Asymmetric Co-movement of Asian Currencies with the Chinese Yuan Since Its Inclusion in the SDR[1]

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Abstract

We examine dependencies during 2010-2018 between the Chinese Yuan and eight Asian currencies using normal and symmetrized Joe–Clayton (SJC) copulas. After the Yuan had been included in the SDR, the co-movement of the Chinese and Asian currencies increased. Our results suggest that financial and trade links contributed to this increase in dynamic dependencies. We also find that this co-movement is much stronger when the Chinese Yuan depreciates against the US Dollar than when it appreciates. This pattern is identified both before and after the inclusion of the Chinese Yuan in the SDR, but it is stronger after its inclusion.

JEL-codes: F15; F31; F36

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1 Introduction

The 2008 global financial crisis rekindled the discussion about the future of the international monetary system. Notably the internationalization of the Chinese Yuan attracted attention. Given China's increased role in the global economy, some authors argue that the Chinese Yuan has great potential for becoming an international currency (Ito, 2018). In October 2016, the IMF included the Chinese currency in the Special Drawing Rights (SDR), with a weight of 10.92%.

Some studies examine the role of the Chinese Yuan in regional currency movements (e.g. Shu et al., 2015; Kawai and Pontines, 2016; Ito, 2017). However, the findings of these studies differ. For instance, Shu et al. (2015) report that the currencies of several Asian countries, especially in East Asia, track the Chinese Yuan more closely than the U.S. dollar (USD). Likewise, Ito (2017) provides evidence that under an appreciation (depreciation) of the Chinese Yuan against the USD, Asian currencies tend to appreciate (depreciate) against the USD as well. Ito therefore concludes that the currencies of emerging Asian economics co-move more closely with the Chinese Yuan than with the USD. However, Kawai and Pontines (2016) find that the Chinese Yuan has not surpassed the USD as a predominant anchor of Asian currencies and that no Chinese Yuan block exists in East Asia.

Our study investigates the co-movement of eight Asian currencies and the Chinese Yuan. The first contribution of our paper is that we investigate whether the co-movement of the Chinese Yuan with other Asian currencies is different before and after the inclusion of the Chinese Yuan in the SDR. Liu et al. (2019) propose that it is interesting to investigate the internationalization of the Chinese Yuan after its accession into the SDR basket. Ito (2017: 253) argues that for the Chinese authorities "Getting into a status of SDR composition currency became both a means and an end. The Chinese Yuan becoming a SDR composition currency is an important means for the Chinese Yuan to be recognized as an international reserve currency. However, the Chinese Yuan internationalization was an agreeable objective to rally for liberalizing financial regulation and lifting capital controls. Many policy measures were taken to help Chinese Yuan become an international currency: Adding flexibility to the exchange rate, cautiously opening the capital markets to foreign institutions, and promoting the use of Chinese Yuan for trade invoicing and settlement." This suggests that the inclusion of the Chinese Yuan in the SDR may have affected its co-movement with other Asian currencies.

Most previous studies examining the co-movement of Asian currencies use the approach put forward by Frankel and Wei (1994). In the Frankel-Wei approach, an exchange rate against a common numeraire (like the US Dollar) is regressed on other exchange rates against this numeraire. Kawai and Pontines (2016) point out that the difficulty with the Frankel-Wei approach is that the correlation between the USD and the Chinese Yuan is high, especially when the Chinese Yuan was pegged to the USD. Thus, given that the Chinese Yuan strongly correlates with the USD in some periods, there is a multicollinearity problem in Frankel-Wei regressions.

Previous studies tried to circumvent the problem of multicollinearity in two ways: by dropping periods during which the Chinese Yuan is strongly pegged to the USD or by eliminating the USD components in the Chinese Yuan movements.

A good example of the first approach is Subramanian and Kessler (2013), who estimate Frankel-Wei regressions for the periods July 2005 to August 2008 and July 2010 to July 2013. Likewise, Ito (2017) divides the Chinese exchange rate regime into four sub-periods, excluding the fixed exchange rate regime periods, while McCauley and Shu (2018) classify their sample into three periods: transition, basket management and countercyclical management.

In the second approach, the USD component from the Chinese Yuan movements is purged and then these "independent" movements of the Chinese Yuan are incorporated into Frankel–Wei regressions. This approach has been applied, for instance, by Fratzscher and Mehl (2014) and Kawai and Pontines (2016).

An issue that has received limited attention is that the Frankel-Wei approach presumes that the interdependence between two currencies is the same when the currency under investigation appreciates and depreciates, thereby ignoring possible asymmetric patterns. Patton (2006), for instance, finds that exchange rates fluctuate less during a boom than during a recession. The second contribution of our paper is that we test whether the co-movement of the Chinese Yuan and other Asian currencies is symmetric, i.e. whether it is the same when the Chinese Yuan depreciates and when it appreciates against the USD.

The third contribution of our paper is that instead of using the Frankel-Wei approach, we apply copulas to estimate the (possibly non-linear) dependence of eight Asian currencies on the Chinese Yuan. This approach does not require non-collinearity. Our sample period covers July 1, 2010 to May 4, 2018 during which the Chinese Yuan did not have a fixed rate vis-à-vis the USD. We find that after the Chinese Yuan had been included in the SDR, the dependence of the estimated Asian currencies upon the Chinese Yuan strengthened. Our results also suggest that this increase in the dynamic dependencies did not only occur through financial links but also through trade links. Furthermore, we find that this co-movement is much weaker when the Chinese Yuan appreciates against the USD than when it depreciates. This pattern is identified before and after the inclusion of the Chinese Yuan in the SDR, but it is stronger after its inclusion. This prevailing asymmetric dependence could be the result of "fear of appreciation".

The remainder of the paper is as follows. Section 2 introduces the normal and the symmetrized Joe-Clayton copula. Section 3 shows our data and summary statistics, while Section 4 gives our results. Section 5 discusses the currency co-movement mechanisms and Section 6 concludes.

2 Methodology

In this section, we first retrospect the theory of copulas, and then introduce the normal copula and symmetrized Joe-Clayton copula models. Using copulas, we can flexibly construct multivariate distributions (Lu et al., 2014). In addition, we are able to capture tail dependence during extreme periods.[2] Furthermore, the copula of basic random variables is invariant after the variables have been transformed non-linearly and strictly increasing (Lu et al., 2014; Reboredo, 2011). This property ensures that the copulas of exchange rates do not change when GARCH models are used to fitting the exchange rate returns (Lu et al., 2014). We obtain the copulas by the inversion method, which replaces the original joint distribution with the marginal quantile distribution. Thus, we can extract the influence that marginal distributions impose on the dependence.

2.1 Copula theory

H represents the joint distribution function of k random variables, X_1, $X_2 \ldots X_k$, with corresponding marginal distributions (cumulative density functions) F_1; $F_2 \ldots F_k$, respectively. In Sklar's (1959) Theorem, a copula function C is:

$$C\,(F_1\,(x_1), F_2\,(x_2), F_3\,(x_3)\,\ldots\,F_k\,(x_k)) = H\,(x_1, x_2 \ldots x_k). \tag{1}$$

A unique C exists with continuous F_1; $F_2 \ldots F_k$. Now, define $u_1=F(x_1)$, $u_2=F(x_2)\ \ldots\ u_k=F(x_k)$. Take the partial derivatives with regard to each random variable in Equation (1) and then we get:

$$f\,(x_1,x_2,\ldots,\ x_k)= \frac{\partial^k C(F_1\,(x_1),F_2(x_2),\ldots,F_k(x_k))}{\partial x_1 \partial x_2,\ldots,\partial x_k}, \tag{2}$$

$$=c\,(u_1,\ u_2,\ldots,u_k)\prod_{i=1}^{k} f_i(x_i),$$

in which

$$c\,(u_1,u_2,\ldots,u_k) = \frac{\partial^k C\,(u_1,u_2,\ldots,u_k)}{\partial u_1 \partial u_2,\ldots,\partial u_k},$$

and

$$f_i\,(x_i)=\frac{\partial F_i(x_i)}{\partial x_i}.$$

According to Equation (2), the multivariable joint density can be decomposed into corresponding univariate densities, $f_1(x_1)$, $f_2(x_2)$, $f_3(x_3)\ \ldots\ f_k(x_k)$ and a copula density, $c\,(u_1, u_2 \ldots u_k)$. The copula density contains the dependence structure of these variables. Using Equation (2), we separate the univariate dynamic structure from the correlation of these random variables, and we can obtain the best descriptions of this correlation by fitting the univariate distributions with more

[2] Exchange rate returns commonly exhibit tail dependence (Patton, 2006). This also holds for Asian currencies (Lien et al., 2013).

flexibility and associating these distributions with copula functions. We thereby are able to introduce flexible multivariate distributions.

We continue with extending Sklar's Theorem (1959) to conditional distributions. Take the bivariate distribution as an example:

$$F_{XY|W}(x, y|w)=C\,(F_{X|W}(x|w), (F_{Y|W}(y|w)|w),$$

in which W is a conditioning variable, $F_{X|W}(x|w)$ and $F_{Y|W}(y|w)$ are the conditional distributions of $X|W$=w and $Y|W=w$ separately, and $C(F_{X|W}(x|w), (F_{Y|W}(y|w)\ |w)$ is a group of conditional copulas which can be measured in w. Assuming that we can differentiate all conditional density functions, we have the conditional joint densities:

$$f_{XY|W}(x,y|w)=f_{X|W}(x|w)\cdot f_{Y|W}(y|w)\ |w)\cdot c(u,v|w),$$

in which $c(u,v|w) = \partial^2 C(u,v|w)/\partial u\partial v$ are conditional copula densities, $f_{X|W}(x|w)$ and $f_{Y|W}(y|w)\ |w)$ represent the bivariate conditional density functions of the variables X and Y.

2.2 The Copula function

We examine two copulas, the normal (or Gaussian) copula that investigates the linear dependence between variables and the "symmetrized Joe–Clayton" copula that allows both symmetric and asymmetric dependence with and without time variation.

H is taken as a multivariable normal distribution that has zero-mean-value, unit variances, correlation matrix $\sum$, and standardized normal marginal F_i. Thus, we obtain the normal copula from Equation (2) and the corresponding copula density as follows:

$$c(u_1,u_2,\dots,u_{k;\sum})=\frac{1}{|\sum|^{1/2}}exp\Big(-\frac{1}{2}(\emptyset^{-1}(u'))(\textstyle\sum^{-1}-I_k)(\emptyset^{-1}(u))\Big),$$

where $\emptyset^{-1}(u)=(\emptyset^{-1}(u_1),\dots,\emptyset^{-1}(u_k))$ with $\emptyset^{-1}(u_i)$ being the inverse of the standard normal *CDF* (cumulative distribution function) and I_k being a unit matrix with k dimensions. When k=2, we have the bivariate normal copula function:

$$c\,(u_1,u_2)=\frac{1}{\sqrt{1-\rho^2}}exp\Big(\frac{2\rho z_1 z^2-z_1^2-z_2^2}{2(1-\rho^2)}+\frac{z_1^2+z_2^2}{2}\Big), \quad (3)$$

in which $z_1=\emptyset^{-1}(u_1)$ and $z_2=\emptyset^{-1}(u_2)$ and ρ is a parameter from the normal copula, which examines the linear correlation of the paired stochastic variables. $c\ (u_1, u_2)$ is the dependence function of the paired stochastic variables, x_1 and x_2. Now we can use $c\ (u_1, u_2)$ to construct a bivariate density.

Equation (3) assumes linear dependence. However, in reality, it is unlikely that ρ is constant. Instead, ρ may change when a structural event occurs. To examine the effect of the inclusion of the Chinese Yuan in the SDR on October 1, 2016, we assume a shift in the linear dependence of the estimated Asian currencies upon the Chinese Yuan. We separate our sample into a pre-SDR period and a post-SDR period, and model ρ_1 and ρ_2 accordingly, where, ρ_1

measures the dependence between two currencies in the pre-SDR period, while ρ_2 measures their dependence in the post-SDR period.

The second copula function we use is the "symmetrized Joe–Clayton" copula evolving from the "BB7" copula; see Patton (2006) for details.[3] Modifying Clayton's copula by Laplace transformation, we get the Joe–Clayton copula function:

$$C_{JC}(u, v|\tau^U, \tau^L) = 1-(1-\{[1-(1-u)^k]^{-\gamma} + [1-(1-v)^k]^{-\gamma} - 1\}^{-1/\gamma})^{1/k},$$

in which $k = 1/\log_2(2-\tau^U)$

$\gamma = -1/\log_2(\tau^L)$,

and $\tau^U \in (0,1)$, $\tau^L \in (0,1)$

where τ^U and τ^L are measures of tail dependence. We define these measures as follows: If the limit

$$\lim_{\varepsilon\to 0} Pr[U \le \varepsilon | V \le \varepsilon] = \lim_{\varepsilon\to 0} Pr[V \le \varepsilon | U \le \varepsilon] = \lim_{\varepsilon\to 0} C(\varepsilon, \varepsilon)/\varepsilon = \tau^L$$

exists, the lower tail dependence exists in copula C if $\tau^L \in (0,1]$. A larger lower tail means that it is more likely to observe a smaller value of V under the assumption that there is a smaller value of U. Similarly, if the limit

$$\lim_{\delta\to 1} Pr[U > \delta | V > \delta] = \lim_{\delta\to 1} Pr[V > \delta | U > \delta]$$
$$= \lim_{\delta\to 1}(1 - 2\delta + C(\delta, \delta))/(1-\delta) = \tau^U$$

exists, the upper tail dependence exists in copula C if $\tau^U \in (0,1]$. A larger upper tail means that it is more likely to observe a larger value of V under the assumption that there is a larger value of U. However, if $\tau^L = 0$ and/or $\tau^U = 0$, no lower and/or upper tail dependence exists. Notably, U and V are derived from the probability integral transforms (PITs) of the marginal distributions.

The normal copula cannot capture tail dependence ($\tau^U = \tau^L = 0$), while the tail dependencies range from zero to one in the Joe–Clayton copula. Since we need a model that takes both asymmetry and symmetry into consideration, we adopt the "symmetrized Joe–Clayton" (SJC) copula:

$$C_{SJC}(u, v|\tau^U, \tau^L) = 0.5*(C_{JC}(u, v|\tau^U, \tau^L) + C_{JC}(1-u, 1-v|\tau^U, \tau^L) + U + V - 1) \quad (4)$$

The SJC copula evolves from the original Joe-Clayton copula, but its functional form allows for symmetric construction when $\tau^U = \tau^L$. Compared to the Joe–Clayton copula, the SJC copula is more powerful. To capture time-varying correlation, we take the change in the tail dependence into consideration by adopting a process similar to ARMA (1, 10) between the two variables (Patton, 2006). Thus, we have:

$$\tau^U_t = \Lambda\left(\omega_U + \beta_U \tau^U_{t-1} + \alpha_U * \frac{1}{10}\sum_{j=i}^{10} |u_{t-j} - v_{t-j}|\right) \quad (5)$$

$$\tau^L_t = \Lambda\left(\omega_L + \beta_L \tau^L_{t-1} + \alpha_L * \frac{1}{10}\sum_{j=i}^{10} |u_{t-j} - v_{t-j}|\right) \quad (6)$$

[3] BB7 copula is a family of bivariate copulas introduced by Joe (1997).

in which $\Lambda(x) \equiv (1 + e^{-x})^{-1}$ is the logistic transform that we use for maintaining τ^U and τ^L in the (0, 1) range at all times. We thus can capture the variation of the stochastic variables in extremity by tail dependence. In our application, τ^U (τ^L) measures the dependence of the eight Asian currencies on the Chinese Yuan in periods when the Chinese Yuan depreciates (appreciates) strongly against the USD. The tail dependence evolution equations are explained by the autoregressive terms, ω_U and ω_L, $\beta_U \tau^U_{t-1}$ and $\beta_L \tau^L_{t-1}$, and by the forcing variable, $\alpha_U * \frac{1}{10}\sum_{j=i}^{10}|u_{t-j} - v_{t-j}|$ and $\alpha_L * \frac{1}{10}\sum_{j=i}^{10}|u_{t-j} - v_{t-j}|$.[4] Considering the difficulty in identifying a time varying limit possibility, we follow Patton (2006) and define the forcing variable as the mean absolute difference between u_t and v_t over the previous 10 observations. β_U (β_L) represents persistence, i.e. the effect of τ^U_{t-1} (τ^L_{t-1}) on τ^U_t (τ^L_t), and α_U (α_L) measures variation in the dependencies of other Asian currencies on the Chinese Yuan.

2.3 Marginal distributions of currency returns

Before using copulas, we should first explain the marginal distribution models of the estimated exchange rate returns.

Taking the well documented properties of daily exchange rate returns into consideration, such as excess kurtosis, fat tails, non-normally and conditional heteroscedasticity, we model the returns as AR(n)-t-GARCH (1,1) models.[5] Specifically, as to individual exchange returns, each conditional variance obeys a GARCH (1, 1) process while the individual conditional mean follows a specified AR(n) process to explain underlying sequential correlation in the returns (cf. Patton, 2006).

The specified AR process of each currency improves the accuracy of the marginal distribution. In our case, the marginal distributions are fitted with the following models:

$$R_{i,t} = \mu_{i,} + k_i R_{i,t-n} + \varepsilon_{i,t} , \tag{7}$$

$$\sigma^2_{i,t} = \omega_i + \alpha_i \sigma^2_{i,t-1} + \beta_i \varepsilon^2_{i,t-1}, \tag{8}$$

$$\sqrt{\frac{v_i}{\sigma^2_{x,t}(v_i - 2)}}\ \varepsilon_{i,t} \sim iid\ t_{v_i} \tag{9}$$

where $R_{i,t}$ is currency *i*'s exchange rate return against the USD, while $\varepsilon_{i,t}$ is currency *i*'s residual. $\sigma^2_{i,t}$ represents currency *i*'s conditional variance, while v_i means the degrees of freedom of currency *i*. In Equation (7), μ_i is a constant, *n* represents the lag order of the specified AR process and $k_i < 1$. In Equation (8), ω_i, α_i nd β_i are non-negative parameters.

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[4] Patton (2006) experimented with several variations of this forcing variable. As these did not yield a significant improvement, we follow Patton (2006) and we use the simplest model.

[5] Patton (2006) employs Student's–t distribution in a GARCH model for the D-mark-dollar and yen-dollar exchange rates. He assumes that different exchange rate returns follow different AR progresses to improve the goodness-of–fit for the marginal distributions. The D-mark-dollar exchange rate follows an AR (1), t-GARCH (1, 1) specification, while the yen-dollar exchange rate follows an AR (1,10), t-GARCH (1,1) specification.

3 Data and first results

3.1 Data

In view of the available data, we choose eight other Asian currencies, i.e. the Indonesian Rupiah, the Indian Rupee, the Korean Won, the Japanese Yen, the Malaysian Ringgit, the Philippine Peso, the Singapore Dollar, and the Thai Baht.[6] Their daily exchange rates against the USD are from the Wind database. The dependence between these currencies with the Chinese Yuan may come from the change of the USD when the Chinese Yuan had a fixed rate vis-à-vis the USD. Therefore, we exclude those fixed exchange rate periods (cf. Ito, 2017). Our sample period covers July 1, 2010 to May 4, 2018. During this period, the People's Bank of China enhanced currency flexibility and reformed its exchange rate regime (Zhao et al., 2013).

Table 1 displays descriptive statistics of currency returns. We calculate the currency returns (cr_t) as $cr_t = 100\ Ln\ (ex_t\text{-}ex_{t-1})$, where ex_t is the current exchange rate and ex_{t-1} is the exchange rate in the previous period. The kurtosis and skewness suggest that the distributions of the series are non-normal. In the pre-SDR period, the Indonesian Rupiah and Malaysian Ringgit exhibit slightly negative skewness. The same holds for the Korean Won and the Thai Baht in the post-SDR period. Excess kurtosis exists in all series. Column 6 displays the results of the Jarque–Bera test. We reject normality at the 1% significant level for all series except for the Korean Won and the Philippine Peso in the post-SDR period. Moreover, as shown in the last column of Table 1, ARCH effects are significant in all returns.

We conduct the augmented Dickey–Fuller (ADF) test to examine unit roots in the exchange rates of the eight Asian currencies against the USD and the Chinese Yuan in the pre-SDR and post-SDR periods. The results are shown in Tables 2 and 3, respectively. We find that all series are stationary at the 1% significance level.

[6] Data for the Vietnamese Dong, the Bangladesh Taka and the Sri Lankan Rupee were also available. However, the returns for these currencies do not fit our specified AR (n)-GARCH (1,1) marginal models. This may be the result of their exchange rate regimes. Hence, we choose the remaining eight currencies to investigate the dynamic and asymmetric dependencies with the Chinese Yuan.

Table 1. Summary statistics

	(1) Minimum	(2) Maximum	(3) Mean	(4) Skewness	(5) Kurtosis	(6) Jarque-Bera	(7) ARCH test
				Pre-SDR period			
R_{Yuan}	-1.149746	1.809701	-0.000995	1.491017	32.12219	53990.67*	6.4168*
R_{Rupiah}	-3.331811	3.135755	0.028884	-0.126650	11.94876	4761.913*	6.8098*
R_{Rupee}	-2.679298	4.019982	0.030488	0.429227	8.725854	1962.454*	35.3760*
R_{Yen}	-2.736819	3.841403	0.008327	0.324616	7.239312	1169.505*	4.0134*
R_{Won}	-1.916560	2.791816	-0.002300	0.354612	4.698501	206.3799*	16.5242*
$R_{Ringgit}$	-2.561684	2.335693	0.025626	-0.207096	5.685661	443.9829*	18.1737*
R_{Peso}	-1.038563	1.432362	0.009148	0.142669	3.793222	42.04495*	8.0283*
R_{SGD}	-1.570692	2.095756	0.002119	0.235966	5.658149	446.7228*	16.7981*
R_{Baht}	-1.421077	1.146370	0.010187	0.026464	4.470477	128.5525*	6.0154*
				Post-SDR period			
R_{Yuan}	-0.966009	1.055184	-0.012439	-0.154940	6.305456	176.3530*	4.3930*
R_{Rupiah}	-0.754265	1.135086	0.018697	0.637688	6.531291	200.8765*	2.3478**
R_{Rupee}	-1.010528	1.021334	9.10E-05	0.103042	4.871853	53.19454*	2.8820*
R_{Yen}	-1.744081	2.278395	0.021553	0.349412	4.351937	38.21547*	3.4329*
R_{Won}	-1.680150	1.274327	-0.008507	-0.019580	3.043269	0.052931	1.9542**
$R_{Ringgit}$	-0.807509	1.219882	-0.015356	0.153555	4.958589	60.10216*	4.2667*
R_{Peso}	-0.667597	0.743701	0.022904	0.163026	3.255548	2.567078	1.8250*
R_{SGD}	-0.811953	0.854706	-0.010656	0.174053	3.349094	3.797572*	2.3096**
R_{Baht}	-1.358366	0.802792	-0.027058	-0.326297	5.417732	94.85352*	2.4776*

Note: This table displays descriptive statistics of variables investigated in our study. We use 10 lags to conduct the ARCH test of Engle (1982). *, **, *** denote the significant levels of 1%, 5%, and 10%s, respectively.

Table 2. Unit root tests of currencies vis-à-vis the USD

	R_{Rupiah}	R_{Rupee}	R_{Yen}	R_{Won}	$R_{Ringgit}$	R_{Peso}	R_{SGD}	R_{Baht}
				Pre-SDR period				
ADF	-35.3497*	-36.7864*	-38.0959*	-40.0792*	-14.7204*	-32.4951*	-38.8802*	-35.2724*
				Post-SDR period				
ADF	-15.9075*	-18.7353*	-18.6908*	-21.5429*	-14.7203*	-17.0377*	-19.6882*	-18.1375*

Note: *, **, *** denote significance at the 1%, 5%, and 10% levels, respectively

Table 3. Unit root tests of currencies vis-à-vis the Chinese Yuan

	R_{Rupiah}	R_{Rupee}	R_{Yen}	R_{Won}	$R_{Ringgit}$	R_{Peso}	R_{SGD}	R_{Baht}
				Pre-SDR period				
ADF	-34.5794*	-34.6366*	-34.8771*	-35.3924*	-34.1167*	-18.7465*	-35.2261*	-36.9937*
				Post-SDR period				
ADF	-18.8640*	-19.0161*	-19.4697*	-20.0305*	-14.7203*	-18.7465*	-19.7213*	-18.8768*

Note: *, **, *** denote the significant levels of the 1%, 5%, and 10%, respectively.

3.2 Dynamics of individual currency returns

Table 4 reports the estimates of Equations (7), (8) and (9) for the marginal distributions of the eight Asian currencies against the USD. As the Chinese Yuan may follow different AR processes in different pairs[7], Table 5 displays the estimates of Equations (7), (8) and (9) for the marginal distribution of the Chinese Yuan in different pairs with the eight other Asian currencies. We estimate n, $\mu_{i,t}$ and k_i in Equation (7), ω_i, α_i and β_i in Equation (8) and the degrees of freedom (v_i) in Equation (9). Panel A in both tables presents estimations for the pre-SDR period and Panel B shows estimates for the post-SDR period.

The USD exchange rate against the Indonesia Rupiah, Philippine Peso and Singapore Dollar follow an AR (5) process in the pre-SDR period, which is shown in column (1) in Table 4. The USD-Indian Rupee and USD-Malaysian Ringgit exchange rates are AR (3) processes, while the USD-Japanese Yen, USD-Korea Won and USD-Thai Baht exchange rates follow an AR (8), AR (4) and AR (1) process, respectively. In the post-SDR period, the USD-Indonesia Rupiah and USD-Thai Baht exchange rates are AR (4) processes, while the USD-Indian Rupee and USD-Japanese Yen exchange rates follow an AR (2) process. The USD-Singapore Dollar exchange rate is an AR (7) process and the remaining exchange rates are AR (1) processes. The USD exchange rates against the Chinese Yuan in the pair with the Indonesia Rupiah, Korean Won, Japanese Yen and Malaysian Ringgit follow an AR (5) process in the pre-SDR period, which is displayed in column (1) of Table 5. The USD-Chinese Yuan in the pair with the Indian Rupee is an AR (1) process and the USD-Chinese Yuan in the remaining pairs follow an AR (3) process. In the post-SDR period, the USD-Chinese Yuan in the pair with the Japanese Yen is an AR (4) process and that in the pair with the Malaysian Ringgit follows an AR (1) process, while those in the remaining pairs are AR (3) processes.

Column (2) in Table 4 shows the mean returns μ_i of those eight Asian currencies in our sample. In the pre-SDR period, the mean is significantly positive for the Indonesian Rupiah and

[7] Note that we excluded some days in order to apply the copulas, which need bilateral data. Those excluded daily data are different for each country pair, thus the Chinese Yuan may follow different AR processes in different pair panels. The use of different AR processes in different panels improves the fit of the marginal distributions, which, in turn, gives more accurate results for the copulas.

the Indian Rupee, while it is significantly negative for the Korean Won. However, in the post-SDR period, only the Thai Baht has significantly negative average returns. The Indian Rupee, the Japanese Yen, the Korean Won, the Malaysian Ringgit and the Singapore Dollar also have negative but insignificant average returns. Our results indicate that the Thai Baht significantly appreciated against the USD in the post-SDR period. The autoregressive term k_i, as shown in column (3) in Table 4, is statistically significant for the Indonesian Rupiah, the Japanese Yen, the Malaysian Ringgit, the Singapore Dollar, and the Thai Baht in pre-SDR period. They are also significant for these currencies (except for the Japanese Yen), the Korean Won and the Philippine Peso in the post-SDR period. The autoregressive terms for the other currencies are insignificant.

Table 4. Parameter estimates of eight Asian currencies: Marginal distributions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	n	μ_i	k_i	ω_i	α_i	β_i	v_i
			Panel A: pre-SDR period				
$\boldsymbol{R_{Rupiah}}$	5	0.0196994*	0.0443418***	0.00101605*	0.681234*	0.318766*	3.33284*
		(3.53984)	(1.84048)	(3.03279)	(50.6795)	(6.17362)	(10.2101)
$\boldsymbol{R_{Rupee}}$	3	0.0185238***	-0.0393217	0.00290383**	0.899441*	0.0899384*	9.32468*
		(1.78264)	(-1.42409)	(2.44341)	(54.1518)	(5.70791)	(3.75871)
$\boldsymbol{R_{Yen}}$	8	0.00954395	0.0425597***	0.00498127**	0.926549*	0.0633933*	4.61033*
		(0.768071)	(1.73189)	(2.18422)	(58.4412)	(4.32361)	(8.98661)
$\boldsymbol{R_{Won}}$	4	-0.0221222***	-0.0283913	0.00156096*	0.935676*	0.0616152*	10.1455*
		(-1.83327)	(-1.06794)	(1.69496)	(74.0411)	(5.00569)	(5.13206)
$\boldsymbol{R_{Ringgit}}$	3	0.0122445	-0.0426604**	0.00237945*	0.912303*	0.0814501*	7.78265*
		(-1.3088)	(2.12726)	(4.57544)	(21.5961)	(5.96874)	(13.3002)
$\boldsymbol{R_{Peso}}$	5	0.0101918	-0.0183036	0.00211172**	0.898907*	0.0769204*	16.6554*
		(1.44325)	(-0.669537)	(2.3126)	(39.4115)	(4.515)	(2.69349)
$\boldsymbol{R_{SGD}}$	5	-0.00109429	-0.0528252**	0.000681778***	0.936678*	0.0600168*	7.98645*
		(-0.148571)	(-1.99989)	(1.73631)	(77.0311)	(4.96516)	(4.94854)
$\boldsymbol{R_{Baht}}$	1	-0.0003608	0.0610279**	0.00495153*	0.818013*	0.133557*	7.11174*
		(-0.053966)	(2.19592)	(3.18837)	(25.2648)	(5.03813)	(4.54299)
			Panel B: post-SDR period				
$\boldsymbol{R_{Rupiah}}$	4	0.00624162	0.164037*	0.00371094**	0.687771*	0.283919*	4.04276*
		(0.782921)	(3.35698)	(2.10692)	(7.1777)	(2.63484)	(4.46471)
$\boldsymbol{R_{Rupee}}$	2	-0.00825351	-0.0852532	0.0325624**	0.322655	0.238176**	6.00622**
		(-0.651403)	(-1.58421)	(2.32027)	(1.43465)	(2.43755)	(2.49847)
$\boldsymbol{R_{Yen}}$	2	-0.00375903	-0.076124	0.00762665	0.935939*	0.0384564***	10.0004***
		(-0.137561)	(-1.43618)	(1.00538)	(22.7912)	(1.67722)	(1.72065)
$\boldsymbol{R_{Won}}$	1	-0.0152511	-0.111133**	0.00262543	0.966862***	0.020747	
		(-0.631148)	(-2.11405)	(0.708065)	(34.1976)	(1.26742)	
$\boldsymbol{R_{Ringgit}}$	1	-0.00572587	0.169034*	0.0030998***	0.763177*	0.205805*	7.62877**
		(-0.526963)	(2.92782)	(1.76088)	(11.5464)	(3.08235)	(2.17492)
$\boldsymbol{R_{Peso}}$	1	0.0148176	0.121075**	0.00339359	0.839945*	0.0954863**	60.1215
		(1.28341)	(2.05627)	(1.29313)	(10.1871)	(1.99364)	(0.271686)
$\boldsymbol{R_{SGD}}$	7	-0.020609	-0.119023**	0.00430643	0.880712*	0.0656557**	
		(-1.39595)	(-2.07438)	(1.46347)	(16.5911)	(2.15933)	
$\boldsymbol{R_{Baht}}$	4	-0.0189553***	0.094014***	0.00471177***	0.701899*	0.265712*	5.77503*
		(-1.79003)	(1.75973)	(1.88265)	(8.31897)	(2.95224)	(2.83765)

Note: This table shows the parameter estimates of Equations (7) - (9) to describe the marginal distributions of the eight Asian currencies' exchange rate returns against the USD. Panel A (before the Yuan joined the SDR) and Panel B (after the Yuan joined the SDR) show the estimates and their corresponding t-statistics in parentheses. *, **, *** denote the significant levels of the 1%, 5%, and 10%, respectively.

The marginal distributions suggest significant GARCH effects considering that the sum of α_i and β_i in all returns are almost equal to 1, except for the Indian Rupee in the post-SDR period in Table 4.

Table 5. Parameter estimates of the Chinese Yuan: Marginal distributions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	n	$\mu_{i,t}$	k_i	ω_i	α_i	β_i	v_i
Panel A: pre-SDR period							
Rupiah	5	-0.00212438	0.0802296*	0.00101605*	0.681234*	0.318766*	3.33284*
		(-1.06065)	(3.5931)	(4.64704)	(19.5272)	(5.77148)	(13.2007)
Rupee	1	-0.00290438	0.018863	0.000871685*	0.703096*	0.296903*	3.37273*
		(-1.43334)	(0.723176)	(4.46687)	(21.0813)	(5.74323)	(13.4456)
Yen	5	-0.00300884	0.0386577***	0.000828679***	0.690859*	0.309141*	3.56143*
		(-1.50784)	(1.66179)	(4.6906)	(21.18)	(6.17419)	(13.3247)
Won	5	-0.00189368	0.0988184*	0.000779562*	0.702348*	0.297652*	3.46747*
		(-0.979727)	(4.51707)	(4.61919)	(21.998)	(6.16222)	(13.4547)
Ringgit	5	-0.0026224	0.0479828**	0.000871658*	0.700278*	0.299722*	3.41962*
		(-1.3088)	(2.12726)	(4.57544)	(21.5961)	(5.96874)	(13.3002)
Peso	3	-0.00324612	0.0616672**	0.000933721*	0.686015*	0.313985*	3.40245*
		(-1.6324)	(2.7395)	(4.58466)	(19.9118)	(5.91164)	(13.2211)
SGD	3	-0.00245253	0.0472853**	0.000941714*	0.691413*	0.308587*	3.41676*
		(-1.23253)	(2.09544)	(4.63967)	(20.5827)	(5.9403)	(13.3008)
Baht	3	-0.00222538	0.0903784*	0.000840376*	0.712157*	0.287843*	3.31335*
		(-1.12995)	(3.97443)	(4.4949)	(22.2856)	(5.79834)	(13.2343)
Panel B: post-SDR period							
Rupiah	3	0.00285353	0.0832752	0.00114075	0.836957*	0.163043*	3.75084*
		(0.343354)	(1.63329)	(1.48267)	(18.5741)	(2.58016)	(5.11346)
Rupee	3	0.00152315	0.0950958**	0.00138079	0.815491*	0.184509*	3.672*
		(0.184905)	(1.93587)	(1.5631)	(16.7863)	(2.7167)	(5.08146)
Yen	4	0.000787322	0.091824***	0.00137959	0.808559***	0.191441*	3.99371*
		(0.0949321)	(1.81968)	(1.62255)	(15.8835)	(2.75623)	(4.89654)
Won	3	0.00154879	0.113098**	0.00121568	0.833986*	0.166014*	3.64768*
		(0.192379)	(2.27589)	(1.52879)	(18.7922)	(2.7128)	(5.07054)
Ringgit	1	0.00178619	0.0503905	0.00149101	0.807666*	0.192334*	3.95183*
		(0.218071)	(0.99119)	(1.59297)	(15.3011)	(2.73916)	(4.93105)
Peso	3	0.0032193	0.075395	0.00119628	0.829493*	0.170507**	3.6576*
		(0.395363)	(1.54373)	(1.51787)	(18.2086)	(2.7045)	(5.07724)
SGD	3	0.00212347	0.0887605***	0.00128176	0.832029*	0.167971*	3.69572*
		(0.264595)	(1.78641)	(1.52137)	(18.1745)	(2.70427)	(4.99837)
Baht	3	0.000404888	0.101427**	0.00104945	0.839432*	0.160568*	3.74818*
		(0.0490444)	(2.07338)	(1.47785)	(20.3196)	(2.77962)	(5.00646)

Note: This table shows the parameter estimates of Equations (7) - (9) to describe the marginal distributions of the Chinese Yuan in different pairs with eight other Asian currencies. Panel A (before the Yuan joined the SDR) and Panel B (after the Yuan joined the SDR) report the estimates, with the corresponding t-statistics in parentheses. *, **, *** indicates significance at the 1%, 5%, and 10% level, respectively.

In general, the estimated degrees of freedom vary from 3 to 11 (as shown in the last columns of Tables 4 and 5). However, rather than fitting to the Student's-t distribution, the return series of the Korean Won as well as the Singapore Dollar in the post-SDR period better fit the normal GARCH (1, 1) model. Due to the varying degrees of freedom, it is possible that the multivariate GARCH model is inappropriate. Hence, we use copulas to estimate the dependence given the joint-t distributions characterized by varying degrees of freedom.

Modeling the copulas properly presumes that the fitting of these marginal models accurately expresses the true marginal distribution. Hence, it is of great importance to examine the goodness of fit of the estimated model before using copulas. Following Patton (2006), we test the goodness of fit in two steps. Firstly, we test for serial independence of the variables that are the probability integral transformations (PITs) of the marginal distributions of these pairs of the eight Asian currencies and the Chinese Yuan using the Ljung-Box **(***LB*) test. Secondly, we adopt the Kolmogorov–Smirnov (KS) test to examine whether the PITs follow a uniform (0, 1) distribution. Table 6 displays the *p*-values of the LB as well as the KS test. The table shows that all p-values are greater than 0.1, suggesting that we cannot reject the null hypothesis of the LB and KS tests, which indicates that the PITs are characterized by independence and a uniform distribution. We conclude that the specified AR (n) – t-GARCH (1, 1) model for each currency is appropriate. Hence, the copula models we use correctly capture the dependence of the eight estimated Asian currencies upon the Chinese Yuan.

Table 6. Specification tests

	R_{Rupiah}	R_{Rupee}	R_{Yen}	R_{Won}	$R_{Ringgit}$	R_{Peso}	R_{SGD}	R_{Baht}
Pre-SDR period								
LB Test	0.7293	0.8435	0.8498	0.8799	0.8719	0.8803	0.9820	0.3445
KS Test	0.4299	0.9853	0.8553	0.8918	0.5504	0.911	0.7195	0.9096
Post-SDR period								
LB Test	0.8290	0.6293	0.7511	0.8113	0.8719	0.9482	0.6997	0.5564
KS Test	0.9921	0.4873	0.8457	0.2206	0.5504	0.8783	0.9128	0.9267

Note: This table shows the *p*-values for the tests of Ljung-Box (LB) and Kolmogorov–Smirnov (KS).

4. Main results

Tables 7 and 8 display the estimations results for the normal copula model as well as the constant SJC and time-varying SJC copula models. The normal copula estimates linear dependence while the SJC copulas capture the tail dependence in periods with high volatility of the investigated exchange rate pair.

Table 7. Parameter estimates of the normal copula (equation 3)

	R_{Rupiah}	R_{Rupee}	R_{Yen}	R_{Won}	$R_{Ringgit}$	R_{Peso}	R_{SGD}	R_{Baht}
Pre-SDR period								
ρ_1	0.2899	0.2448	0.1339	0.3286	0.3092	0.0010	0.3723	0.2693
Post-SDR period								
ρ_2	0.4435	0.2912	0.5155	0.4414	0.4405	-0.0425	0.6359	0.5029

Note: This table presents the estimations for the parameter ρ from normal copula model given in Equation (3). ρ_1 refers to the dependence of each eight Asian currencies upon the Chinese Yuan in the pre-SDR period, while ρ_2 represents the dependence of each eight Asian currencies on the Chinese Yuan in the post-SDR period.

Table 7 reports the dynamic dependencies during the pre-SDR period and the post-SDR period between the Chinese Yuan and eight Asian currencies by presenting estimations for ρ_1 and ρ_2 of the normal copula model shown in Equation (3).

Table 7 shows that the parameters' absolute values in the post-SDR period increased significantly, which suggests that the dependence of the other estimated Asian currencies on the Chinese Yuan has strengthened during the post-SDR period. The estimation for correlation between those Asian currencies and the Chinese Yuan in the pre-SDR period are positive in the normal copula model. In the pre-SDR period, the Singapore Dollar has a relatively high correlation with the Chinese currency (0.3723), followed by the Korean Won and the Malaysian Ringgit. The Philippines Peso and the Japanese Yen have lower correlations with the Chinese Yuan; the latter correlation is only 0.0010. In the post-SDR period, the co-movement between the Chinese Yuan and the other Asian currencies increased obviously. Notably, the correlation with the Japanese Yen is substantially higher, followed by that with the Thai Baht and the Singapore Dollar. In general, our results indicate a clear increase in the co-movement between the Chinese Yuan and the Asian currencies considered in the post-SDR period.[8]

Table 8 tabulates the estimations for the parameters in the SJC copula models. Both the results in the constant and time varying SJC copula model suggest that the dependencies of the estimated Asian currencies on the Chinese Yuan strengthened in the post-SDR period. Furthermore, the asymmetric co-movement of Asian currencies with the Chinese Yuan (i.e. stronger/weaker co-movement when the Yuan depreciates/appreciates against the USD) becomes stronger in the post-SDR period.

Recall that $\tau^U(\tau^L)$ gives the possibility that currency *i* extremely depreciates (appreciates) against the USD if the Chinese Yuan depreciates (appreciates) against the USD. The estimates for the constant SJC copula model imply that in the pre-SDR period, both upper and lower tail

[8] However, the correlation of the Philippines Peso with the Chinese Yuan reversed from positive to negative in the post-SDR period, while the absolute value of the correlation increased. In 2016, China became the largest trading partner of the Philippines. Its trade deficit with China surged by 73.6% in 2016. This led to a deprecation of the Philippines Peso.

dependencies of the Japanese Yen and the Philippine Peso with the Chinese Yuan is insignificant, but for the other currencies the tail dependencies (both upper and lower) are statistically significant. Moreover, compared with the upper tail dependencies upon the Chinese Yuan, these lower tail dependencies are obviously smaller with the exception of the Philippine Peso. Therefore, in the pre-SDR period, our estimates indicate that the dependence of the estimated Asian currencies on the Chinese Yuan is much stronger when the Chinese Yuan depreciates against the USD than when the Chinese currency appreciates. This asymmetric dependence may be the result of "fear of appreciation" (Levy-Yeyati et al., 2013). A temporary undervaluation of the currency protects the development of the infant industries (Glüzmann et al., 2012). Furthermore, it may stimulate export growth (Aizenman and Lee, 2007). The motivation for maintaining a competitive position in export markets would lead other Asian countries to devalue their currencies against the USD when the Chinese Yuan depreciates against the USD. From another point of view, when the Chinese Yuan appreciates against the USD, other Asian countries are glad to see their currencies depreciate against the Chinese Yuan.

In the post-SDR period, we find a significant increase of both upper tail dependence and lower tail dependence (except for the Philippines Peso) which is significant at the 5% level (except for the lower dependence of the Indonesian Rupiah and both tail dependencies of the Indian Rupee). Our results indicate that in the post-SDR period, the co-movement of Asian currencies with the Chinese Yuan is higher during periods with extreme fluctuations. Except for the Indian Rupee and the Korean Won, the upper tail dependencies are larger than the lower ones. In other words, our results suggest that the asymmetric tail dependencies identified during the pre-SDR period prevailed in the post-SDR period (although the constant SJC does not suggest asymmetric dependence between the Chinese Yuan and the Philippines Peso).

As the log likelihood of the time-varying SJC model is larger than that of the constant SJC model, the time-varying SJC model better captures dependence than the constant SJC model (except for the Thai Baht in the post-SDR period).

As to the time-varying SJC copula, we first analyze the parameters of the upper-tail dependence. A higher autoregressive term ω^U indicates a higher upper tail dependence. The autoregressive terms are insignificant with the exception of the Indian Rupee as well as the Korean Won in the pre-SDR period. Nevertheless, the autoregressive terms are statistically significant for the Indonesian Rupiah, the Japanese Yen, the Malaysian Ringgit and the Philippines Peso in the post-SDR period. The autoregressive terms in the post-SDR period increase substantially for the Indonesian Rupiah and the Malaysian Ringgit. This increase indicates a strengthened upper tail dependence in the post-SDR period. This is in line with the results for the constant SJC model. The parameter α^U is significantly positive for the Korean Won in the pre-SDR period but insignificant for the other currencies. In the post-SDR period, α^U is significantly positive for the Indonesian Rupiah, the Japanese Yen and the Malaysian Ringgit while it is negative for the Philippines Peso. As the parameter α^Ucaptures the degree of variation of dependence, our estimates suggest that the dependencies of the estimated Asian currencies upon the Chinese Yuan fluctuate significantly in the post-SDR period.

Furthermore, the degree of persistence of the upper tail dependence (as measured byβ^U) is often significant (except for the Indonesian Rupiah and the Japanese Yen in the pre-SDR period, and the Korean Won, the Philippines Peso, the Singapore Dollar and the Thai Baht in the post-SDR period). If β^U is negative, the upper tail dependence has the ability of self-revising. This holds for the Indian Rupee and the Thai Baht in the pre-SDR and for the Indonesian Rupiah and the Malaysian Ringgit in the post-SDR period.

Next, we consider the estimates of the parameters for the lower tail dependence. As our results show, the autoregressive terms (ω^L) of the Indonesian Rupiah, the Philippines Peso, the Malaysian Ringgit and the Thai Baht in the post-SDR period increase substantially. This suggests that the lower tail dependence of these Asian currencies on the Chinese Yuan has increased in the post-SDR period, which is in line with our findings for the constant SJC model.

In the pre-SDR period, the autoregressive terms ω^U are larger than the autoregressive terms ω^L only for the Indonesian Rupiah, the Japanese Yen, the Korean Won and the Philippines Peso. However, in the post-SDR period, ω^U is larger than ω^L for all Asian currencies with the exception of the Thai Baht, which indicates that in the post-SDR period, the correlations are higher when the Chinese Yuan depreciates against the USD than when it appreciates against the USD. This is in line with the results for the constant SJC copula model.

In the pre-SDR period, the parameter α^L is significantly negative for the Indonesian Rupiah, the Japanese Yen, the Korean Won, the Singapore Dollar and the Thai Baht, and insignificantly for the remaining currencies. However, in the post-SDR period, α^L is mostly indifferent from zero, except for the Korean Won.

In the pre-SDR period, the degree of persistence of the lower tail dependence (β^L) is significantly positive for the Japanese Yen, the Philippines Peso, the Singapore Dollar and the Thai Baht, significantly negative for the Indian Rupee, and insignificant for the remaining currencies. Our findings suggest that the lower tail dependencies with the Chinese Yuan keep constant except for the Indonesian Rupiah, the Korean Won and the Malaysian Ringgit. The lower tail dependence between the Indian Rupee has the ability of self-revising. In the post-SDR period, the degree of persistence is significantly positive for the Indian Rupee, the Korean Won, the Philippines Peso, the Malaysian Ringgit and the Singapore Dollar, and insignificantly for the remaining currencies.

Table 8. Parameter estimates for the SJC copulas

	Rupiah	Rupee	Yen	Won	Peso	Ringgit	SGD	Baht
Pre-SDR period								
Constant SJC Copula (equation 4)								
τ^U	0.1513* (4.3512)	0.0980* (2.8537)	0.0238 (0.9429)	0.1579* (4.1852)	0.0000 (116087189.5743)	0.1448* (3.8234)	0.2462* (6.8173)	0.1290 * (3.5509)
τ^L	0.0931** (2.6494)	0.0563*** (1.6953)	0.0103 (0.5807)	0.1482* (3.6609)	0.0000 (967243.3323)	0.1114* (2.8489)	0.1462* (3.3415)	0.0817** (2.1314)
Copula likelihood	-65.064	-40.6460	-12.6331	-82.2394	0.1036	-66.5660	-113.1412	-53.0667
Time Varying SJC Copula (equations 5-6)								
ω^U	-1.4332 (-1.2927)	-3.6941*** (-1.6513)	-2.5054 (-0.0576)	-1.3013 ** (-2.1972)	-8.2467 (-0.8507)	0.0280 (0.0541)	0.0300 (0.8188)	-0.2949 (-0.1496)
α^U	0.7499 (0.2480)	-0.4647 (-0.0439)	2.6634 (0.0259)	2.7450*** (1.7275)	-1.4967 (-0.0146)	-1.9635 (-0.6643)	-0.1952 (-1.0344)	-10.0000 (-1.2680)
β^U	0.1107 (0.4650)	-0.9783 * (-128.4752)	0.5385 (0.2172)	0.5618* (3.0888)	9.0789** (2.3618)	0.6618* (3.3680)	0.9761*** (43.3507)	-0.9610* (-32.8393)
ω^L	-0.2366 (-0.4822)	-4.4027 (-1.0343)	1.4034*** (1.9084)	1.1980 (1.2513)	-5.3992 (-0.7357)	-0.1649 (-0.3105)	1.3704** (2.0891)	0.3341** (2.1469)
α^L	-1.2384* (4.7455)	-1.9911 (-0.1221)	-8.1886 *** (-1.7959)	-9.9919** (-2.0793)	-1.0342 (-0.0116)	-2.2374 (-0.7906)	-8.9483** (-2.0814)	-1.6063** (-2.2542)
β^L	0.7114 (-0.9291)	-0.9587 * (-25.4657)	0.8133* (12.7034)	0.0901 (0.4628)	6.3362* (4.0256)	0.5678 (1.5195)	0.5581* (2.8464)	0.9691* (116.2903)
Copula likelihood	-65.3295	-42.3272	-15.2908	-85.7933	3.2431	-68.1919	-120.4073	-61.8625
Post-SDR period								
Constant SJC Copula (equation 4)								
τ^U	0.3296* (5.9094)	0.1186 (1.3696)	0.3529* (5.3316)	0.2032** (2.3642)	0.0000 (30291140559142 524)	0.2867* (4.5334)	0.4654* (9.6786)	0.4122* (6.6416)
τ^L	0.1519*** (1.9325)	0.1430*** (1.8345)	0.3146* (3.9342)	0.3562* (5.8748)	0.0000 (97416706011242 3 .6250)	0.2391* (3.2361)	0.4375* (7.6272)	0.2032** (2.2919)
Copula likelihood	-36.2963	-15.5070	-54.4587	-44.4718	0.0866	-38.4945	-95.7379	-53.0938
Time Varying SJC Copula (equations 5-6)								
ω^U	-2.1312** (-2.0410)	-3.5155 (-1.5634)	-0.0500 * (-4.3926)	0.5707 (0.3299)	-9.9935* (-361.3592)	-2.5502 ** (-2.1491)	-0.4417 (-0.3916)	-0.5722 (-0.5935)
α^U	7.2826* (3.3209)	10.0000 (1.5612)	0.1670* (34.3107)	-8.0473 (-0.7270)	-7.945*** (-1.7563)	6.3418* (3.3075)	3.4674 (0.3732)	3.3193 (0.7397)
β^U	-0.9857* (-62.7523)	0.6073* (3.6482)	1.0174* (20134.6956)	-0.3431 (-0.6369)	0.1147 (0.7917)	-0.9975 * (-255.6784)	0.5726 (0.3990)	0.3292 (1.1114)
ω^L	1.5733 (0.8545)	-0.8114 (-1.2240)	-0.0002 (-0.0000)	-0.5694 ** (-1.9421)	-8.3867 ** (-2.3728)	-0.6815 (-1.2374)	-0.1953 (-1.0997)	0.7131 (0.3769)
α^L	-9.9999 (-0.9272)	2.6908 (1.2244)	-1.0729 (-0.0663)	2.4041** (2.1581)	-2.4698 (-0.1581)	2.1299 (1.1111)	1.0176 (1.1167)	-6.2643 (-0.6471)
β^L	0.5844 (1.5846)	0.9552* (57.8431)	-0.0990 (-0.0174)	0.7819* (9.3128)	0.9585*** (1.6873)	0.7256* (3.7945)	1.0020* (66.9310)	0.4715 (1.2246)
Copula likelihood	-39.1469	-21.6962	-61.1697	-47.5690	1.3924	-42.7450	-99.4680	-52.8602

Note: This table displays these parameters from the constant SJC copula shown in Equation (4) as well as from the time-varying SJC copula presented in Equations (5) - (6), with t-statics in parentheses, using maximum likelihood estimates. *, **, *** denote the significant levels of the 1%, 5%, and 10%, respectively.

Due to its appreciation in the post-SDR period, the Thai Baht shows asymmetric dependence with the Chinese Yuan. The asymmetric dependencies of the Indian Rupee, the Malaysian Ringgit and the Singapore Dollar with the Chinese Yuan changed in the post-SDR period. For the Indian Rupee this may reflect the effects of its appreciation due to high inflation. India's headline inflation rose close to 10% during 2010–2011, while it has fallen to 5.2% in early 2015. This suggests that initially the Indian authorities gave priority to price stability rather than competitiveness of exports but the drop of inflation indicates that they changed their priorities, hence a change of the asymmetric dependence between the Indian Rupee with the Chinese Yuan exists. The Singapore authorities adopted a "modest and gradual appreciation" of the weighted currencies of a basket of major trading nations from October 14, 2010. However, on April 14, 2016, the Monetary Authority of Singapore announced that it would ease monetary policy and stop the appreciation of the Singapore Dollar. These different economic policies arguably led to the asymmetric dependence of the Singapore Dollar against the Chinese Yuan. In the pre-SDR period, the Malaysian Ringgit depreciated from September 2014 onwards. The Bank Negara Malaysia (BNM) intervened to curb the fall of its currency. Consequently, the co-movement between the Malaysian Ringgit and the Chinese Yuan is higher when the Yuan appreciates against the USD comparing with when the Yuan depreciates against USD.

5 What explains the dynamic and asymmetric dependencies?

In this section, we examine whether trade links and/or financial relations drive the dependence of other Asian currencies upon the Chinese Yuan. As China's increased role in the global trade, the currencies of those economies participating in the same value chain with China may respond to shocks in a similar way as the Chinese Yuan. Because of increased financial linkages across countries, international investors may hold the viewpoint that Asian currencies have similar risk. In that case, a stronger Chinese Yuan causes international investors to buy other currencies in Asia as well, leading to a high co-movement between all these currencies.

We examine the effect of trade linkage and financial integration on the co-movement of the Chinese with eight other Asian currencies using a fixed effects model. In order to get time series for dependence, we first estimate annual dependencies, ρ_{it}, from 2011 to 2017. For this purpose, we estimate annual dependence using the normal copula model. Table A1 in the Appendix shows the parameter estimates.

To proxy trade links, we use the trade intensity introduced by Davis (2014) between countries i and j (T_{ij}) as follows:

$$T_{ij} = \frac{1}{2T}\sum_t \frac{X_{ijt}+M_{ijt}}{Y_{it}+Y_{jt}} \tag{10}$$

where X_{ijt} represents the export of country i to country j at time t; M_{ijt} represents the import of country i from country j at time t; Y_{it} denotes the GDP of country i at time t and Y_{jt} is the GDP of country j at time t. We calculate trade intensity using annual bilateral trade data from 2011 to 2017. The data are from China's General Administration of Customs and the Word Bank.

We calculate the similarity of bond and equity returns (cf. Davis, 2014) to measure bilateral financial linkage of countries i and j. We examine bond market linkage and equity market linkage by the mean absolute difference of bond returns, C_{ij} and K_{ij} are mean absolute deviations of bond and equity returns, respectively. For paired countries with strong financial integration, C_{ij} and K_{ij} should be small. The aggregate measurement of financial integration is $F_{ij}= C_{ij} + K_{ij}$.

$$C_{ij}=\frac{1}{T}\sum_{t=1}^{t}\left|r_{it}^{b}-r_{jt}^{b}\right| \tag{11}$$

$$K_{ij}=\frac{1}{T}\sum_{t=1}^{t}\left|r_{it}^{s}-r_{jt}^{s}\right| \tag{12}$$

in which r_{it}^{b} represents the government bond yield of country i at time t and r_{jt}^{b} represents country j's government bond yield at time t; r_{it}^{s} denotes country i's stock returns and r_{jt}^{s} denotes country j's stock returns We use monthly government bond interest rate to calculate C_{ij} and daily stock returns to construct K_{ij}. Our data are from the IFS and the Wind databases.

The estimated regression is as follows:

$$\rho_{it}=\alpha_{it}+\beta_1 T_{it}+\beta_2 F_{it}+\beta_3 D_{SDR}+\beta_4 T_{it}*D_{SDR}+\beta_5 F_{it}*D_{SDR}+\varepsilon_{i,t} \tag{13}$$

where ρ_{it} is country *i's* dependence with China at time t; T_{it} and F_{it} represent country i's trade and financial linkage with China; and D_{SDR} denotes the dummy variable that equals one in the post-SDR period and zero otherwise.

Table 9 reports our estimation results. It turns out that the coefficient on trade linkage is insignificantly positive, the coefficient on financial integration and D_{SDR} are significantly positive, while the coefficient on the interaction between D_{SDR} and trade intensity (financial integration) is positive (insignificant). Based on our results, we draw the following conclusions. First, the significance of the coefficient on D_{SDR} confirms our previous finding that the Chinese Yuan's inclusion in the SDR significantly increased co-movements between the Chinese Yuan and other currencies. Second, the insignificant coefficient on the interaction of D_{SDR} and financial integration and the significant coefficient on financial integration suggest that the influence of financial integration on the co-movement of currencies has not changed since the Yuan became part of the SDR. During the entire period, financial integration has played an important role in the co-movement of Asian currencies with the Chinese Yuan. Finally, the significant coefficient on the interaction of D_{SDR} and trade intensity suggests that since the inclusion of the Yuan in the SDR, trade intensity in the paired countries of China and the other Asian economies has enhanced the dependence of the eight Asian currencies upon the Chinese Yuan.

Table 9. Impact of Chinese Yuan's inclusion in SDR on Asian currencies' co-movement with the Chinese Yuan

	T	F	D_{SDR}	$T^{*} D_{SDR}$	$F^{*} D_{SDR}$
Coefficients	19.21639 (12.6586)	0.0299923** (0.0160247)	0.1859461* (0.0653548)	16.08967** (8.734826)	-0.012631 (.0148692)

Note: This table shows the estimations of equation (13). Standard errors are in parentheses. *, **, *** denote the significant levels of the 1%, 5%, and 10%, respectively.

6 Conclusion

We investigate the dynamic structure of the dependence of the eight other Asian currencies upon the Chinese Yuan. In contrast to previous studies examining the co-movement of Asian currencies, we do not use the framework introduced in Frankel and Wei (1994) but adopt the copula approach to investigate the (possibly non-linear) dependence structure of the eight Asian currencies upon the Chinese Yuan. This approach does not require non-collinearity. Furthermore, it allows us to investigate whether the interdependence between two currencies is the same when the Yuan appreciates against the USD and when the Chinese currency depreciates against the USD. Our sample period covers July 1, 2010 to May 4, 2018 during which the Chinese Yuan did not have a fixed rate vis-à-vis the USD. As the inclusion of the Chinese Yuan in the SDR may have changed the dependence structure, we examine whether the co-movements in the pre-SDR and post-SDR period differ.

We adopt the normal copula approach to estimate the dependence before and after Chinese Yuan had been included in the SDR and find that after its inclusion the eight other Asian currencies co-move more closely with the Chinese Yuan. In addition, we use the constant and time-varying SJC copula to accommodate possible non-linear dependence. Our results point to a time varied dependence. Furthermore, it is characterized by asymmetry as the upper tail dependence is larger than the lower tail dependence. Generally, the co-movement between Asian currencies and the Chinese Yuan is weaker when the Chinese currency appreciates against the USD than when it depreciates against the USD. This pattern is identified before and after the inclusion of the Chinese Yuan in the SDR, but it is stronger after its inclusion. This prevailing asymmetric dependence could be the result of "fear of appreciation". In order to maintain competitiveness of their export, the authorities of other Asian countries tend to intervene in foreign exchange markets when the Chinese Yuan depreciates.

Our results suggest that financial integration affected the dependence of other Asian currencies upon the Chinese Yuan over the entire period. After the Yuan had been included in the SDR, also trade links of China and the other Asian economies considered positively affected the co-movement of the Asian currencies with the Chinese Yuan.

Appendix

Table A1. 2011-2017 parameter estimates for the normal copula

	2011	2012	2013	2014	2015	2016	2017
R_{Rupiah}	0.3001	0.317	0.0829	0.1877	0.3790	0.4538	0.3729
R_{Rupee}	0.3334	0.2039	0.1716	0.0934	0.2413	0.2975	0.2890
R_{Yen}	0.1431	0.0539	0.1353	0.1183	0.0849	0.3446	0.5101
R_{Won}	0.3304	0.3509	0.2263	0.1967	0.2970	0.4935	0.4588
$R_{Ringgit}$	0.3011	0.3921	0.1918	0.2064	0.2033	0.4266	0.4098
R_{Peso}	0.0261	-0.0178	-0.0153	-0.0018	-0.1291	0.0804	-0.0828
R_{SGD}	0.3173	0.3937	0.301	0.2406	0.2445	0.6124	0.5919
R_{Baht}	0.2460	0.3956	0.1037	0.2428	0.1965	0.5661	0.4478

Note: This table displays the annual dependence of the estimated Asian currencies upon the Chinese Yuan calculated by the normal copula using each year's exchange rate against USD.

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