sterilized foreign exchange market interventions. This exchange rate policy is reflected in the drop in correlation with China after the Malaysian Central Bank's announcement, followed by stabilization of the coefficient at values close to 0 (Figure 3). In contrast to this, both the Philippine Peso and Taiwan Dollar were floated, on March 15, 1998 and April 3, 1989 respectively, and display relatively strong interdependence with China over the whole sample. In particular, the daily correlations fluctuate around 0.21 in the case of Philippines and around 0.30 in the case of Taiwan. It would appear that the correlation structure of those countries with respect to China has not changed significantly since adoption of a flexible exchange rate regime.

Thus far, our analysis must be accompanied by one important caveat: the discussion has focussed on estimation of time-varying co-movements across countries, while abstracting from the economic forces that may bring about these volatility spillovers. This raises a number of valid questions which must now be tackled: What are the factors that cause such co-movements? Are they regional in nature or can they be traced to specific developments in individual countries? These issues are discussed in the next section.

5 Economic fundamentals and cross-country comovements

The evidence of cross-country heterogeneity with respect to NDF market correlations with China discussed in Section 4 can seem bewildering at first glance: for some countries the average conditional correlations are large, while for others they are close to zero. What factors help to explain the degree of heterogeneity in the magnitudes of the co-movements? And through which channels does the transmission process take place? A related fundamental problem with the econometric approach is that the non-structural data-based approach in a sense hard wires policy parameters and therefore is not suitable for addressing

and a recovery is underway in the tourism and retail sectors. In order to stabilise the exchange rate the Hong Kong Monetary authority sold a total of 11 billion Hong Kong dollars.

questions of interest to policymakers.[22] Therefore, as a final step, we apply some eclectic tenets of economic analysis to explain these cross-country differences. First of all, we identify three possible sources of such differences: degree of trade openness, degree of financial openness, and exchange rate regime. We then choose a set of indicators to use as proxies for these possible explanations. In particular, we take bilateral and total exports as trade openness indicators, bilateral and total foreign direct investment (FDI) as financial openness indicators, and utilize both the *de jure* and the *de facto* exchange rate regime classifications. Finally, in Figure 5 we present a set of scatter diagrams, each plotting the conditional correlation coefficients for the analysed country on the vertical axis and the values of the given indicator on the horizontal axis together with a regression fit line.

The obvious difficulty researchers face in analysing the co-movement of asset prices is the identification problem. Since future exchange rates are determined simultaneously, it is hard to trace the origin of exchange rate developments for a single country. The observed relationship between certain country characteristics and magnitudes of conditional correlations could reflect causality from the former to the latter or vice versa. For example, countries enjoying better macroeconomic performance may systematically choose to adopt a certain exchange rate regime. In order to mitigate the "reverse causality", or "endogeneity" problem, we have used indicators dated 1998.[23]

The prime candidate expected to influence these cross-country co-movements is trade. Greater trade integration enhances financial market interdependence, as is apparent when a devaluation in one country temporarily increases its competitiveness, and thus also adversely affects its trading competitors.[24] This mechanism is likely to have become relatively more important as a result of the removal of trade barriers and increasing degree of integration in recent years. This is borne out by the fact that trade flows between China and other Asian countries soared between 2000 and 2005. All in all, the role of China within

[22] Despite their sound statistical background, multivariate GARCH models are "black box" methods from an economic point of view. The volatility co-movements should therefore not be interpreted as causal relationships.

[23] In the previous sections we adopted an empirical-based modeling approach. The economies in question, however, are characterised by a high degree of simultaneity and forward-looking behavior, and are subject to changing policy regimes and policy rules. In the context of a reduced-form model, it is therefore difficult to infer a cause and effect relationship.

[24] The role of trade as a catalyst of co-movements was originally highlighted in to the context of currency crises. See, for example, Glick and Rose (1999). Using a common factor model, Forbes and Chinn (1994) test the trade channel and other potential determinants of comovements also for non-crisis periods. They find that both trade and financial linkages have played important roles since the mid 1990s. Furthermore, their paper shows that regional spillovers can occur, emanating from the largest economy and spilling into smaller countries in the region.

Asian intra-regional trade is still difficult to define with precision. Commentators' views on this Chinese role can be regarded as falling into two distinct categories.[25] According to the first line of thought, China and other Asian economies share mutual benefits from the increased incomes of Chinese consumers, as well as from the potential for greater integration of product lines across the region, both of which are reflected in the expanding intra-regional trade in Asia. The contrasting view sees China and emerging Asia as competitors, specializing in the production of export goods that are relatively close substitutes wcich compete for market share in major export markets. Our findings appear to support the former of these viewpoints: from the two plots on the first row of Figure 5 it appears clear that trade openness can indeed be considered a plausible explanation for the degree of interdependence between Asian countries and Chinese NDF market returns, as higher export countries are also those with the higher correlation coefficients (Hong Kong, Korea, Taiwan).[26]

One would also expect financial integration impact the extent of linkage between Chinese and other Asian NDF markets. Over the last 20 years, East Asian economies have promoted financial integration by liberalizing their capital account and financial sector through the relaxation of financial regulations. Financial openness can be quantified using a variety of measures: in Figure 5 we employ both bilateral country-to-country FDI flow, a quantity-based measure of cross-border financial intensity, and total FDI as measures of capital account openness. From the two plots on the second row of Figure 5 it appears that countries with greater exposure to bilateral capital flows with China, such as Hong Kong, Taiwan and Korea, experience stronger interdependence among NDF markets compared to countries where bilateral FDI inflows are of relatively smaller magnitude. Viewed as a whole, our results suggest that the magnitude of co-movements between the renminbi and other Asian-currency NDF contracts is indeed related to the degree of real and financial integration.[27]

A further issue worth exploring when analysing the determinants of cross-country differences in correlation coefficients is the type of exchange rate regime operating in each country. Empirical analysis seeking to uncover the link between countries' exchange rate

[25] For a more detailed discussion see, e.g., Ahearne et al. (2003).
[26] The majority of FDI flowing into China originates from Hong Kong and Taiwan. Zhang (2005) has analysed and identified various determinants of this dominant Hong Kong and Taiwan direct investment.
[27] One striking finding to emerge from the second row of Figure 5 is that the degree of integration with the rest of the world in its entirety appears to play as important a role as bilateral integration with China in explaining the correlation coefficients.

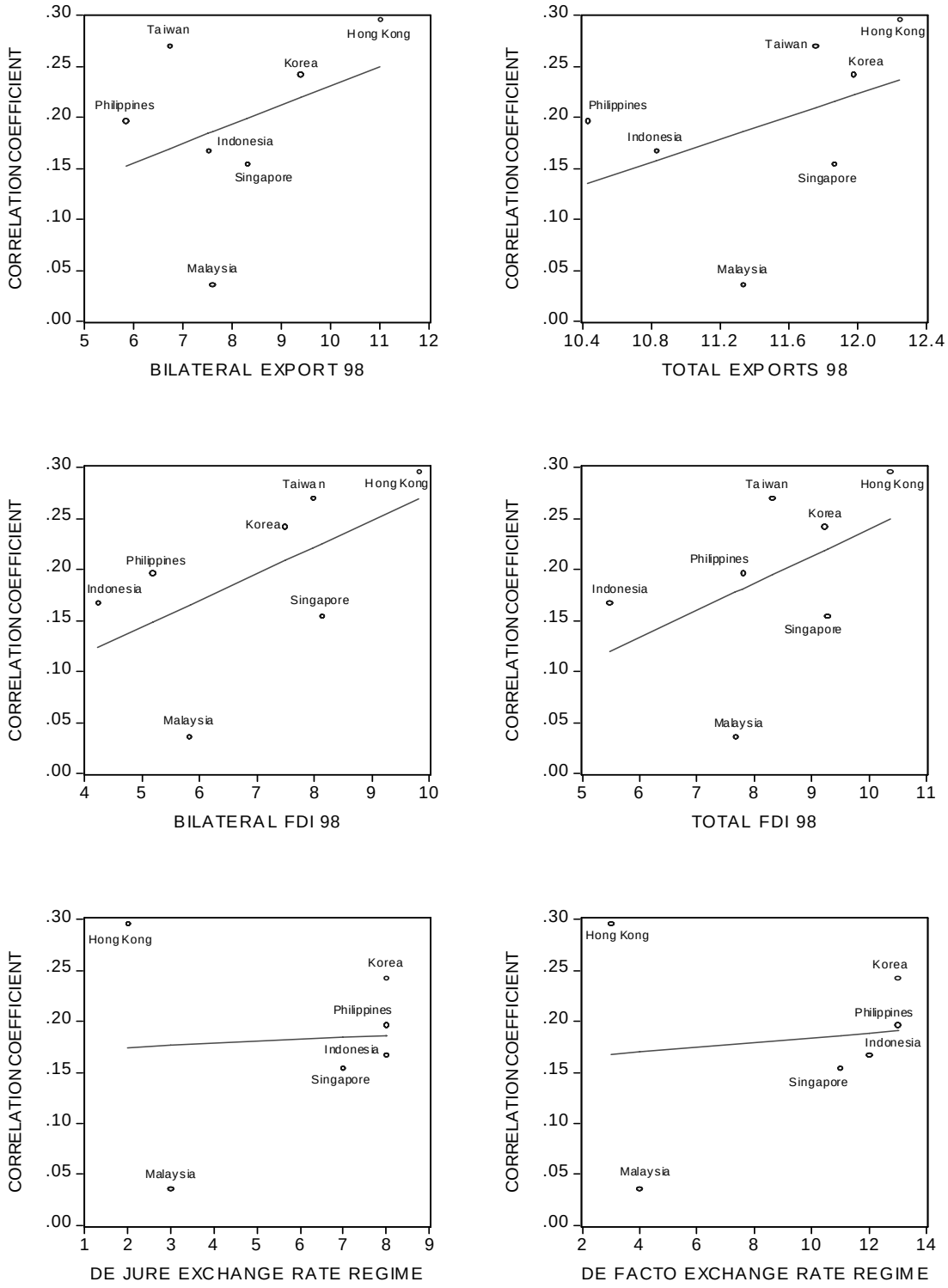
regimes and their macroeconomic performance depend critically on how the regimes are classified.[28] The official (*de jure*) IMF exchange regime classification categorizes member's exchange rate regimes based on their official reports to the IMF. The exchange rate regime declared by a country, however, often differs from its operational regime. In East Asia, both crisis-hit countries, including Korea, Indonesia, Thailand, and non-crisis countries such as Singapore and Taiwan, officially announced a particular exchange rate regime but in reality most of them possess substantially less exchange rate flexibility than they have reported. In recognition of this problem, the IMF has moved to a *de facto* classification since January 1999. This new classification combines available information on the exchange rate, monetary policy, and authorities' formal or informal policy intentions with data on actual exchange rate and reserve movements to reach a judgment on the actual exchange rate regime in operation.

In order to allow for a more nuanced assessment, we use recent advances in the classification of exchange rate regimes to gain further insights into co-movements across regimes and consider both the de jure and de facto classifications within our set of indicators.[29] From the two plots in the third row of Figure 5 no clear cross-country connection between exchange rate regime and degree of interdependence appears to emerge. Hong Kong and Malaysia, the only two countries with pegged currencies, exhibit the highest and lowest correlation coefficients with China, respectively, while the correlations of the other countries, possessing flexible regimes, range from the 0.15 (Singapore) to the 0.24 (Korea). These results do not appear to provide strong grounds for regarding the exchange rate regime as a candidate for explaining the observed cross-country differentials in correlation coefficients.

[28] It is not our purpose to evaluate the success of specific exchange rate regimes in meeting their stated objectives, nor do we claim to judge the impact of alternative regimes on macroeconomic performance and social welfare dimensions beyond these regimes' influence on volatility transmission.

[29] Baig (2001) and Bubula and Ötker-Robe (2002) compiled de facto exchange rate regimes of Asian countries after the economic and financial crisis in 1997/98. Exchange rate regime classifications for Taiwan are not available. Compared to *de facto* classification, the *de jure* classification overstates the number of true floats and pegs, suggesting that fewer countries are at the polar extremes than that implied by their official reports.

Figure 5 Economic fundamentals and cross-country correlation coefficients with China



Note: The conditional correlation coefficients are obtained from CCC-GARCH models. Bilateral export refers to exports into China from the reporting country, in millions of U.S. dollars. Bilateral FDI refers to the FDI flow into China from the reporting country, in millions of U.S. dollars. Sources: IMF, DOT; National Bureau of Statistics of China.

Bringing together the various strands of this discussion, the underlying economic explanations for different co-movements across countries are partially resolved.[30] While both trade and financial openness appear to be plausible determinants of the magnitude of co-movements across NDF markets in Asian countries, with the more open countries also exhibiting stronger correlation with China, the exchange rate regime does not appear to affect the correlation coefficients.

6 Conclusions and further comments

At the heart of this paper lies one fundamental question: what linkages exist between Mainland China and other Asian economies? A thorough understanding of the dynamic properties of cross-market volatility transmission is vital for assessing the level of integration between markets, both for investment purposes and for increasing the capacity to produce reasonable forecasts. To this end, the analysis undertaken in this paper embarks on a hitherto untraveled route. In a context of growing interest in the Chinese renminbi's future path, as well as in co-movements across Asian currencies, we focus on links between renminbi NDF exchange rates and those of other Asian countries and proceed to investigate the nature of the volatility spillovers across markets. In order to model the volatility transmission mechanism we estimate several multivariate GARCH models which allow for a time-varying correlation structure.

The empirical results of this study are threefold. Firstly, the estimates arising from our models highlight the presence of strong GARCH effects in virtually all of the regressions, with the sum of (statistically significant) estimated coefficients very close to one. This evidence implies that there are indeed volatility spillover effects between China and the other seven Asian NDF markets. Secondly, from the analysis of time-varying conditional correlations it emerges that the coefficients are all positive and display changes in their patterns throughout the time span under consideration. What is more, these coefficients tend to increase in magnitude towards the end of the sample period. Therefore, it would appear that renminbi NDFs have indeed been a driver of various Asian currency markets. It is also evident that such co-movements exhibit a substantial degree of hetero-

[30] The small number of observations plotted in the scatter diagrams raises concerns about the robustness of the conclusions drawn. Due to these data limitations our results on potential determinants are indicative only.

geneity across countries. As a final step, we identify three possible sources of such heterogeneity: degree of trade openness, degree of financial openness, and exchange rate regime. We analyze their roles in explaining the different correlation levels across countries. We find that it is the degree of real and financial integration that are the key conduits for volatility transmission – the exchange rate regime does not appear to play a role in this process.

One key policy implication, in particular, emerges from this paper: there exists clear evidence of renminbi externalities impacting on other Asian countries. Even if some countries have been clearly less affected by renminbi shocks than others, none can claim to have been completely immune from Chinese exchange rate shocks. From a broader perspective, closer integration with Mainland China would represent both an opportunity for further economic stimulus and a potential source of macroeconomic risk for the emerging economies of Asia. One would expect greater trade integration in Asia to facilitate the transmission of shocks between economies in the region, a reason being that China has become a source of demand for final goods produced in Asian countries. More generally, shocks to Mainland China's economy are likely to resonate in the other Asian economies through confidence effects. By now, China's economy has grown to such an extent and has become so integrated with the rest of Asia that investor sentiment toward emerging Asia depends to an increasing degree on the economic climate expected to prevail in China.

While we emphasize that this paper should rightly be regarded as an initial exploration into the role played by cross-market volatility transmission in the linkages that exist between Mainland China and other Asian economies, it is clear that the significance of this issue in understanding the economic interactions of the region cannot be underestimated. It is hoped that, once more comprehensive datasets become available, this paper will provide the platform from which a more meticulous study can be launched.

Additional evidence from other countries is required if one wishes to gain more detailed insights.

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