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Asymmetric arbitrage trading on offshore and onshore renminbi markets

Sercan Eraslan

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Non-technical summary

Research Question

Fundamentally, onshore and offshore renminbi exchange rates represent the same economic quantity and, thus, should be driven by the same pricing mechanism according to the law of one price. However, the two renminbi rates can deviate markedly from each other over many days due to distinctive market conditions such as a more strongly regulated onshore market. This paper investigates the time-varying driving forces behind the adjustment process of the two rates.

Contribution

The existing literature studies the distinctive conditions on the onshore and offshore renminbi markets as well as their consequences for the onshore-offshore pricing mechanism. However, these studies do not investigate the particular behaviour of onshore and offshore exchange rates, but only focus on the onshore-offshore price differential itself. Moreover, the potential impact of appreciation and depreciation trends on the adjustment process of the two rates has not attracted much attention in recent studies.

Results

This paper finds empirical evidence for the time-varying influence of external factors on onshore and offshore renminbi rates. The estimation results suggest that the existence and the effects of arbitrage trading depend on market regulation, the size of the onshore-offshore pricing differential, and appreciation and depreciation trends. For example, when the onshore market was strongly regulated and the renminbi appreciated persistently, arbitrage trading was restricted to periods when the offshore renminbi was distinctly weaker than its onshore counterpart, and it had effects on the offshore rate only. In periods without arbitrage trading, the dynamics of the renminbi rates are mainly dominated by global risk sentiment, directional expectations, and local as well as global liquidity conditions.

Nichttechnische Zusammenfassung

Fragestellung

Bei Onshore und Offshore Renminbi Wechselkursen handelt es sich grundsätzlich um dieselbe ökonomische Größe. Daher sollten beide Wechselkurse demselben Preisbildungsmechanismus unterliegen. Allerdings können beide Wechselkurse über mehrere Tage deutlich voneinander abweichen. Dies geschieht aufgrund unterschiedlicher Marktbedingungen wie zum Beispiel einer stärkeren Regulierung des Onshore Devisenmarktes. Diese Arbeit untersucht die zeitvariablen Bestimmungsfaktoren, die dem Anpassungsprozess beider Wechselkurse zugrunde liegen.

Beitrag

Die existierende Literatur studiert die unterschiedlichen Bedingungen auf den Onshore und Offshore Renminbi Devisenmärkten und deren Einflüsse auf die Onshore-Offshore Kursdifferenz. Allerdings vernachlässigen diese Studien meistens die spezifische Entwicklung von Onshore und Offshore Wechselkurs, da sie sich nur auf die Kursdifferenz selbst konzentrieren. Darüber hinaus wurde der Einfluss von Abwertungs- bzw. Aufwertungstrends auf den Anpassungsprozess der Wechselkurse bisher nicht untersucht.

Ergebnisse

Es zeigt sich, dass externe Faktoren zeitvariable Einflüsse auf Onshore und Offshore Wechselkurs besitzen. Die Schätzergebnisse deuten darauf hin, dass das Vorliegen und die Effekte von Arbitragehandel maßgeblich von Regulierung, dem Ausmaß der Onshore-Offshore Kursdifferenz und dem Vorliegen von Abwertungs- bzw. Aufwertungstrends abhängen. So fand Arbitragehandel zum Beispiel in Zeiten starker Regulierung des Onshore Marktes und einer dauerhaften Aufwertungsphase nur dann statt, wenn der Offshore Renminbi deutlich niedriger bewertet war als der Onshore Renmimbi, und Wechselkurseffekte des Arbitragehandels zeigten sich nur auf dem Offshore Markt. In Zeiten ohne Arbitragehandel wird der Verlauf der Wechselkurse vor allem von globalen Risikoeinschätzungen, der Richtung der Markterwartungen, sowie lokaler und globaler Marktliquidität bestimmt.

Bundesbank Discussion Paper No 13/2017

Asymmetric Arbitrage Trading on Offshore and Onshore Renminbi Markets*

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Abstract

This paper investigates the asymmetries in arbitrage trading with onshore and offshore renminbi spot rates, focusing on the time-varying driving factors behind the deviations of the two rates from their long-run equilibrium. Fundamentally, offshore and onshore renminbi rates represent the same economic quantity and hence should be driven by the same pricing mechanism. However, the two exchange rates deviate remarkably from each other, creating arbitrage opportunities over many days. For the empirical analysis, I build a three-regime threshold vector error correction model with offshore and onshore spot rates and further regime-dependent explanatory variables. The model is estimated in different periods in order to consider the impact of appreciation and depreciation expectations on possible arbitrage trading. The estimation results suggest that directional expectations, global risk sentiment, and local as well as global liquidity conditions dominate the adjustment process in the absence of arbitrage trading when the offshore rate is stronger than its onshore counterpart. However, the error correction mechanism of the offshore (onshore) rate toward its equilibrium with the onshore (offshore) rate is driven by the arbitrage trading due to a relatively weaker (stronger) offshore (onshore) rate in the upper regime in times of appreciation (depreciation) expectations.

Keywords: Threshold cointegration, vector error correction model, arbitrage trading, renminbi exchange rates, onshore and offshore markets

JEL classification: C32, F31, G15.

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*Contact address: Deutsche Bundesbank, Wilhelm-Epstein-Strasse 14, 60431 Frankfurt am Main, Germany. Phone: +49 (0)69 9566-6634. E-mail: sercan.eraslan@bundesbank.de. This paper is a revised version of the second chapter of the author's doctoral thesis, written at Hamburg University. The idea of possible arbitrage trading on offshore and onshore renminbi markets was initially brought to my attention by Michael Funke. I am grateful to him for sharing his intuitions with me. Moreover, I thank Malte Knüppel (the editor) and Christoph Fischer for their helpful comments.
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1 Introduction

Against the background of a fast-growing accumulation of foreign exchange reserves and increasing concerns about the potential risks of a US Dollar overreliance in the aftermath of the global financial crisis, China has started to promote the renminbi's internalisation in recent years. Accordingly, the use of the renminbi (RMB) outside mainland China has also gained momentum due to a number of supportive policies. As an important part of the RMB internalisation, the offshore renminbi foreign exchange market in Hong Kong started to trade in late August 2010. The offshore renminbi market is mostly liberalised, whereas the onshore spot market remains heavily managed and highly regulated in mainland China. These distinctive market conditions lead to remarkable deviations of the two exchange rates from each other and result in different adjustment processes for appreciations and depreciations of the offshore (onshore) renminbi against its onshore (offshore) counterpart.[1]

Fundamentally, offshore and onshore renminbi rates represent the same financial product and thus should be driven by the same price mechanism according to the law of one price. However, the two renminbi spot rates deviate remarkably from each other over many days. Consequently, these deviations result in arbitrage opportunities when the pricing gap between the offshore and onshore rate exceeds the fixed costs, such as transaction costs, associated with arbitrage trading. In this context, conventional linear estimation techniques would implicitly assume that the adjustment process of the offshore and the onshore renminbi rates toward their long-run equilibrium is linear, continuously active, and symmetric for both offshore/onshore (CNH/CNY) appreciations and depreciations. However, the fixed costs associated with arbitrage trading require a nonlinear cointegration relationship between the offshore and onshore renminbi rates depending on the size and the sign of the deviations from the long-run equilibrium. More precisely, the adjustment process of the offshore and onshore renminbi is only evident when the absolute value of the CNH/CNY pricing gap is more than the fixed costs of arbitrage trading. This implies a nonlinear cointegration relationship which is only active when arbitrage trading is profitable and is not necessarily symmetric for positive and negative deviations from the equilibrium.

The existing literature on the CNH/CNY domain has been quite limited so far. Among others, Maziad & Kang (2012) investigate the time-varying cross correlations between the offshore and onshore spot as well as futures markets using bivariate GARCH models. Cheung & Rime (2014) show that the offshore rate has an increasing influence on its onshore counterpart. On the other hand, Li, Hui & Chung (2012) investigate the price discrepancies between the CNY deliverable forward and the CNH non-deliverable forward exchange rates considering the possibility of parameter uncertainty. Focusing on the CNH/CNY price differential, Craig et al. (2013) employ a threshold autoregressive model for the offshore and onshore differential and show that the changes in investor sentiment and offshore liquidity trigger the sharp deviations of the two rates, while the restrictive capital controls across the border limit arbitrage opportunities. In addition, Funke et al.

[1] The reader is referred to Maziad & Kang (2012), Craig, Hua, Ng & Yuen (2013), Shu, He & Cheng (2015) and Funke, Shu, Cheng & Eraslan (2015) among others, for a more comprehensive overview of the internationalisation of the renminbi, distinctive offshore and onshore market conditions as well as of the factors influencing the CNH/CNY pricing gap.

(2015) investigate the determinants of the CNH/CNY differential considering a broader range of factors like the economic fundamentals, contagion and policy measures within an extended GARCH framework.

Previous studies highlight the distinctive conditions on the offshore and onshore renminbi markets as well as the consequences for the CNH/CNY pricing differential. Among others, Craig et al. (2013), Funke et al. (2015) and Shu et al. (2015) point out the fact that the pricing differential between the offshore and onshore renminbi spot rates can lead to some arbitrage opportunities. While both Craig et al. (2013) and Funke et al. (2015) investigate the drivers behind the CNH/CNY pricing differential, Craig et al. (2013) also find evidence for asymmetries in the possible arbitrage trading due to restrictions on capital flows between mainland China and Hong Kong. However, these studies focus only on the CNH/CNY price differential and do not investigate the particular behaviour of the offshore and onshore rates during the arbitrage trading. This paper aims to fill this gap by examining the behaviour of the offshore and onshore spot rates separately during the price adjustment process associated with the arbitrage trading.

This paper can be considered as a generalisation of Craig et al. (2013) and Funke et al. (2015), with a longer sample period covering times of remarkable appreciation as well as depreciation trends. However, the main focus is on the discontinuous and asymmetric adjustment process of the offshore and onshore renminbi rates toward their long-run equilibrium with each other. In addition, I also examine the time-variation in the relative importance of the driving factors behind the adjustment process during the possible arbitrage trading. For this purpose, I employ a three-regime threshold vector error correction model with additional explanatory variables. In the first step, the lower and upper threshold values are estimated empirically via grid search method. Then, the three-regime model is augmented with additional variables based on the findings of the previous studies. Moreover, I allow the factors influencing the offshore and onshore renminbi rate to be regime-dependent in order to document the time-variation in their importance on the adjustment process. Finally, the model is estimated over the full sample as well as in three different subperiods in order to capture the effect of appreciation/depreciation expectations on possible arbitrage trading.

Overall, the estimation results are broadly in line with the expectations and confirm the empirical findings of the previous studies. On top of the findings of the existing literature, this paper also finds empirical evidence for asymmetric arbitrage trading as well as for the time-varying influence of the external factors on the offshore and onshore renminbi spot rates. Accordingly, directional expectations, global risk sentiment, and local as well as global liquidity conditions play a more important role in the adjustment of an appreciated offshore rate than arbitrage trading, whereas arbitrage opportunities are rapidly monetised when the offshore spot rate is depreciated against its onshore counterpart in times of appreciation pressure on the renminbi. In contrast, against the background of the more recent depreciation trend of the renminbi, arbitrage trading starts to play a major role in the adjustment of an appreciated onshore rate against the weaker offshore rate.

This paper is an empirical study with a focus on the practical implications of the CNH/CNY pricing differential associated with arbitrage opportunities for investors and policy makers. Thus, the reader should also be aware of what is not provided in this paper. During the empirical analysis, this paper does not consider the policy measures influencing the CNH/CNY differential explicitly. For a more detailed investigation of the impact of the regulatory changes and policy measures on the offshore and onshore renminbi spot markets, the reader is referred to the recent studies mentioned above, among others. In comparison with the related literature, this paper focuses on the first moment dynamics of the offshore and onshore renminbi spot rates in different periods and does not model the second moment characteristics of the related markets.

The remainder of this study is structured as follows. Section 2 gives a brief overview of the different market conditions for the offshore and onshore renminbi markets. Section 3 continues with the empirical analysis. Subsection 3.1 gives a brief overview of the data and conducts a preliminary analysis, while the next Subsection 3.2 briefly introduces the econometric methodology. The estimation results are presented and compared to those of the related studies in Subsection 3.3. Finally, Section 4 summarises the findings of this study and concludes.

2 Characteristics of the CNH and CNY markets[2]

This section aims to summarise the distinctive conditions on the offshore and onshore renminbi spot markets, focusing on the factors influencing arbitrage opportunities. The reader is referred to Craig et al. (2013), Funke et al. (2015) and Shu et al. (2015) for a more detailed analysis of the characteristics of the CNH and CNY markets.

Developments of the offshore renminbi market in Hong Kong, also referred to as the CNH market, are particularly notable and are supported by liquidity growth due to cross-border trade settlements, continuous widening of the renminbi product range, and supportive measures on the technical front. Nevertheless, capital outflows from mainland China to the offshore RMB markets seem to remain more restrictive than capital inflows from the offshore renminbi markets to mainland China, as documented by the recent studies. The CNH market, consisting of both spot and forward rates, requires the actual renminbi liquidity and hence it is closely tied to the general conditions of demand and supply for the currency. All entities outside mainland China can have access to the offshore market and anyone who has access to the offshore market can hold and trade the offshore renminbi in the CNH market. Against this backdrop, the offshore RMB market is also affected by changing global risk factors and contagion. Moreover, the offshore spot rate can float freely as there is no intervention by the People's Bank of China (PBoC) or the Hong Kong Monetary Authority (HKMA) in the CNH market. However, the PBoC possibly intervened in the offshore market in early 2016. Overall, the offshore market is mostly liberalised in spite of its short history and still relatively small scale.

In comparison with the offshore renminbi market, the onshore foreign exchange market, referred to as the CNY market, has a longer history and relatively deep liquidity. However, the CNY market still remains strictly regulated in mainland China. Access to the CNY market is restricted to domestic banks and finance companies as well as domestic subsidiaries of foreign banks. Moreover, the China Foreign Exchange Trade System, an affiliation of the PBoC, sets the central parity rate, also known as CNY fixing, each morning. The ±2% daily trading band against the US dollar remains in place, and the People's Bank of China has a presence in the onshore renminbi market in order to keep the fluctuations of the onshore renminbi rate within the trading band.

[2]This section draws from Section 2 of Funke et al. (2015), which is based on Shu et al. (2015).

Although the offshore renminbi spot rate represents fundamentally the same currency as its onshore counterpart in mainland China, distinctive conditions on the offshore and onshore markets as well as ongoing segmentation on both renminbi markets result in two different pricing mechanisms for the two renminbi spot rates. For this reason, offshore and onshore renminbi spot rates deviate from each other substantially, creating arbitrage possibilities over many days, whereas they trade quite closely on most days. However, not so many market players can capitalise on these arbitrage opportunities due to limited simultaneous access to both markets. Moreover, different market dynamics and narrow cross-border channels as well as asymmetric trade restrictions between the mainland and Hong Kong lead to different adjustment dynamics for the two renminbi spot rates toward their long-run equilibrium relationship.

3 Empirical Analysis

3.1 Data and preliminary analysis

This paper analyses the nonlinear adjustment process of the CNH (CNY) spot price to the long-term equilibrium with its onshore (offshore) counterpart in a threshold vector error correction modelling framework. During the empirical analysis, I employ daily data for the offshore and onshore renminbi spot rates against the US dollar as well as their bid-ask spreads, a dummy for the directional expectations based on the $3m$ CNY risk reversal, the volatility index VIX and 10-year US Treasury bond yields covering a period from 23.08.2010 to 31.12.2016. The data corresponds to the daily closing prices of each series, and non-trading days such as weekends and public holidays are excluded from the analysis. All time series data are downloaded from Bloomberg.

The offshore spot rate, the onshore spot rate, the first difference of the CNH, the first difference of the CNY and the VIX index in first difference are denoted by the variables cnh_t, cny_t, Δcnh_t, Δcny_t and ΔVIX_t, respectively and are given in logs if not stated otherwise. Moreover, the error correction term is denoted by the variable ect_t and defined basically as the difference between the two spot rates $ect_t = cnh_t - cny_t$. On the other hand, the variables $mexp_t$, $cnhbas_t$, $cnybas_t$ and $\Delta us10yr_t$ refer to the directional expectations, the bid-ask spread of the CNH, the bid-ask spread of the CNY and the first difference of the US Treasury Bonds, respectively, and are not in logs.

In order to investigate the relative importance of the driving forces behind the offshore and onshore spot rates, this paper includes a set of additional variables relying on the findings of related studies. Therefore, these variables aim to capture the time-varying impact of the market view on the RMB, global risk factors, liquidity conditions on the offshore and onshore markets as well as global liquidity on the offshore and onshore spot rates in different regimes.

First, I use three-month CNY risk reversal as a proxy for the market view on the direction of the renminbi, along similar lines to Craig et al. (2013).[3] However, I create

[3]Currency risk reversals are mostly interpreted as directional expectations of the underlying spot rates over the next maturity date and are briefly calculated as the difference in the implied volatilities of the call and put options. As the risk reversal indices are observable on the financial markets, they are also widely used in theoretical as well as empirical research. See Beber, Breedon & Buraschi (2010), Brunnermeier, Nagel & Pedersen (2008), Campa, Chang & Reider (1998) and Carr & Wu (2007) for application of risk

a dummy variable $mexp_t$ in order to interpret the changes in the reversal as directional market expectations regardless of the magnitude of absolute changes in the currency reversal. Hence, the market expectations dummy takes the following form $mexp_t = 1$ if $\Delta cnyrr3m_t > 0$, -1 otherwise. Moreover, I use the same variables as Funke et al. (2015), such as the VIX index, bid-ask spreads of the related spot rates, and the US interest rates, to capture the impact of global risk factors, liquidity conditions on the two offshore and onshore markets and global liquidity on the renminbi spot rates. Specifically, the volatility index is the Chicago Board Options Exchange Market Volatility Index, which is referred to as the VIX index. The bid-ask spreads of the offshore and onshore spot rate are denoted as $cnhbas_t$ and $cnybas_t$, respectively. Moreover, the 10-year US Treasury bond yields are used to capture the effect of global liquidity on the adjustment process of the two renminbi rates due to their availability as daily data. The related variable is in first-differenced form and denoted as $\Delta us10yr_t$, while higher US interest rates indicate tightening global liquidity conditions.

Figure 1 plots the variables cnh_t and cny_t over the full sample. As the time series plot illustrates, the offshore and onshore renminbi spot rates trade quite closely with each other, with some significant deviations from their long-run equilibrium in the considered period. Moreover, both spot rates exhibit an appreciation trend against the US dollar in the first half of the sample (25 August 2010 − 30 December 2013). However, after stabilising in 2014/2015 (1 January 2014 − 10 August 2015) the renminbi started to depreciate considerably after August 2015 (11 August 2015 − 30 December 2016). Against this background, I investigate the adjustment process of both rates toward their equilibrium in three subperiods in order to examine the possible impact of appreciation/depreciation expectations on arbitrage trading.

Figure 1: CNH & CNY

Sources: Bloomberg.
Notes: This figure plots the log of the offshore (black solid line) and onshore (grey dashed line) renminbi spot rates.

reversals in foreign exchange rates.

Taking a look at Figure 1, the offshore and onshore renminbi rates may contain unit root behaviour. Hence, I test the unit root properties of the cnh_t and cny_t as well as of the additional variables used in this study in the next step. To this end, I apply the ADF unit root test, based on Dickey & Fuller (1979), and the Phillips & Perron (1988)'s unit root test allowing for a break in the series to all variables. The test results are presented in the following Table 1.[4]

Table 1: ADF unit root test results

Variables	Full sample	Appreciation	Stabilisation	Depreciation
cnh_t	-0.43	-1.99	-2.18	-1.21
cny_t	-0.27	-2.54	-2.34	-0.93
Δcnh_t	-13.08^{***}	-10.05^{***}	-6.53^{***}	-6.29^{***}
Δcny_t	-11.98^{***}	-10.25^{***}	-6.34^{***}	-5.74^{***}
$cnhbas_t$	-8.46^{***}	-6.71^{***}	-6.30^{***}	-4.60^{***}
$cnybas_t$	-5.21^{***}	-7.07^{***}	-3.44^{**}	-3.04^{**}
$mexp_t$	-10.13^{***}	-6.51^{***}	-5.37^{***}	-5.69^{***}
ΔVIX_t	-16.48^{***}	-11.86^{***}	-8.54^{***}	-7.32^{***}
$\Delta us10yr_t$	-14.38^{***}	-10.96^{***}	-7.23^{***}	-5.85^{***}
ect_t	-5.17^{***}	-4.03^{***}	-2.55	-3.05^{**}

Notes: The table reports the ADF unit root test results with a constant and fixed eight lags for the full sample and different subperiods. Critical values at 1%, 5% and 10% levels ADF are −3.44, −2.87, −2.57, respectively (H_0: nonstationarity).
*** Rejection of the null at the 1% significance level
** Rejection of the null at the 5% significance level
* Rejection of the null at the 10% significance level

The ADF as well as Phillips and Perron (PP) unit root test results show that the series cnh_t and cny_t contain a unit root, whereas there is no statistical evidence for unit root behaviour in their first differences, denoted by the variables Δcnh_t and Δcny_t, respectively. Moreover, the unit root test results indicate the rejection of the null hypothesis at all conventional significance levels for the additional variables.

According to Engle & Granger (1987), nonstationary series, which are integrated of order one, are cointegrated when the linear combination of these nonstationary series is stationary. In fact, the series cnh_t and cny_t do not reject the null hypothesis of unit root, whereas their difference, namely the error correction term ect_t, rejects the null of unit root indicating that the offshore and onshore renminbi spot rates are cointegrated. However, the methodology introduced by Engle & Granger (1987) assumes a linear cointegration relationship which is symmetric and continuously in place.

Although the unit root test results for the error correction term ect_t do not hint at a nonlinear process, the previous studies find some empirical evidence for an asymmetric behaviour of the CNH/CNY pricing differential. In fact, Craig et al. (2013) show that the CNH/CNY differential exhibits an asymmetric adjustment process using a threshold autoregressive model. Against this backdrop, Balke & Fomby (1997), Granger & Lee

[4] Phillips and Perron test results are in line with the ADF results. For brevity, they are not presented here, but are available from the author upon request.

(1989) and Seo (2006) emphasise that tests for linear cointegration may be misspecified if the adjustment toward long-run equilibrium is asymmetric.

Thus, I test for a nonlinear error correction mechanism in the adjustment process of the offshore and onshore renminbi rates toward their long-run equilibrium, considering Craig et al. (2013)'s findings on the asymmetric behaviour of the CNH/CNY differential. Based on the Enders & Granger (1998) threshold unit root test, the Enders & Siklos (2001) threshold cointegration test allows for an asymmetric adjustment process toward the long-run equilibrium. In this context, I assume a known cointegration vector and set it to $\beta' := (1, -1)$, relying on the law of one price. Therefore, I employ the Enders & Siklos (2001) threshold cointegration test on the CNH/CNY differential, which is the error correction term ect_t in this study, with an unknown threshold value. The TAR-type test statistic is $\phi^* = 27.23$, while the related critical value is 9.18 at the 1% significance level.[5] Accordingly, the threshold cointegration test results clearly reject the null hypothesis of no cointegration in favour of the alternative of a TAR-type adjustment process toward the long-run equilibrium.

3.2 The econometric methodology

This paper employs a three-regime threshold vector error correction model (TVECM) with additional variables for the empirical analysis of asymmetric arbitrage trading with the offshore and onshore renminbi spot rates.

Balke & Fomby (1997) introduced the threshold cointegration approach in order to model a discontinuous adjustment process toward the long-run equilibrium. In this modelling framework, the error correction term exhibits a threshold autoregressive process, as initially introduced by Tong (1983, 1990), which is only mean-reverting outside a predefined territory.[6] Since then, threshold models are widely used in finance literature to test the law of one price and investigate the resulting arbitrage opportunities. Among others, Tsay (1998) proposed a testing and modelling framework for multivariate threshold models and investigated the arbitrage possibilities with the S&P500 stock index spot and future contracts in the US. Lo & Zivot (2001) examined the nonlinear adjustment process of a wide range of tradable and nontradable goods in the US employing a three-regime Band-TVECM framework. Moreover, Hansen & Seo (2002) found evidence for a threshold effect in the term structure of interest rates with a two-regime threshold cointegration model. Furthermore, Sarno, Taylor & Chowdhury (2004) studied the mean-reverting properties of five major foreign exchange rates against the US dollar within a TAR-framework and found strong evidence for a nonlinear adjustment toward equilibrium value.

Against the background of the asymmetric nature of the adjustment process toward the long-run equilibrium of the CNH/CNY differential, this study employs the threshold cointegration approach introduced by Balke & Fomby (1997), considering an asymmetric error correction as emphasised by Granger & Lee (1989). The threshold cointegration model used in this paper is similar to the TVECM of Lo & Zivot (2001), which is based on the three-regime Band-TAR specification of Balke & Fomby (1997). The choice of

[5]The critical value for one lagged change and unknown threshold value for a TAR-type adjustment is taken from Enders & Siklos (2001).

[6]The reader is referred to the original work of Balke & Fomby (1997) for a more detailed overview of the different specifications of the threshold cointegration models.

this specification is also supported by Sarno et al. (2004), where the authors emphasise that the Band-TAR model is a more appropriate framework in the presence of costs associated with arbitrage trading. Moreover, I augment the TVECM with additional regime-dependent variables to examine the time-varying influence of external factors on the adjustment process of the offshore and onshore renminbi rates toward their long-run equilibrium.

As shown in Section 3.1, both renminbi rates cnh_t and cny_t contain a unit root, and there exists a nonlinear cointegration relationship between these two renminbi spot rates.[7] Although the threshold cointegration test does not make any suggestion on the number of possible thresholds and regimes, I use three regimes relying on the law of one price along similar lines to the empirical studies of Balke & Fomby (1997), Lo & Zivot (2001), Sarno et al. (2004) and Craig et al. (2013) among others. Accordingly, the three-regime TVECM used in this paper has the general form

$$\Delta y_t = \phi_0^j + \sum_{p=1}^{k} \Phi_p^j \Delta y_{t-p} + \sum_{q=0}^{l} \Gamma_q^j \Delta x_{t-q} + \Pi^j y_{t-1} + u_t^j \tag{1}$$

where y_t is the K-dimensional vector of the time series variable of interest. The term Δ stands for the differencing operator, which takes the first difference if not stated otherwise, and t is the time index. The upper index j refers to the number of regimes which are separated by $j-1$ thresholds. The vector of deterministic terms is denoted by ϕ_0^j and may include a constant and/or a time trend. With $\Pi^j = \alpha^j \beta'$ the factors α^j, β, Φ_p and Γ_q are the parameter matrices. The term $\sum_{p=1}^{k} \Phi_p^j \Delta y_{t-p}$ stands for p lags of dependent variables vector y_t multiplied by the $(K \times p)$ coefficient matrix Φ_p^j, while the term $\sum_{q=0}^{l} \Gamma_q^j \Delta x_{t-q}$ stands for q distributed lags of the additional regressors vector x_t multiplied by its $(K \times q)$ coefficient matrix Γ_q^j. The term $\alpha^j \beta' y_{t-1}$ is the long-run part of the model and is also referred to as the error correction term. The $(K \times r)$ matrix β is called the cointegration matrix with $rk(\beta) = r$ and $\beta' y_{t-1}$ represents the r linearly independent cointegration relationships. The other $(K \times r)$ matrix α^j, which is also called the loading matrix, contains the adjustment coefficients and has the rank r. The parameters in α^j describe how strong the variables in Δy_t respond to short-term deviations from cointegration relations in each regime. Since the rank of α and β are equal $rk(\alpha) = rk(\beta) = r$, the rank of the Π matrix, denoted as $rk(\Pi) = r$, is called the cointegration rank. In a K-dimensional model, it is expected that there are at most $K-1$ cointegration relationships. Finally, u_t^j is a vector containing the white noise error term of the time series with zero mean and positive definite covariance matrix $\sum_u$.

The model specification involves the lag order selection, the identification of the cointegration relationship as well as the estimation of threshold values. The optimal lag length of the TVECM is determined using information criteria. While AIC and HQ suggest a lag length of $p = 2$ for the VAR-part of the equation (1), BIC/Schwarz information criteria suggest only one lagged dependent variable for the estimation. The estimation covering the full sample has been run with two lags of the dependent variables, while

[7] As the offshore and onshore renminbi rates fundamentally represent the same financial product, they should be driven by the same mechanism regarding the law of one price. Thus, the cointegration relationship is assumed to be known, which is also confirmed by the threshold cointegration test results presented in Section 3.1.

the lag length is settled down to $p = 1$ during the estimations for the subperiods as the second order lags of the dependent variables were mainly not statistically significant. Moreover, no lagged values of the additional variables are added into estimations to avoid over-parameterisation of the model. Furthermore, the cointegration vector β is assumed to be known and set to $\beta' := (1, -1)$ relying on the law of one price. Confirming the economic theory, the Enders & Siklos (2001) threshold cointegration test results hint at a TAR-type adjustment process of the offshore and onshore renminbi spot rates toward their long-run equilibrium.

Overall, this paper follows the model building procedure proposed by Tsay (1989, 1998) for multivariate threshold models. First, the lag order of the VAR-part is set to 1 according to BIC/Schwarz information criteria. The second step involves the selection of the delay parameter d of the threshold series ect_{t-d}. In this regard, this paper takes the error correction term as the threshold variable considering the specific characteristics of the CNH/CNY markets and the related literature on the law of one price. Therefore, this paper implicitly assumes that the delay parameter is equal to one $d = 1$. This is also partly confirmed by Tsay's arranged regression test as $d = 1$ maximizes the F-statistic in some specifications. Then, the location of the threshold values could be estimated using a grid search conditional on the lag order $p = 1$ and the delay parameter $d = 1$.

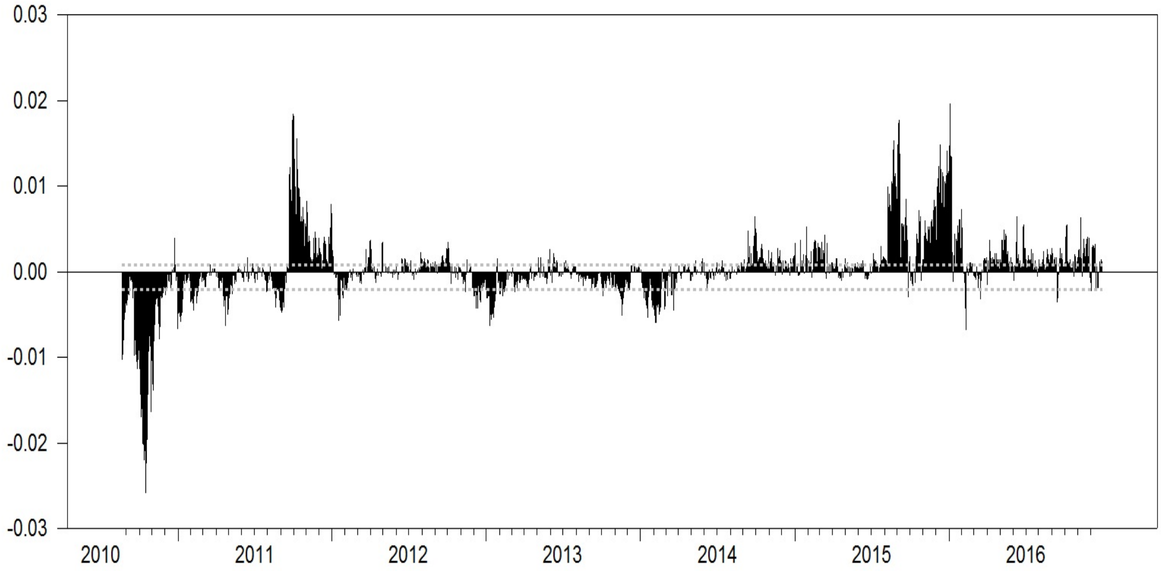
In this context, the relevant procedure is to search over the potential threshold values which minimise the sum of squared residuals from the fitted model.[8] The interval for possible threshold values lying in the middle 70% of the arranged values of the error correction term is equal to $[-0.0021; 0.0024]$ for both the lower and the upper threshold, denoted by τ_l and τ_u, respectively. Against this backdrop, I run the grid search for $\tau_l \in [-0.0021; 0.0000]$ and $\tau_u \in [0.0000; 0.0024]$ in order to ensure a lower and an upper threshold similar to the related studies. Finally, the values for lower and upper thresholds are estimated using the grid search method using 200 points on each interval and $d = 1$. The grid search results in the lower threshold $\tau_l = -0.0021$ and in the upper threshold $\tau_u = 0.0008$.

Figure 2 illustrates the error correction term and both empirically estimated thresholds as well as the three-regimes of the TVECM. The negative values of the error term refer to times in which the offshore rate is appreciated against the onshore rate, whereas positive deviations indicate periods with a depreciated offshore rate against its onshore counterpart. Accordingly, the lower regime corresponds to the negative range for the $ect_t < \tau_l$, the middle regime is the territory between the two thresholds defined as $\tau_l \leq ect_t \leq \tau_u$ and the upper regime refers to the area with $ect_t > \tau_u$. The middle regime presents the range in which arbitrage is not profitable and hence the error correction mechanism remains inactive in this regime. Accordingly, the middle regime is referred to as the "band of inaction", "arbitrage band and/or transaction cost band" and "no-arbitrage" band by Taylor (2001), Sarno et al. (2004) and Craig et al. (2013), respectively. Throughout this paper, I mostly use the term "no-arbitrage" band (corridor) to refer to the middle regime.

Moreover, Figure 2 shows that the lower and upper thresholds are not symmetric. The upper threshold is much smaller than the lower threshold in absolute terms. This indicates that the error correction process starts at relatively smaller deviations in positive territory

[8] Chan (1993) shows that this approach produces strongly consistent threshold estimates. The reader is referred to Tsay (1998) and Hansen (2000) for a comprehensive discussion of the threshold estimation methods.

Figure 2: Error correction term & no-arbitrage-band



Sources: Bloomberg, author's own calculations.
Notes: Black bars plot the error correction term ect_t. The lower threshold $\tau_l = -0.0021$ and the upper threshold $\tau_u = 0.0008$ are denoted with dashed grey lines. Accordingly, the lower, middle and upper regime has 249, 852 and 557 observations corresponding to 15%, 51% and 34% of the data, respectively.

compared to negative territory, where deviations have to be much larger in absolute terms to be corrected. The asymmetric threshold values are consistent with Craig et al. (2013), who also find a similar asymmetry in the no-arbitrage band for the CNH/CNY differential noting, that the width of the no-arbitrage band may be subject to changes due to a different sample period, varying transaction costs and ongoing institutional reforms on the renminbi markets. Similarly, Sarno et al. (2004) also find different threshold values for various foreign exchange rates and relate these variations to different transaction costs. However, Tsay (1998) emphasises that the estimated threshold values are not identified only by transaction costs. Thus, the threshold values may also encompass other economic factors and costs linked to the arbitrage trading. Therefore, I characterise all the costs associated with the arbitrage trading as arbitrage costs, along similar lines to Sarno et al. (2004).

Against the background of distinctive market conditions and different factors influencing the two renminbi markets, empirically estimated threshold values seem to define the regimes reasonably well.

3.3 Estimation results

The previous section briefly introduced the general form of a threshold vector error correction model. Specifically, the three-regime TVECM used during the empirical analysis takes the following form

$$\Delta y_t = \begin{cases} \phi_0^l + \sum_{p=1}^{k} \Phi_p^l \Delta y_{t-p} + \sum_{q=0}^{l} \Gamma_q^l x_{t-q} + \alpha^l ect_{t-1} + u_t^l & \text{if } ect_{t-1} < \tau_l \\ \phi_0^m + \sum_{p=1}^{k} \Phi_p^m \Delta y_{t-p} + \sum_{q=0}^{l} \Gamma_q^m x_{t-q} + \alpha^m ect_{t-1} + u_t^m & \text{if } \tau_l \leq ect_{t-1} \leq \tau_u \\ \phi_0^u + \sum_{p=1}^{k} \Phi_p^u \Delta y_{t-p} + \sum_{q=0}^{l} \Gamma_q^u x_{t-q} + \alpha^u ect_{t-1} + u_t^u & \text{if } \tau_u < ect_{t-1} \end{cases} \quad (2)$$

where $\Delta y_t = (\Delta cnh_t, \Delta cny_t)'$ is the vector of the first differenced series for the log offshore and onshore renminbi rates, respectively. As in equation (1), ϕ_0^j is the vector of the constant terms in each regime and the term $\sum_{p=1}^{k} \Phi_p^j \Delta y_{t-p}$ stands for p lags of dependent variables vector y_t multiplied by the $(K \times p)$ coefficient matrix Φ_p^j, while the term $\sum_{q=0}^{l} \Gamma_q^j x_{t-q}$ stands for q distributed lags of the additional explanatory variables vector x_t multiplied by its $(K \times q)$ coefficient matrix Γ_q^j in each regime. Moreover, the term z_{t-1} is the threshold series and represents the error correction term $ect_{t-1} = (cnh_{t-1} - cny_{t-1})$ in this model assuming a known cointegration vector of $\beta' := (1, -1)$. As mentioned before, u_t^j is the error vector of each regime and the upper index $j = l, m, u$ refers to different regimes in which the model is estimated.

Throughout this empirical analysis, a TVECM is estimated with one lag, based on the information criteria, additional explanatory variables and one cointegration relationships as adding a stationary variable into the model does not raise any suspicion of further cointegration relationships. Moreover, the threshold values are estimated empirically with the grid search method. Table 2 and Table 3 show the coefficient estimates of the threshold models with additional variables in the three regimes over the full sample and in three subperiods, respectively. The superscripts l, m and u correspond to the equations in the lower, middle and upper regime, respectively. While the lag length is increased to $p = 2$ to avoid autocorrelation problems in the full sample estimation, the multivariate Q-statistics do not indicate any autocorrelation in the standardised residuals at any significance level and underscore that one lag is able to eliminate autocorrelations during estimations in the subperiods. However, an LM-test for a multivariate ARCH effect hints at remaining conditional heteroscedasticity in the standardised residuals. Given the high frequency of the data, conditional heteroscedasticity is not surprising in daily time series of foreign exchange rates. Hence, the model estimations are performed with heteroscedasticity-robust standard errors. Overall, the estimated TVECM model appears to be well specified for the offshore and onshore renminbi rates' return dynamics.

Table 2 presents the results of the coefficient estimates in three regimes over the full sample from August 2010 to December 2016. The estimation results of the lower regime are shown in columns Δcnh_t^l and Δcny_t^l for the offshore and onshore renminbi rates, respectively. The coefficient estimates for the directional market expectations for both renminbi rates are slightly positive and significant. By contrast, the coefficient estimates for global risk sentiment, local liquidity on the onshore market and the global liquidity proxy are only significant for the offshore rate. Moreover, the insignificant α-coefficients show that neither the offshore nor the onshore rate does adjust toward the long-run equilibrium leaving the arbitrage opportunities not capitalised. In the middle regime, referred to as the no-arbitrage band, the error correction mechanism due to arbitrage trading remains inactive as the insignificant α_{cnh}^m coefficient confirms. In addition, the coefficients of the global risk sentiment and of the market expectations are significant for

Table 2: Full sample estimation results of the three-regime TVECM

	Lower Regime		Middle Regime		Upper Regime	
	Δcnh_t^l	Δcny_t^l	Δcnh_t^m	Δcny_t^m	Δcnh_t^u	Δcny_t^u
$constant$	−0.0001	−0.0001	0.0001	0.0000	0.0000	0.0000
	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
Δcnh_{t-1}	0.1852**	0.2190**	0.0927	0.2376***	−0.0347	0.0730*
	(0.0928)	(0.1043)	(0.0698)	(0.0594)	(0.0861)	(0.0432)
Δcny_{t-1}	0.0046	−0.2346**	0.0104	−0.1971***	0.1129	0.0314
	(0.1307)	(0.1112)	(0.0851)	(0.0597)	(0.1145)	(0.0787)
Δcnh_{t-2}	−0.0244	0.0142	−0.0212	0.0379	0.0536	0.0835**
	(0.1048)	(0.0599)	(0.0528)	(0.0440)	(0.0941)	(0.0385)
Δcny_{t-2}	−0.1877	−0.1907	−0.0063	−0.0781*	−0.0321	−0.1475**
	(0.1194)	(0.1232)	(0.0544)	(0.0462)	(0.1306)	(0.0575)
$cnhbas_t$	0.0191	−0.0014	−0.0165	−0.0083	0.0560**	0.0049
	(0.0141)	(0.0086)	(0.0156)	(0.0128)	(0.0237)	(0.0122)
$cnybas_t$	0.0509*	0.0489	0.0117	−0.0002	0.0232	0.0755***
	(0.0272)	(0.0361)	(0.0267)	(0.0191)	(0.0305)	(0.0240)
$mexp_t$	0.0002*	0.0002**	0.0002***	0.0001***	0.0002**	0.0001*
	(0.0001)	(0.0001)	(0.0000)	(0.0000)	(0.0001)	(0.0001)
Δvix_t	0.0059***	0.0020	0.0019***	−0.0004	0.0043***	0.0018**
	(0.0017)	(0.0014)	(0.0007)	(0.0005)	(0.0016)	(0.0009)
$\Delta us10yr_t$	0.0125*	0.0030	0.0023	−0.0006	−0.0002	0.0002
	(0.0069)	(0.0044)	(0.0030)	(0.0019)	(0.0051)	(0.0030)
ect_{t-1}	−0.0083	0.0192	0.0015	0.1085**	−0.0939*	0.0157
	(0.0456)	(0.0230)	(0.0606)	(0.0474)	(0.0513)	(0.0263)
$Q(5)$	28.73					
	[0.09]					

Notes: The full sample covers the period from 25 August 2010 to 30 December 2016. Heteroscedasticity-consistent standard errors are given in parentheses below the coefficient estimates. $Q(p)$ denotes the multivariate Hosking (1981) test for p^{th} order serial autocorrelation in standardised residuals. The related p-values are reported in brackets.

*** Significant at the 1% level
** Significant at the 5% level
* Significant at the 10% level

the offshore rate within the no-arbitrage band. While the onshore spot rate is affected by the directional market expectations, a significant α_{cny}^m coefficient is rather unexpected within the no-arbitrage band. This might be partly explained by the PBoC's interventions in the CNY market to keep the onshore spot rate within a narrow trading band around its fixing rate. Furthermore, the estimation results for the upper regime which refers to the period in which the offshore renminbi spot rate is depreciated against its onshore counterpart are presented in the last two columns of the Table 2. The coefficient estimates for the upper regime point to an asymmetric adjustment process of the offshore rate toward its long-run equilibrium with the onshore rate, as the $\alpha_{cnh}^u = -0.0903$ is significant, whereas the α_{cny}^u coefficient remains insignificant in the upper regime. Moreover, the additional explanatory variables, such as market expectations and global risk sentiment, which may drive arbitrage trading are significant in the upper regime for the offshore rate. This indicates that the arbitrage opportunities arising from a depreciated offshore rate are rapidly capitalised regardless of other factors affecting both offshore and onshore renminbi spot rates.

Overall, the estimated three-regime TVECM is able to capture a significant part of the nonlinear adjustment process of the offshore and onshore renminbi rates toward their long-run equilibrium, while additional regime-dependent explanatory variables find evidence for time-varying driving forces behind the error correction mechanism in different regimes. Moreover, slightly different coefficient estimates for fundamental variables like $mexp_t$, Δvix_t, $cnhbas_t$, $cnybas_t$ and $\Delta us10yr_t$ among the lower and upper regime may also hint at the time-varying relevance of the directional expectations, contagion, liquidity conditions on the offshore and onshore markets as well as global liquidity in the adjustment process of the CNH towards its long-term equilibrium with its onshore counterpart.

This paper focuses on possible arbitrage trading and the time-varying drivers behind the nonlinear adjustment process of the offshore and onshore renminbi spot rates toward their long-run equilibrium value in times of remarkable appreciation/depreciation expectations regarding the renminbi. In this regard, the coefficient estimates in the lower and upper regime in appreciation and depreciation periods are of particular interest. However, the full sample covers three periods with different characteristics. While the first period exhibits a long lasting appreciation trend, both renminbi rates depreciated remarkably in the latter period, mainly driven by the changing market expectations regarding the Chinese currency. These trends may cause appreciation/depreciation pressure on the spot markets and hence affect the adjustment process of the mispriced spot rate toward the long-run equilibrium, leading to more asymmetry in arbitrage trading. Against this backdrop, I focus on three different subsamples and investigate the adjustment process of both renminbi rates toward their long-run equilibrium under appreciation/depreciation pressure.

Table 3 presents the coefficient estimates of the three-regime TVECM's over three different subsamples denoted as appreciation, stabilisation and depreciation periods, respectively. Considering the potential impact of the appreciation/depreciation pressure on the adjustment process of the renminbi the coefficient estimates in the first and the latter period are of particular interest.[9]

Arbitrage trading

As presented in Table 2 and 3, the estimates of the adjustment coefficients suggest a stronger error correction in the upper regime than in the lower regime. The error correction coefficients α^u_{cnh} in the upper regime are significantly larger - in absolute terms - than their counterparts α^l_{cnh} in the lower regime over the full sample as well as across appreciation and stabilisation periods, respectively. In the first subsample, which is referred to

[9]Recent studies such as Craig et al. (2013), Hui, Wong & Li (2013), Gagnon & Troutman (2014), Funke et al. (2015) and Shu et al. (2015), among others, investigate the characteristics of both offshore and onshore spot markets as well as the resulting factors influencing the CNH/CNY pricing differential in a comprehensive range. However, these studies mostly use a sample size extending up to late 2013. Thus, the comparison of the results of recent studies to those of this paper is based on the estimation results of the first subsample corresponding to the appreciation period considered in this study.

Table 3: Estimation results of the three-regime TVECMs in subperiods

	Appreciation Period						Stabilisation Period						Depreciation Period					
	Δcnh_t^l	Δcny_t^l	Δcnh_t^m	Δcny_t^m	Δcnh_t^u	Δcny_t^u	Δcnh_t^l	Δcny_t^l	Δcnh_t^m	Δcny_t^m	Δcnh_t^u	Δcny_t^u	Δcnh_t^l	Δcny_t^l	Δcnh_t^m	Δcny_t^m	Δcnh_t^u	Δcny_t^u
$constant$	−0.0003	−0.0004***	0.0000	0.0000	−0.0004	−0.0001	0.0014*	0.0017***	−0.0001	−0.0002*	−0.0001	−0.0001	0.0000	0.0033	0.0009***	0.0003	0.0002	−0.0004
	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0003)	(0.0002)	(0.0008)	(0.0006)	(0.0002)	(0.0001)	(0.0004)	(0.0003)	(0.0004)	(0.0021)	(0.0003)	(0.0002)	(0.0004)	(0.0003)
Δcnh_{t-1}	0.0976	0.0823	−0.0432	0.1242**	−0.1086	−0.0600	−0.0634	−0.1792	0.1592*	0.3187***	0.0655	0.2747***	1.2370***	1.4839*	0.2112	0.2323*	−0.0144	0.0765
	(0.0924)	(0.0718)	(0.0720)	(0.0571)	(0.1886)	(0.0601)	(0.1985)	(0.1359)	(0.0932)	(0.1047)	(0.1228)	(0.0740)	(0.1207)	(0.8589)	(0.1314)	(0.1248)	(0.0773)	(0.0506)
Δcny_{t-1}	0.1364	−0.1680*	0.2053***	−0.1055*	−0.3152**	−0.1019	0.2754	0.2355*	−0.0355	−0.1805	−0.1499	−0.3647***	−0.3578***	−0.5202**	−0.1669	−0.2370**	0.2431**	0.1209
	(0.1488)	(0.0949)	(0.0677)	(0.0637)	(0.1532)	(0.0812)	(0.1751)	(0.1217)	(0.1140)	(0.1184)	(0.1664)	(0.1053)	(0.0272)	(0.2315)	(0.1330)	(0.1036)	(0.1235)	(0.0851)
$cnhbas_t$	0.0300**	0.0074	−0.0204	−0.0306**	0.0791	0.0266	−0.1806*	−0.1174*	0.1040**	0.0727	0.1801*	0.0386	−0.0182**	0.2727**	−0.0279	−0.0058	0.0493*	0.0070
	(0.0141)	(0.0093)	(0.0176)	(0.0123)	(0.0663)	(0.0255)	(0.1024)	(0.0610)	(0.0509)	(0.0494)	(0.0975)	(0.0635)	(0.0079)	(0.1063)	(0.0458)	(0.0368)	(0.0253)	(0.0155)
$cnybas_t$	0.0739*	0.1559***	0.0108	−0.0017	0.0208	0.0933	−0.2800***	−0.3215**	0.0781	0.0919	0.0902	0.1121	0.1514***	0.2421*	−0.0281	−0.0255	−0.0108	0.0854***
	(0.0380)	(0.0297)	(0.0142)	(0.0099)	(0.1302)	(0.1079)	(0.0436)	(0.1350)	(0.0731)	(0.0657)	(0.0760)	(0.0797)	(0.0130)	(0.1292)	(0.0490)	(0.0407)	(0.0463)	(0.0326)
$mexp_t$	0.0003*	0.0002**	0.0001**	0.0001**	0.0004**	0.0001	0.0003	0.0003	0.0002***	0.0001**	0.0002	0.0002*	−0.0015***	0.0022	0.0002	0.0002	0.0000	0.0000
	(0.0001)	(0.0001)	(0.0001)	(0.0000)	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0014)	(0.0002)	(0.0002)	(0.0002)	(0.0001)
Δvix_t	0.0080***	0.0028*	0.0015**	0.0000	0.0032	−0.0007	0.0027	−0.0025	0.0016	−0.0009	0.0042***	0.0002	−0.0348***	0.0074	0.0046	−0.0018	0.0034	0.0022*
	(0.0021)	(0.0015)	(0.0007)	(0.0005)	(0.0025)	(0.0013)	(0.0025)	(0.0024)	(0.0013)	(0.0011)	(0.0014)	(0.0012)	(0.0024)	(0.0278)	(0.0034)	(0.0025)	(0.0024)	(0.0012)
$\Delta us10yr_t$	0.0153**	0.0037	−0.0026	−0.0028	0.0056	0.0064	0.0189*	0.0049	0.0036	−0.0018	0.0013	0.0011	−0.0692***	0.0063	0.0242**	0.0141	−0.0008	−0.0016
	(0.0075)	(0.0046)	(0.0036)	(0.0019)	(0.0075)	(0.0041)	(0.0097)	(0.0117)	(0.0045)	(0.0036)	(0.0063)	(0.0028)	(0.0068)	(0.0627)	(0.0117)	(0.0096)	(0.0087)	(0.0045)
ect_{t-1}	−0.0227	0.0027	−0.0946	−0.0032	−0.1378**	−0.0438	−0.0383	0.1275	0.1144	0.3409***	−0.3504***	−0.0342	−0.0835***	0.9914***	−0.0782	0.1577	−0.0843	0.0617*
	(0.0455)	(0.0186)	(0.0649)	(0.0497)	(0.0592)	(0.0335)	(0.1990)	(0.1351)	(0.1355)	(0.1071)	(0.1070)	(0.0880)	(0.0305)	(0.3478)	(0.3151)	(0.2465)	(0.0737)	(0.0371)
$Q(5)$	19.71						28.30						28.28					
	[0.48]						[0.10]						[0.10]					

Notes: Appreciation period covers the sample from 25 August 2010 to 30 December 2013, stabilisation period from 1 January 2014 to 10 August 2015 and depreciation period from 11 August 2015 to 30 December 2016, in which a dummy captures the shift on 11 August 2015 due to a devaluation of the renminbi by the PBoC. Heteroscedasticity-consistent standard errors are given in parentheses below the coefficient estimates. $Q(p)$ denotes the multivariate Hosking (1981) test for p^{th} order serial autocorrelation in standardised residuals. The related p-values are reported in brackets.

*** Significant at the 1% level

** Significant at the 5% level

* Significant at the 10% level

as the appreciation period, the error correction mechanism is only in place in the upper regime as the adjustment parameter α^{l}_{cnh} is statistically not significant at any conventional significance level in the lower regime. An inactive adjustment process within the no-arbitrage band is consistent with the arbitrage trading literature, whereas the inactive error correction mechanism in the lower regime is rather unexpected and new compared to the findings of related studies. While this may be partly explained by the limited capital outflows from mainland China to the offshore markets which is needed to monetise the arbitrage opportunities due to a CNH appreciation, the overall appreciation pressure on the renminbi favours monetising the arbitrage of a relatively weaker offshore spot rate. Against this backdrop, the arbitrage opportunities arising from a depreciated offshore rate are rapidly capitalised on in the upper regime, whereas restrictive capital controls and market expectations of a rising renminbi leave the arbitrage possibilities due to a weaker onshore rate unexploited in the lower regime during the appreciation period. However, the direction of the arbitrage trading reverses with the changing market expectations regarding the renminbi.[10] During the depreciation period, the error correction term of the offshore rate turns insignificant, whereas the α^{u}_{cny} becomes significant for the appreciated onshore rate in the upper regime. Given the depreciation pressure, this may be explained by the fact that the market participants regard the stronger onshore rate as mispriced and expect it to adjust toward its weaker offshore counterpart. In addition, the speed of adjustment of the onshore rate remains slower than the adjustment of the offshore rate during the appreciation period as the onshore fixing rate and the narrow trading band on the CNY market weigh on the speed of arbitrage trading. Overall, the arbitrage possibilities in the lower regime remain poorly capitalised, whereas appreciation/depreciation pressure plays an important role in the direction of the arbitrage trading. Otherwise, the adjustment process of the two rates toward their equilibrium is driven by economic factors in the absence of arbitrage trading. For this reason, the focus has been shifted to the time-varying driving factors behind the asymmetric adjustment process of the offshore (onshore) renminbi towards its long-run equilibrium with the CNY (CNH).

Local liquidity conditions

As already emphasised by the related studies, the cross-border capital flows between mainland China and the offshore RMB markets remain the main source of liquidity on the CNH markets in spite of the widening range of offshore renminbi products with the capital flows from the offshore market to the mainland being less restrictive than those in the opposite direction. Against this background, the estimation results show that the liquidity conditions on both offshore and onshore renminbi markets mostly play an important role for an appreciated offshore rate, whereas both bid-ask spreads mainly remain insignificant for the appreciated onshore rate in the upper regime across all subsamples. As low liquidity can result in sharp movements in asset prices, the positive signs of the bid-ask spreads indicate that the appreciation of the CNH against its onshore counterpart is

[10] During the stabilisation period, α^{m}_{cny} becomes significant in the middle regime, which is rather unexpected. In March 2014 the PBoC widened the trading band of the onshore rate from $\pm 1\%$ to $\pm 2\%$ around its fixing, leading to larger fluctuations on the onshore markets. Against this backdrop, the PBoC's efforts to stabilise the renminbi around its fixing with interventions in the onshore market may help to explain the significant error correction term for the onshore rate in the middle regime.

amplified due to low liquidity on the offshore spot market in times of appreciation pressure on the Chinese currency.

Global liquidity

In addition to the local liquidity conditions, this paper also tries to examine the impact of global liquidity on the adjustment process on the offshore and onshore markets. In an earlier study, Reinhart & Khan (1995) already note that capital flows from developed economies to emerging markets may result in stronger currencies in the target economies. However, it is not straightforward to measure global liquidity.[11] Similar to Funke et al. (2015), this paper also uses the 10-year US Treasury bond yields as an indicator for the global liquidity. The coefficient estimates in Table 2 and 3 show that only the offshore renminbi spot rate is affected by the changes in global liquidity rather than the onshore rate. Given the interpretation of increasing US interest rates as a proxy for tightening global liquidity conditions, the positive sign of the $\Delta us10yr_t$ coefficient in the lower regime indicates that decreasing global liquidity leads to depreciation of the offshore rate when it is overvalued relative to its onshore counterpart. However, Gagnon & Troutman (2014) and Funke et al. (2015) do not find clear results on the impact of global liquidity conditions on the offshore and onshore markets. The mixed results may be explained by the fact that only the offshore rate is influenced by global liquidity mostly in the lower regime, which counts for 15% (23%) of the data considered in this study (of the data in the appreciation period which covers a similar period to these recent studies).

Global risk sentiment

The offshore renminbi markets are mostly liberalised and accessible by all entities outside mainland China. This, however, makes the offshore renminbi market more sensitive to global factors, whereas the CNY is traded within a trading band around its fixing in mainland China, shielding the onshore rate from large fluctuations due to external factors. Accordingly, global risk sentiment, captured with the VIX Index, has a significant impact on the offshore rate. By contrast, the effect of changes in global risk sentiment on the onshore rate remain quite muted over different subperiods. This is also consistent with the findings of previous studies.

Return spillovers

The estimation results show that the coefficients of the first lag of offshore renminbi returns are significant for the onshore returns. This may hint at a positive return spillover from the offshore to the onshore renminbi markets across all regimes, confirming the increasing influence of the offshore rate on its onshore counterpart as already mentioned by Cheung & Rime (2014). While making the onshore market more prone to changes in the offshore markets and global market dynamics, this may be partly considered as an outcome of China's financial market liberalisation policies.

[11] Committee on Global Financial System (2011) provides a comprehensive review of various price- and quantity-based global liquidity measures.

Directional market expectations

Against the background of ongoing policy measures to internationalise the renminbi, a causal interpretation of market expectations may be not straightforward on the offshore and onshore renminbi markets. In this regard, the dynamics of RMB forward rates and risk reversal can be also considered as the outcome of changing market segmentation caused by gradual institutional changes. For this reason, a dummy variable for the directional expectations of the RMB is constructed based on the three-month CNY risk reversal in order to quantify the directional market expectations of the renminbi.[12] The estimation results show that the offshore rate mostly responds more strongly to directional expectations than its onshore counterpart as the daily trading band may limit the fluctuations of the CNY around its fixing rate. Moreover, outside the no-arbitrage band, market expectations appear to play - albeit only marginally - a more important role for a weaker offshore rate than in the lower regime in which the offshore rate is overvalued relative to its onshore counterpart during the appreciation period.

In summary, arbitrage opportunities due to a relatively depreciated CNH are rapidly monetised regardless of other factors influencing the two renminbi rates during the appreciation period, whereas arbitrage trading drives the adjustment of a stronger CNY toward the CNH during the depreciation period. In the absence of arbitrage trading, the adjustment process of both rates is mainly determined by external factors such as directional expectation, global risk sentiment, liquidity conditions on the two renminbi markets as well as changes in global liquidity.

4 Conclusion

This study takes a closer look at the asymmetric adjustment process and the time-varying driving forces behind the error correction mechanism on the offshore and onshore renminbi markets in the presence of remarkable appreciation and depreciation expectations regarding the Chinese currency.

To this end, I built a parsimonious three-regime TVECM with additional factors influencing the offshore and onshore renminbi rates. While I relied on the findings of the previous studies in the selection of the additional variables, I did not consider the ongoing institutional reforms related to China's policies on renminbi internationalisation, unlike the related literature. Hence, I only gave a brief overview of the distinctive conditions on the two renminbi spot markets which may have a direct impact on arbitrage trading. Then, I described the data used in the empirical analysis and tested the two renminbi spot rates' long-run equilibrium within a threshold cointegration framework. After identifying the no-arbitrage corridor empirically, I selected additional variables and estimated the TVECM with three-regimes over three periods with different market dynamics as a final step.

The estimation results show that the threshold model is able to capture a substantial part of the nonlinearities in the adjustment process and find significant evidence for time-varying driving forces behind the error correction mechanism on the offshore and onshore renminbi spot rates. Overall, the findings of this paper are mainly consistent

[12] In this regard, Craig et al. (2013) use the $3m$ CNY risk reversal index to capture the changes in investors' expectations regarding the RMB direction.

with those of the related studies. However, the new empirical findings related to the direction of arbitrage trading and the time-varying influence of external factors on the adjustment process may have some important implications for practitioners, especially for those seeking to monetise the arbitrage opportunities on the offshore and onshore renminbi markets. In particular, the estimation results indicate that directional expectations, global risk sentiment, and local as well as global liquidity conditions dominate the adjustment process in the lower regime as arbitrage opportunities cannot be monetised, whereas the error correction mechanism of the CNH (CNY) toward its equilibrium with the onshore (offshore) rate is driven by the monetising of arbitrage trading in the upper regime in times of appreciation (depreciation) pressure.

In this paper, I tried to shed light on the asymmetries in arbitrage trading on the offshore and onshore renminbi spot markets. However, this study focuses only on the first moment dynamics of the two renminbi spot rates. An interesting extension would be to analyse the return and volatility linkages between the two spot markets within a multivariate VECM GARCH framework. Last but not least, using the estimated three-regime TVECM to forecast the arbitrage opportunities in the sense of Huber (2015) can also deliver valuable insights on the timing of arbitrage. However, these possible extensions are left for further research on the offshore and onshore renminbi markets.

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