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Spillover effect of the RMB and Non-USD currencies after the COVID-19 pandemic: Evidence captured from 30-minute high frequency data

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\textbf{ARTICLE INFO}

\textbf{Keywords:}
COVID-19 pandemic
RMB internationalization
Spillover effect
VAR-BEKK-GARCH
Non-USD currencies
RMB independence

\textbf{A B S T R A C T}

Amid the faster- and wider-than-expected spread of COVID-19, which has added new twists to the global economic outlook and profoundly impacted the performance of major currencies around the world, the RMB has been performing well, and thus, its market standing has improved. However, uncertainties about the future pose enormous challenges to the RMB internationalization. By processing 30-min high-frequency data, this paper aims to study changes in the characteristics of the relationship between the RMB and other non-USD currencies at five stages of the pandemic, first by means of auxiliary regression analysis, in which the pandemic is accounted for with a dummy variable, and then with a VAR-BEKK-GARCH model. The research shows that since the latter stages of the global pandemic, significant negative spillover effects among major non-USD currencies can be observed, while the independence of offshore RMB has increased gradually, and there have been weakening trends in the sustainability of the mean spillover and volatility spillover effects among other currencies. As the “regular pandemic prevention and control” begins to take hold in China and the geopolitical uncertainty increasingly outbreaks, the top priority in global currency market should be to resist the pressure of RMB independence with policy changes and increase caution in investing RMB assets.

1. Introduction

COVID-19 has spread worldwide since February 2020; as of 12 September 2022, the number of confirmed cases worldwide had reached over 608 million and of confirmed deaths over 6 million.\textsuperscript{1} The faster- and wider-than-expected spread of COVID-19 has also profoundly impacted the performance of currencies around the world, with conventional safe-haven assets losing their margin of safety due to market panic and the fluctuations in the dollar index at high levels placing downward pressure on emerging market economies’ currencies. Both the short-term shock to the foreign exchange market brought on by market panic and the impact of the continuing spread of COVID-19 overseas on the orders of export-oriented enterprises have disturbed the fundamentals of cross-border capital to

\textsuperscript{1} Data source: World Health Organization. WHO Coronavirus (COVID-19) Dashboard | WHO Coronavirus (COVID-19) Dashboard with Vaccination Data.

https://doi.org/10.1016/j.iref.2022.11.019

Received 20 December 2021; Received in revised form 2 October 2022; Accepted 16 November 2022
Available online 23 November 2022
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varying degrees and increased the risk of exchange rate volatility. The RMB (Renminbi)’s performance during the pandemic can be divided into four stages. In the first stage, rapid spread of the novel coronavirus at home caused the global risk appetite to drop, and the exchange rate of the RMB against the US dollar rose to 7.04 from 6.84. Then, with the continuous fall in the number of confirmed infections, significant recovery of domestic risk appetite, periodic inflow of foreign investments and increased holdings of RMB assets, the RMB against non-USD currencies stabilized. In the second stage, the continuous spread of the pandemic overseas and plummeting oil prices led to tightening dollar liquidity, and the rising dollar index caused passive devaluation of the RMB against the dollar, with the exchange rate reaching 7.12 on March 23, but exchange rates of the RMB against non-USD currencies remained strong, and the CFETS RMB index rose to a high 95.7 at one point. In the third stage, the widespread of the pandemic in other countries caused the pandemic to spiral out of control, countries adopted closure policies and foreign trade was severely affected. At the same time, the development of a vaccine and the stabilisation of the pandemic in China led to a period of continuous appreciation of the RMB. In the fourth stage, the virus mutation further aggravated the pandemic worldwide, while the ongoing pandemic prevention policies put enormous pressure on the world’s economic development. At the same time, the Russia-Ukraine conflict further fragmented the world economy and the RMB continued to depreciate.

To date, there has been much empirical research on the characteristics of the relationship between RMB and non-USD currencies in the context of the pandemic, and micro changes in the relationship characteristics are of great value for preventing risks in the course of accelerating RMB internationalization. Beginning with the spread of the COVID-19 pandemic, some scholars have explored the relationship between the COVID-19 pandemic and exchange rate fluctuations. Narayan (2021) found increased bubble activity in the exchange rates of the Japanese yen, Canadian dollar, Euro and British pound during COVID-19. Konstantakis, Melissaropoulos, Daglis, and Michaelides (2021) analysed currency exchange rate fluctuations, stock indices and commodity prices before and after Covid-19 through spectral non-causality tests, and Markov-switching model with two regimes. The result show that the COVID-19 pandemic significantly changed the determinants of the euro to dollar exchange rate, and the exchange rate volatility of the euro against the dollar during the COVID-19 period was significantly higher than before the COVID-19. Jamal and Bhat (2022) used a panel ARDL model to analyse the impact of COVID-19 deaths and exchange rates in China, India, Brazil, Italy, Turkey, and the United Kingdom, and found that an increase in COVID-19 deaths would depreciate the exchange rates of the sample countries. Tommaso Aquilante, Di Pace, and Masolo (2022) used daily panel VARs for 57 countries under floating and non-floating exchange rate regimes to examine the impact of Covid-19 news on exchange rates, and found that negative news of the virus at the country level immediately leads to a significant depreciation of the national currency against a trade-weighted basket of currencies, and this effect is more pronounced in economies with floating exchange rate regimes.

There are few studies exploring the impact of COVID-19 on the spillover effect of RMB. Wei, Luo, Huang, and Guo (2020) constructed the spillover index of emerging currency market systems in “One Belt, One Road” countries, and analysed the participating currencies such as RMB since the “One Belt One Road” initiative was launched and had time-varying dynamic effects. It was found that the influence of the renminbi has been weakened by the blow of the COVID-19 pandemic. Hence, it is of great immediate significance and necessity to study the spillover effects between the RMB and other currencies of Non- “One Belt, One Road” countries during the different stages of the pandemic. This paper aims to investigate whether the pandemic has changed the characteristics of the relationship between the RMB and non-USD currencies on the basis of 30-min high-frequency data and to propose ideas and suggestions with regard to the impact of the complexity and continuity of such changes on the process of RMB internationalization.

This paper makes the following marginal contributions: (1) Unlike other works that confine themselves to studying the regional influence of a currency, this paper selects the RMB and major global currencies of payment2 as its subjects. (2) Again unlike previous studies, this paper selects 30-min high-frequency data in place of daily data, works out the independent yields of non-USD currencies by bringing in dummy variables and using an auxiliary regression, and captures the exchange rate spillover effects between the RMB and other major non-USD currencies in terms of independent yield through a VAR-BEKK-GARCH model. (3) This paper is of practical significance in that it focuses on the influence of the COVID-19 pandemic on RMB internationalization by combining quantitative and qualitative analysis.

This research is structured as follows: the second part offers a review of the literature on the linkage between the RMB and other currencies; the third part describes the data processing and econometric model specifications; the fourth part analyses the empirical results; the fifth part analyses Continuous Wavelet Transform; and the sixth part contains the conclusions and policy suggestions.

2 In March 2020, the Society for Worldwide Interbank Financial Telecommunication (SWIFT) announced the top 8 most traded currencies, namely, the US dollar, the European euro, the British pound, the Japanese yen, the RMB, the Canadian dollar, the Australian dollar and the Swiss franc.
Kitamura (2010) found that the euro, pound, and Swiss franc rates are interrelated, with the euro occupying a leading position in the transmission of volatility. Boero, Silvapulle, and Tursunalieva (2010) separately observed and studied the volatility relationship of currencies such as the mark, pound sterling, Swiss franc, and yen before and after the introduction of the euro and found that this relationship was stronger after the introduction of the euro than before. Antonakakis (2012) reached a similar conclusion and further found that extreme events and appreciation of the US dollar have an impact on spillover between currencies.

As RMB internationalization moves forward continuously, the spillover effects of the exchange rates of the RMB and other currencies are attracting increasing academic attention, and research into the RMB’s international influence has distinct regional characteristics.

Since the 2005 exchange rate reform, research into the RMB’s regional influence has seen a strong surge. Gronwald et al. (2010) examined the linkage between the exchange rates of China and the United States. Chow-Tan and Hwee (2011) pointed out that the RMB has not yet become a regional anchor currency. Henning (2013) pointed out that since China implemented exchange rate reforms in 2005, Singapore, Thailand, Malaysia and the Philippines, among ASEAN countries, have all paid close attention to the RMB to a certain extent, forming a loose and flexible “RMB zone”. Research by Subramanian and Kessler (2013) showed that the influence of the RMB has been gradually rising to a global level, especially since mid-2010. Shu et al. (2015) used an external currency model to identify that the RMB has a significant impact on East Asia and that the offshore market has an obvious guiding function. Morck and Yeung (2016) researched the volatility spillover effects of onshore RMB against other Asian currencies and found that the market-based reform of the RMB exchange rate would increase the degree of the identified volatility spillover effects.

Research shows that there is a significant spillover effect between RMB and currencies in East Asia, indicating that RMB has a strong influence in East Asia and this influence is getting stronger. Branson and Healy (2006) pointed out that the main way that the RMB influences the currencies of Asian countries is trade. Shachmurove and Shachmurove (2007) studied the linkage relationship of currency exchange rates in the Asia-Pacific region from 1997 to 2004 and found that after the Southeast Asian financial crisis, China’s influence on neighbouring ASEAN countries increased. An empirical analysis conducted with a multivariate GARCH model and an SV model by Ding and Yang (2007) on the volatility spillover between onshore RMB and seven East Asian currency exchange rates found that after the 2005 reform, the volatility spillover of the seven East Asian currencies against the RMB were enhanced, and there were significant bidirectional volatility spillover between onshore RMB and HKD, NTD, KRW and MYR. Colavecchio and Funke (2008) used a dual DCC-GARCH model to conduct empirical analysis and found significant two-way volatility spillovers between the RMB and non-deliverable forward (NDF) exchange rates of seven Asian currencies. It is generally believed that there is a long-run linkage between the exchange rates of China and the United States but that the effect is not obvious in the short term. Dobson and Masson (2009) discussed China’s economic growth and pointed out that if the Chinese authorities want to encourage international use of the RMB and if the Chinese economy, with its powerful party control, can gain international acceptance for its currency, then the RMB has the potential to become the world’s major currency. Balasubramaniam et al. (2011) selected 132 world currencies for analysis and found that 34 currencies are sensitive to changes in the RMB exchange rate; thus, the RMB may play a potentially important role in global exchange rates. Wang and Yang (2014), by constructing a VAR-DCC-MVGARCH model and a structural break model, analysed issues such as the time-varying correlation, contagion and structural breaks of the exchange rates of China and ASEAN countries and found that short-term fluctuations of the RMB exchange rate have a certain regional influence on ASEAN countries and that transmission of changes in the RMB exchange rate to the exchange rates of most ASEAN countries is effective, although with a nonobvious characteristic of continuity. Based on Frankel’s external currency model, Shu et al. (2010) investigated the RMB’s influence on major East Asian currencies and found that the RMB has a significant influence in the East Asian region and that RMB regionalization has apparently picked up speed.

Since China launched the “One Belt One Road” initiative in October 2013, there have been an increasing number of studies on this initiative and RMB internationalization. Relevant studies show that RMB has a certain regional impact on countries along “One Belt One Road”, but the impact is not significant. Cai and Lin (2018) applied VAR-DCC-MVGARCH-BEKK to further study the dynamic exchange rate linkage between the RMB and currencies of major countries along the “One Belt One Road” and found that fluctuations in the RMB exchange rate have some regional influence over the selected countries but that the influence is not very strong, which means that the RMB has yet to be widely accepted and recognized along the “One Belt One Road”. Li and Cai (2019) selected the exchange rates of currencies along the “One Belt One Road” as their sample, employed the seemingly unrelated regression (SUR) approach to empirically examine the RMB’s influence on these currencies, and found that the exchange rates of the RMB against the currencies are increasingly strengthening, especially in the East Asian region, South Korea in East Asia, India in South Asia, Russia in Eastern Europe, and South Africa in Africa.

Since the outbreak of the COVID pandemic, some scholars have been investigating the correlations between the pandemic and RMB internationalization, but they focus mainly on qualitative analysis without the support of quantitative analysis. Guan Tao (2020) pointed out that the Federal Reserve’s splashing of dollars has a positive externality on RMB internationalization in the short term and that there are two prospects for RMB internationalization in the long run: one is that there will be more room for RMB internationalization thanks to the multiple advantages enjoyed by China’s economy as it emerges first from the pandemic; the other is that uncertainties over the future could lead to a global financial crisis, under which RMB internationalization would face major challenges.

The academic discussion on the spillover effect of RMB has distinct regional characteristics, and mainly focuses on East Asian countries. Meanwhile, there is a lack of studies that examine the process of RMB internationalization at different stages during the spread of the COVID-19. This paper will analyse this gap by analysing the spillover effects between the RMB and non-US currencies which is not part of East Asia and the “One Belt One Road” countries.
3. Data processing and econometric model specifications

3.1. Establishment of sampling intervals

The development of COVID-19 can be roughly divided into four phases: the spread in China, the spread worldwide, promotion of vaccines and the spread of Omicron (B.1.1.529). Within these four major phases, there are still important events that influence the course of the pandemic. For this reason, we have further detailed the 4 phases as shown in Fig. 1.

Based on the development phases of COVID-19, we set up concrete sampling intervals as following, aiming to portray the characteristics of the spillover effects between the RMB and non-USD currencies in different stages of the pandemic.

Important events and sampling intervals of COVID-19.

| Stage | Start Events | Period |
|-------|--------------|--------|
| 1st   | Before COVID-19 | 2019/12/31 0:00 – 2020/1/20 0:00 |
| 2nd   | The Spread in China | 2020/1/20 0:20 – 2020/3/11 0:00 |
| 3rd   | The Spread Worldwide | 2020/3/11 0:20 – 2020/4/16 0:00 |
| 3-2   | Lockdowns Policy | 2020/4/16 0:20 – 2020/7/4 0:00 |
| 3-3   | No Specific Medication | 2020/7/4 0:20 – 2020/12/31 0:00 |
| 4th   | The First World Vaccine | 2020/12/31 0:20 – 2021/5/7 0:00 |
| 4-2   | The First Vaccine Created by China | 2021/5/7 0:20 – 2021/11/26 0:00 |
| 5th   | Omicron (B.1.1.529) | 2021/11/26 0:20 – 2022/2/3 0:00 |
| 5-2   | Cases Out of Control | 2022/2/3 0:20 – 2022/7/20 0:00 |

3.2. Data selection and processing

The reasons for selecting 30-min high-frequency data are as follows. Shao Xidong et al. (2009) found that the prediction ability of vector autoregression (VAR) based on ultrahigh-frequency volatility was significantly better than that of a GARCH model based on daily data. It is difficult to estimate volatility from low-frequency data, such as daily, weekly or monthly observations. Compared with low-frequency data, high-frequency data have a large sampling frequency, rich information content and unique statistical characteristics. The use of high-frequency data is conducive to identifying more detailed market fluctuation information and analysing market fluctuations.

Based on the availability of 30-min high-frequency data and the latest currency ranking for global payments by share issued by SWIFT, this paper studies seven non-USD currencies, namely, the offshore RMB\(^3\) (CNH), the Japanese yen (JPY), the Swiss franc (CHF), the British pound (GBP), the European euro (EUR), the Australian dollar (AUD) and the Canadian dollar (CAD). The sampling interval is from 0:00 on December 31, 2019, to 00:00 on July 20, 2022, and the data source is CHOICE. As official holidays and the time when the market closes at the end of a month vary in different countries, we identify time intervals that lack sample data to ensure that the high-frequency data of the seven currencies during the sampling intervals are all balanced and obtain 4396 figures in each series after adjustment.

The yield of the exchange rate series is calculated using the following equation:

\[
R_t = \ln\left(\frac{P_t}{P_{t-1}}\right) \times 100
\]

where \(R_t\) stands for the currency’s yield at time \(t\) and \(P_t\) stands for the closing exchange rate at time \(t\).

As the exchange rates of the non-USD currencies chosen herein are all unilateral exchange rates against the US dollar using the direct quotation method, the regression result has greater explanatory power to explore the relations between the RMB and non-USD currencies. We refer to the auxiliary regression method proposed by Shu C (2010, pp. 221–235) and extract the separate rates of change in non-USD currencies’ exchange rates. Therefore, we run an auxiliary regression of the yields of non-USD currencies against the US dollar’s yield\(^4\) and substitute the residual series after regression for the yield series of non-USD currencies.

\[
R_{it} = C + \text{Rusdx}_t + e_{it}
\]

As the speed of spread of COVID-19 has varied in different countries, to better investigate its impact on the yield of non-USD currencies, we incorporate eight dummy variables, i.e.:

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\(^3\) This paper uses 30-min high-frequency data over 24 h. As there is no night trading of onshore RMB, this paper chooses the exchange rate of offshore RMB (CNH) against the US dollar as the research variable.

\(^4\) This paper takes the US Dollar ICE Bank Yield Index published by the Intercontinental Exchange (ICE) as the proxy variable for the US dollar yield.
After introducing the dummy variables, the auxiliary regression equation is written as equation (1):

$$R_{it} = C + Rusdx + \sum_{i=1}^{8} D_{it} + r_{it}$$

(1)

where $R_{it}$ represents the yield of non-USD currencies, $Rusdx$ represents the yield of the US dollar, and $r_{it}$ represents the independent rate of change in non-USD currencies.

3.3. Statistical description

In the first stage (Table 1), based on the direct quotation method, the yields of the Swiss franc, the offshore RMB and the Canadian dollar were all negative, while the yields of other non-USD currencies were positive, which means the Swiss franc, the offshore RMB, the Canadian dollar and the US dollar were all appreciating. The standard deviation of the offshore RMB yield is the smallest, and the standard deviation of the British pound yield is the largest, which means that in the first stage, the RMB was more stable than the other seven currencies.

In the second stage, the pandemic was raging in China and had yet to spread worldwide. The Swiss franc, the Japanese yen and the euro were appreciating with a negative yield, while the offshore RMB started to depreciate after appreciating. Although the offshore RMB’s standard deviation rose slightly, it remained as the most stable currency.

In the third stage, the pandemic was largely under control in China but spreading more than expected internationally. Except for the US dollar, all currencies depreciated in stage 3–1 and appreciated in stage 3-3 with significantly rising standard deviations, and the offshore RMB remained the least volatile.

In the fourth stage, vaccines have been successfully developed and gradually popularized worldwide. The Swiss franc and the Japanese yen depreciated in stage 4–1 while the offshore RMB and the US dollar appreciated in stage 4–2 with significantly falling standard deviations, and the RMB remained the least volatile.

In the fifth stage, Omicron (B.1.1.529) made a whole new phase in the spread of the pandemic, with the number of infections rising sharply. The Swiss franc, the offshore RMB, the Canadian dollar were appreciating with a negative yield in stage 5–1, while all...
Table 1
Descriptive statistics of the yield series of all Currencies.

|        | RCNH | RAUD | RCAD | RCHF | REUR | RGBP | RJPY | RUSDX |
|--------|------|------|------|------|------|------|------|-------|
| Mean   | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Standard deviation | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Kurtosis | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| Skewness | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Minimum | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Maximum | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Observed value | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| J-B     | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table 2
Descriptive statistics of the yield series of all Currencies (continued on next page).

|        | RCNH | RAUD | RCAD | RCHF | REUR | RGBP | RJPY | RUSDX |
|--------|------|------|------|------|------|------|------|-------|
| Mean   | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Standard deviation | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Kurtosis | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| Skewness | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Minimum | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Maximum | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Observed value | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| J-B     | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

(continued on next page)
 currencies started to depreciate in stage 5–2. Only the US dollar kept appreciating in the entire stage 5, and the offshore RMB’s still remained the most stable currency.

### 3.4. Econometric model specifications

Compared to the conventional univariate GARCH model, the BEKK-GARCH model not only can guarantee positive definiteness of the covariance matrix under weak conditions but also can capture the significance and direction of the volatility spillover effect between different financial time series with conditional covariance matrix residuals. Meanwhile, this model requires a relatively small number of parameters, resulting in a lower loss in the degree of freedom. This paper chooses the VAR-BEKK-GARCH model to investigate the volatility spillover effect between different financial markets very well (e.g., Chng, 2009), i.e., \( p = 1 \).

Mean equation VAR (p):

\[
r_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{i-1} r_{t-i} + \varepsilon_t, \quad \varepsilon_t \sim N(0, H_t)
\]  

(2)

where \( r_t \) is the vector of the currency yield, \( p \) is the number of lag orders of the autoregression explanatory variable, and \( \varepsilon_t \) is the random disturbance term.

Engle and Kroner (1995) proposed imposing positive definiteness restrictions on the parameters to obtain the BEKK-GARCH model, set up as follows:

\[
H_t = C' C + \sum_{k=1}^{K} \sum_{i=1}^{q} A_{ik} \varepsilon_{t-i} \varepsilon_{t-i}' A_{ik} + \sum_{k=1}^{K} \sum_{i=1}^{p} B_{ik} H_{t-i} B_{ik}'
\]  

(3)

To keep things simple, we usually set \( K = 1 \), and much academic research has shown that a BEKK-GARCH(1,1) can describe the volatility spillover effect between different financial markets very well (e.g., Chng, 2009), i.e., \( p = q = 1 \).

\[
H_t = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}, \quad C = \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix}, \quad A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}, \quad B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}
\]

where \( H_t \) is the conditional covariance matrix. \( C \) is the constant matrix. \( A \) is the coefficient matrix of the ARCH term, measuring the impact of the lag order residual term on the conditional variance of the current period and representing the clustering of volatility. \( B \) is the coefficient matrix of the GARCH term, measuring the impact of the lag order conditional variance on the conditional variance of the current period and representing the continuity of volatility.

Specifically, \( a_{12} \) reflects the GARCH volatility spillover shock transmission from \( r_{1t} \) to \( r_{2t} \), and \( b_{12} \) reflects the GARCH volatility spillover shock transmission from \( r_{2t} \) to \( r_{1t} \). To test the volatility spillover effect from market 1 to market 2, the null hypothesis is \( H_0: a_{12} = b_{12} = 0 \), i.e., the volatility in market 2 is assumed not to be affected by the volatility in market 1, whereas to test the volatility spillover effect from market 2 to market 1, the null hypothesis is \( H_0: a_{21} = b_{21} = 0 \), i.e., the volatility in market 1 is assumed not to be affected by the volatility in market 2. We use the Wald test, and when the Wald test statistics are greater than the critical value, the null hypothesis is rejected.

### 4. Analysis of empirical results

#### 4.1. Auxiliary regression analysis

The auxiliary regression analysis results (Table 2) show that the development of COVID-19 created a significant shock on the offshore RMB yield. Although the different time periods of the pandemic did not have a significant impact on the yields of the other

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**Table 2**

| C. Lu et al. | Table 1 (continued) |
|-------------|---------------------|
| Mean equation VAR (p): | $r_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{i-1} r_{t-i} + \varepsilon_t, \quad \varepsilon_t \sim N(0, H_t)$ |

(2)

where $r_t$ is the vector of the currency yield, $p$ is the number of lag orders of the autoregression explanatory variable, and $\varepsilon_t$ is the random disturbance term.

Engle and Kroner (1995) proposed imposing positive definiteness restrictions on the parameters to obtain the BEKK-GARCH model, set up as follows:

$$H_t = C'C + \sum_{k=1}^{K} \sum_{i=1}^{q} A_{ik} \varepsilon_{t-i} \varepsilon_{t-i}' A_{ik} + \sum_{k=1}^{K} \sum_{i=1}^{p} B_{ik} H_{t-i} B_{ik}'$$

(3)

To keep things simple, we usually set $K = 1$, and much academic research has shown that a BEKK-GARCH(1,1) can describe the volatility spillover effect between different financial markets very well (e.g., Chng, 2009), i.e., $p = q = 1$.

$$H_t = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}, \quad C = \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix}, \quad A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}, \quad B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$$

where $H_t$ is the conditional covariance matrix. $C$ is the constant matrix. $A$ is the coefficient matrix of the ARCH term, measuring the impact of the lag order residual term on the conditional variance of the current period and representing the clustering of volatility. $B$ is the coefficient matrix of the GARCH term, measuring the impact of the lag order conditional variance on the conditional variance of the current period and representing the continuity of volatility.

Specifically, $a_{12}$ reflects the GARCH volatility spillover shock transmission from $r_{1t}$ to $r_{2t}$, and $b_{12}$ reflects the GARCH volatility spillover shock transmission from $r_{2t}$ to $r_{1t}$. To test the volatility spillover effect from market 1 to market 2, the null hypothesis is $H_0: a_{12} = b_{12} = 0$, i.e., the volatility in market 2 is assumed not to be affected by the volatility in market 1, whereas to test the volatility spillover effect from market 2 to market 1, the null hypothesis is $H_0: a_{21} = b_{21} = 0$, i.e., the volatility in market 1 is assumed not to be affected by the volatility in market 2. We use the Wald test, and when the Wald test statistics are greater than the critical value, the null hypothesis is rejected.

### 4. Analysis of empirical results

#### 4.1. Auxiliary regression analysis

The auxiliary regression analysis results (Table 2) show that the development of COVID-19 created a significant shock on the offshore RMB yield. Although the different time periods of the pandemic did not have a significant impact on the yields of the other
### Table 2
Result of auxiliary regression.

|         | Explanatory Variable | RUSDX | D1     | D2     | D3     | D4     | D5     | D6     | D7     | D8     |
|---------|----------------------|-------|--------|--------|--------|--------|--------|--------|--------|--------|
| RCNH    | No dummy variable    | 0.34528*** | 0.00398*** | 0.00305* | 0.00324* | 0.00229 | 0.00290* | 0.00260* | 0.00308* | 0.00341** |
|         | Introducing dummy variable | 0.34524*** | 0.00398*** | 0.00305* | 0.00324* | 0.00229 | 0.00290* | 0.00260* | 0.00308* | 0.00341** |
| RJPY    | No dummy variable    | 0.55974*** | 0.00288 | 0.00044 | −0.00073 | −0.00100 | 0.00003 | −0.00073 | −0.00123 | 0.00112 |
|         | Introducing dummy variable | 0.55948*** | 0.00288 | 0.00044 | −0.00073 | −0.00100 | 0.00003 | −0.00073 | −0.00123 | 0.00112 |
| RCAD    | No dummy variable    | 0.68620*** | 0.00380 | 0.00037 | −0.00010 | 0.00088 | −0.00029 | 0.00086 | 0.00139 | −0.00001 |
|         | Introducing dummy variable | 0.68633*** | 0.00380 | 0.00037 | −0.00010 | 0.00088 | −0.00029 | 0.00086 | 0.00139 | −0.00001 |
| RCHF    | No dummy variable    | 0.86524*** | 0.00033 | 0.00074 | 0.00111 | 0.00140 | 0.00169 | 0.00098 | 0.00098 | 0.00079 |
|         | Introducing dummy variable | 0.86530*** | 0.00033 | 0.00074 | 0.00111 | 0.00140 | 0.00169 | 0.00098 | 0.00098 | 0.00079 |
| REUR    | No dummy variable    | 1.08437*** | 0.00004 | −0.00081 | −0.00051 | −0.00004 | 0.00018 | 0.00007 | 0.00012 | −0.00039 |
|         | Introducing dummy variable | 1.08442*** | 0.00004 | −0.00081 | −0.00051 | −0.00004 | 0.00018 | 0.00007 | 0.00012 | −0.00039 |
| RGBP    | No dummy variable    | 1.03004*** | 0.00134 | −0.00087 | 0.00108 | 0.00027 | −0.00045 | 0.00002 | 0.00001 | 0.00056 |
|         | Introducing dummy variable | 1.03010*** | 0.00134 | −0.00087 | 0.00108 | 0.00027 | −0.00045 | 0.00002 | 0.00001 | 0.00056 |
| RAUD    | No dummy variable    | 1.15324*** | 0.00220 | −0.00302 | −0.00384 | −0.00116 | −0.00158 | −0.00096 | −0.00015 | −0.00260 |
|         | Introducing dummy variable | 1.15342*** | 0.00220 | −0.00302 | −0.00384 | −0.00116 | −0.00158 | −0.00096 | −0.00015 | −0.00260 |

Note: ***, ** and * represent significance levels of 10%, 5% and 1%, respectively.
Table 3
Statistics of ADF test.

|       | Stage 1 |     | Stage 2 |     | Stage 3-1 |     | Stage 3-2 |     | Stage3-3 |     | Stage4-1 |     | Stage4-2 |     | Stage5-1 |     | Stage5-2 |     |
|-------|---------|-----|---------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|
|       | Statistics | P  |       | Statistics | P  |       | Statistics | P  |       | Statistics | P  |       | Statistics | P  |       | Statistics | P  |       | Statistics | P  |
| rcnh  | 8.449   | 0.0000 | -11.400 | 0.0000 | -10.918 | 0.0000 | -14.716 | 0.0000 | -18.569 | 0.0000 | -16.243 | 0.0000 | -18.058 | 0.0000 | -13.945 | 0.0000 | -18.024 | 0.0000 |
| rchf  | 9.353   | 0.0000 | -13.946 | 0.0000 | -11.740 | 0.0000 | -14.194 | 0.0000 | -18.176 | 0.0000 | -15.850 | 0.0000 | -18.488 | 0.0000 | -12.039 | 0.0000 | -18.341 | 0.0000 |
| rjpy  | -9.138  | 0.0000 | -9.560  | 0.0000 | -11.834 | 0.0000 | -13.945 | 0.0000 | -18.863 | 0.0000 | -16.421 | 0.0000 | -18.126 | 0.0000 | -14.011 | 0.0000 | -17.240 | 0.0000 |
| rcad  | -9.351  | 0.0000 | -12.104 | 0.0000 | -11.199 | 0.0000 | -13.008 | 0.0000 | -17.282 | 0.0000 | -15.218 | 0.0000 | -18.423 | 0.0000 | -13.054 | 0.0000 | -17.860 | 0.0000 |
| reur  | -9.313  | 0.0000 | -10.754 | 0.0000 | -9.636  | 0.0000 | -14.007 | 0.0000 | -19.618 | 0.0000 | -16.245 | 0.0000 | -18.592 | 0.0000 | -12.901 | 0.0000 | -17.192 | 0.0000 |
| rgbp  | -9.282  | 0.0000 | -12.120 | 0.0000 | -11.236 | 0.0000 | -13.848 | 0.0000 | -18.572 | 0.0000 | -16.298 | 0.0000 | -18.804 | 0.0000 | -13.566 | 0.0000 | -17.862 | 0.0000 |
| raud  | -9.162  | 0.0000 | -11.132 | 0.0000 | -12.155 | 0.0000 | -13.552 | 0.0000 | -18.451 | 0.0000 | -15.080 | 0.0000 | -19.526 | 0.0000 | -13.251 | 0.0000 | -17.120 | 0.0000 |
currencies, the trends in the coefficients of the dummy variables are still informative. In particular, the pandemic had a positive impact on the Swiss franc and a negative impact on other currencies for most of the period. This result provides some evidence of the Swiss franc’s safe-haven role. The coefficient for the offshore RMB declined during the period when the pandemic was spreading around the world and started to rise after the vaccine was launched. As for other currencies, in general, the coefficients of all currencies, except the Japanese yen and the Swiss franc, fall between the spread of the world pandemic and the Omicron (B.1.1.529). During the global spread phase of the pandemic, the coefficients of the Swiss franc and the Japanese yen rose and the other currencies fell; during the promotion phase of the vaccine, there was an upward or flat trend in the coefficients of all currencies except for the British pound; during the spread phase of the Omicron (B.1.1.529), there was a downward trend in the coefficients of all currencies except for the British pound.

In comparison to the results of the specification without a dummy variable, the coefficient (absolute value) of the US dollar yield against the offshore RMB and the Japanese yen yield dropped after we introduced the dummy variables, and the coefficients (absolute value) of the US dollar yield against the yields of other non-USD currencies rose. Among these coefficients, the absolute value of the change in the offshore RMB and the European eEuro coefficient was the smallest, which means that before and after the outbreak of the pandemic, the impact of the US dollar yield on the offshore RMB and the eEuro yield has been most stable, with no significant change versus other non-USD currencies.

4.2. Unit root test

The result of the augmented Dickey-Fuller (ADF) stationarity test on the currency’s independent yield series (Table 3) shows that the time series of the selected variables are all stationary and significant at a 1% confidence level, meeting the requirement to further study the mean and volatility spillovers.

According to the Schwarz Criterion, the model’s number of lag orders is 1 and the Ljung-Box test proves that the residuals after fitting the VAR model to the data are white noise, indicating that the selection of 1 as the lag coefficient is reasonable.

The following set of figures (Fig. 2-8) shows that the independent yields of seven currencies exhibit different volatility characteristics. Among them, the Swiss franc, the Japanese yen, the British pound and the Australian dollar fluctuate drastically in specific stages, while the euro, the Canadian dollar and the offshore RMB remain relatively stable.

4.3. Analysis of mean spillover effect

As shown in Table 4, when we take offshore RMB yields as the explained variable, the offshore RMB’s independent yield is subject to a significant negative impact from the Lag 1. In the second stage, the strongest negative impact on the offshore RMB yields is exerted by the one-phase lag, which diminishes in the later stages, indicating that there is a certain degree of clustering in the yield. With regard to other currencies, yen yields had a significant negative spillover effect on offshore RMB yields only in the first period while thus significance disappears in the latter stages. There is a negative mean spillover in the first stage and a positive mean spillover in the third stage from the Canadian dollar’s independent yield to the offshore RMB’s independent yield, with a result of insignificance in the fourth and fifth stage. In the second stage, the Swiss franc’s independent yield has a negative effect on the offshore RMB’s independent yield, but this spillover effect fades as the pandemic spreads. Although not significant in the first two stages, the mean spillover effect from the euro’s independent yield to the offshore RMB’s independent yield shows negative spillover in the third, fourth and fifth stage. The negative mean spillover effect from the independent yields of the British pound to the offshore RMB’s independent yield is most significant and strongest in the fifth stage, while the results of the Australian dollar show positive effect in the second stage and a trend

![Fig. 2. Independent yield trend of Swiss franc.](image)
of positive effect > negative effect > positive effect in the third stage. Table 5 shows the spillover effect from the offshore RMB’s independent yield to other non-USD currencies when we take offshore RMB as the explanatory variable. In the second to fourth stage, there is a rising positive mean spillover from the offshore RMB’s independent yield to the yen, while a negative mean spillover in the fifth stage. The results of the Canadian dollar show a significant negative mean spillover in the second and fourth stage. The Swiss franc shows a trend of positive effect > negative effect > positive effect in the second and third stage. The results of the euro, the British pound and the Australian dollar show negative mean spillover in the second or the third stage respectively.

As shown in Tables 4 and 5, as this pandemic has unfolded, there have been significant changes in the mean spillover from the offshore RMB’s independent yield to the other six currencies’ independent yields. With the offshore RMB as the explained vector, the final spillover effect can be divided into three categories: yields of the Japanese yen and Swiss franc have significant spillover effect on the offshore RMB in the first and second stages only; yields of the Canadian dollar and Australian dollar have significant spillover effect on the offshore RMB lasting until the third stage; yields of the British pound and the euro have significant negative spillover effect on the offshore RMB in the fourth and fifth stages only. This process reflects the weakening influence and increased independence of the RMB from ordinary currencies as the pandemic progresses. However, for the euro and the pound, two currencies with a large SDR weighting, the RMB is instead subject to stronger negative spillover effect. With the offshore RMB as the explanatory variable, by contrast, the offshore RMB has a spillover effect on other non-US currency yields during the second/third stage of the outbreak. The spillover effect on other currencies’ yields disappears as we move into the fifth stage, suggesting that the influence of the RMB declines through the pandemic. In particular, the results for the Japanese yen suggest that the positive spillover from the offshore RMB turns
into a negative spillover in the fifth stage, with the negative impact of the RMB on the Japanese yen strengthening.

4.4. Analysis of volatility spillover effect

Table 6 shows the estimates of the overall volatility spillover effect between the offshore RMB and other currencies in terms of independent yield.

By country, the volatility spillover effect between the offshore RMB and the Japanese yen exhibits significant new characteristics. In the first and third stages, unidirectional volatility spillover of the offshore RMB exchange rate from the Japanese yen was significant. However, in the second, fourth and fifth stages, there were bidirectional volatility spillover effects between the offshore RMB and the Japanese yen. In particular, in the second stage, there were bidirectional ARCH and GARCH volatility effects and the linkage between the Japanese yen and the RMB reached its highest level. This indicates that, as the pandemic develops, the linkage between the Japanese yen and the RMB gradually weaken.

The volatility spillover effect between the offshore RMB and the Canadian dollar has increased significantly. In the first stage, there was only a unidirectional ARCH volatility spillover effect of the offshore RMB from the Canadian dollar. After entering the second stage, a unidirectional GARCH volatility effect from the offshore RMB to the Canadian dollar emerged, while a unidirectional volatility spillover effect from the Canadian dollar to the offshore RMB appeared, with significant ARCH and GARCH effects. This indicates that the Canadian dollar’s influence over the offshore RMB increased.

The changes in the volatility spillover effect between the offshore RMB and the Swiss franc exhibit significant new characteristics.
In the first stage, there was only a bidirectional volatility spillover effect between the offshore RMB and the Swiss franc. Contrary to the Japanese yen, these effects all but disappear in the second stage. This suggests that the pandemic spreading in China has temporarily severed the spillover effects between the offshore RMB and the Swiss franc. In the fourth and fifth stages, the offshore RMB shows a unidirectional GARCH effects to the Swiss franc, while the Swiss franc generates ARCH and GARCH effects against the offshore RMB in the third and fifth periods. This means that as COVID-19 spread, the spillover effects of the Swiss franc to the RMB is not stable, but there was a tendency for it to increase.

There have been structural changes in the volatility spillover effect between the offshore RMB and the euro. In the first stage, there was a bidirectional volatility spillover effect between the offshore RMB and the euro. As the pandemic spread in China, the GARCH and ARCH volatility spillover effects disappeared. After entry into the third stage, there was a significant bidirectional volatility spillover effect between the offshore RMB and the euro. However, entering the fifth stage, only a GARCH effect remains between the RMB and the euro, and the volatility linkage between the offshore RMB and the euro became more independent.

New changes have arisen in the volatility spillover effect between the offshore RMB and the British pound. In the first stage, there was a bidirectional volatility spillover effect between the offshore RMB and the British pound and it culminated in the second stage. After entry into the third stage, as the pandemic spread more than expected abroad, the bidirectional ARCH volatility spillover effect faded, and there was only a bidirectional GARCH volatility spillover effect and it gradually diminished or even disappeared. This indicates that as the pandemic developed, the volatility linkage between the offshore RMB and the British pound became more independent.

There have also been structural changes in the volatility spillover effect between the offshore RMB and the Australian dollar. In the
| rcnh (explained variable) | Stage 1 | Stage 2 | Stage 3-1 | Stage 3-2 | Stage 3-3 | Stage 4-1 | Stage 4-2 | Stage 5-1 | Stage 5-2 |
|-------------------------|---------|---------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| L1.rcnh 0.07138         | -0.01575 | -0.01575 | -0.01575 | -0.01575 | -0.01575 | -0.01575 | -0.01575 | -0.01575 | -0.01575 |
| L1.rjpy -0.07864**      | 0.00896  | 0.00896  | 0.00896  | 0.00896  | 0.00896  | 0.00896  | 0.00896  | 0.00896  | 0.00896  |
| L1.rcad -0.08083*       | -0.00735 | 0.029002 | 0.029002 | 0.029002 | 0.029002 | 0.029002 | 0.029002 | 0.029002 | 0.029002 |
| L1.rchf 0.004299        | 0.055846** | 0.020299 | 0.020299 | 0.020299 | 0.020299 | 0.020299 | 0.020299 | 0.020299 | 0.020299 |
| L1.reur -0.15765        | 0.033387 | 0.05033  | 0.04115  | 0.05085* | 0.05085* | 0.05085* | 0.05085* | 0.05085* | 0.05085* |
| L1.rgbp 0.04587         | 0.03566  | 0.007602 | 0.00919  | 0.002944 | 0.002944 | 0.002944 | 0.002944 | 0.002944 | 0.002944 |
| L1.raud 0.023637        | 0.085609*** | -0.01527* | 0.017368* | -0.02534** | 0.012606 | 0.005703 | 0.00117  | 0.008965 |

Note: ***, ** and * stand for significance levels of 10%, 5% and 1%, respectively. Due to limited space, this table lists only the mean value model outcomes with the offshore RMB (CNH) as the explained variable.
Table 5
Regression results of the mean equation (CNH as the explanatory variable).

| rchn (explanatory variable) | Stage 1  | Stage 2  | Stage 3-1 | Stage 3-2 | Stage 3-3 | Stage 4-1 | Stage 4-2 | Stage 5-1 | Stage 5-2 |
|-----------------------------|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| L1.jpy                      | 0.024638 | 0.2005***| 0.022909  | 0.02295   | 0.02308*  | 0.01584   | 0.06499***| −0.01456  | −0.0875***|
| L1.rcad                     | −0.0257952 | −0.125***| −0.09125  | −0.006749 | 0.007643  | 0.03228   | −0.04796* | −0.02795  | 0.003566  |
| L1.rchf                     | −0.00893  | 0.097365***| −0.02931 | −0.07019**| 0.04411***| 0.0003996 | −0.008298 | −0.02067  | −0.027282 |
| L1.reur                     | −0.009745 | −0.03041**| 0.003592  | 0.004368  | 0.006437  | −0.008346 | −0.003272 | −0.01105  | 0.01285   |
| L1.rgbp                     | −0.01187  | −0.02747  | −0.05549  | −0.00702  | −0.05659**| −0.002436 | −0.0070364| −0.02756  | 0.004417  |
| L1.raud                     | −0.08366  | −0.4166***| −0.1146761| 0.01615   | 0.0002567 | 0.01446   | −0.03958  | 0.02274   | 0.01094   |

Note: ***, ** and * stand for significance levels of 10%, 5% and 1%, respectively. Due to limited space, this table lists only the mean value model outcomes with the offshore RMB (CNH) as the explanatory variable.
Table 6
Estimates of volatility spillover effect.

|          | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 |
|----------|---------|---------|---------|---------|---------|
| cnh-jpy  | \(a_{12}\) | -0.358622646 | -0.060870481* | -0.044962875 | 0.01662500 |
|          | \(a_{22}\) | 0.105722307 | 0.049595009** | -0.023725249 | -0.006689545* |
|          | \(b_{12}\) | -0.094532985 | 0.126135336*** | 0.039973389 | 0.005193471 |
|          | \(b_{22}\) | 0.401715427*** | -0.061911872** | 0.029159355*** | 0.010476006 |
|          | \(a_{13}\) | 0.214133940 | 0.252150524 | -0.063579690 | -0.026760256 |
|          | \(a_{23}\) | 0.418630851*** | 0.119922720*** | -0.038141377* | -0.01183478 |
|          | \(b_{13}\) | -0.064050788 | 0.054864077 | 0.279134355*** | 0.05902106** |
|          | \(b_{23}\) | -0.233737204 | -0.000118096 | -0.028438122*** | -0.013099868 |
|          | \(a_{14}\) | 1.098199279*** | 0.009790698 | 0.071465982 | 0.013651243 |
|          | \(a_{24}\) | 0.085498400 | 0.019666052 | 0.025860586 | 0.020520010 |
|          | \(b_{14}\) | 0.056754444 | 0.031140794 | 0.026782676 | 0.017120797 |
|          | \(b_{24}\) | -0.181613989*** | -0.03041867 | 0.065375763 | 0.04138787 |
|          | \(a_{15}\) | -0.151994579* | 0.017402021 | 0.009460144 | 0.011902253 |
|          | \(a_{25}\) | 0.931533357*** | 0.091736209 | 0.008794455 | 0.004875365 |
|          | \(b_{15}\) | 0.086951950*** | 0.00951904 | -0.028438122*** | 0.03144409** |
|          | \(b_{25}\) | 1.352019987*** | -0.287994490 | 0.065375763 | 0.031318654*** |
|          | \(a_{16}\) | -0.562959054* | 0.038706089* | -0.083708747 | -0.032127816 |
|          | \(a_{26}\) | 0.257961155** | 0.047318707 | 0.000527781 | -0.083708747 |
|          | \(b_{16}\) | -0.090904791 | 0.357941949*** | 0.039033236 | 0.059468411*** |
|          | \(b_{26}\) | 0.187115118*** | -0.04173544** | 0.028061060 | 0.056166895*** |
|          | \(a_{17}\) | 0.139228428 | 0.228952368*** | 0.104863139 | 0.030121823 |
|          | \(a_{27}\) | -0.623847278*** | -0.04671246** | -0.005752552 | -0.030927646 |
|          | \(b_{17}\) | -0.001271023 | -0.206234348*** | -0.004445746 | 0.055503495 |
|          | \(b_{27}\) | 0.001494761 | 0.016539175* | 0.004600640 | -0.049250735 |

Note: Nonmain diagonal elements: \(a_{12}\) is the ARCH volatility effect from the offshore RMB’s independent yield to the yen’s, and \(a_{22}\) is the opposite; \(b_{12}\) is the GARCH volatility effect from the offshore RMB’s independent yield to the yen’s, and \(b_{22}\) is the opposite.
Table 7
Joint test result of volatility spillover effect.

| Null hypothesis | Stage 1 | Stage 2 | Stage 3-1 | Stage 3-2 | Stage 3-3 | Stage 4-1 | Stage 4-2 | Stage 5-1 | Stage 5-2 |
|-----------------|---------|---------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| cnh-jpy         |         |         |           |           |           |           |           |           |           |
| $H_0$: $a_{12} = b_{12} = a_{21} = b_{21} = 0$ | 22.974364*** | 52.357745*** | 32.931340*** | 11.193398** | 11.193398** | 5.915165 | 11.193398** | 8.173440* | 41.933911*** | 55.850931*** |
| $H_1$: $a_{12} = b_{12} = 0$ | 3.307540 | 32.784225*** | 13.938466*** | 2.643690 | 2.643690 | 0.591107 | 11.193398** | 3.154070 | 0.216031 | 49.148954*** |
| $H_2$: $a_{21} = b_{21} = 0$ | 18.743592*** | 27.757995*** | 12.522401*** | 10.011659*** | 10.011659*** | 0.411676 | 4.866418* | 4.866418* | 33.569393*** | 10.102809*** |
| cnh-cad         |         |         |           |           |           |           |           |           |           | |
| $H_0$: $a_{13} = b_{13} = a_{23} = b_{31} = 0$ | 24.891004*** | 34.274750*** | 67.452712*** | 68.072940*** | 68.072940*** | 90.909984*** | 62.510748*** | 2.200723 | 43.463235*** |
| $H_1$: $a_{13} = b_{13} = 0$ | 1.325890 | 5.892120*** | 63.778339*** | 64.085929*** | 64.085929*** | 77.273689*** | 39.502960*** | 0.420367 | 4.589451 |
| $H_2$: $a_{23} = b_{31} = 0$ | 24.335054*** | 27.924418*** | 13.010418*** | 4.351287 | 4.351287 | 40.060294*** | 9.963814*** | 2.184007 | 43.103561*** |
| cnh-chf         |         |         |           |           |           |           |           |           |           | |
| $H_0$: $a_{14} = b_{14} = a_{43} = b_{41} = 0$ | 42.078270*** | 3.490105 | 17.962377*** | 46.706700*** | 46.706700*** | 14.151704*** | 63.481086*** | 16.148797*** | 30.775016*** |
| $H_1$: $a_{14} = b_{14} = 0$ | 22.149995*** | 2.030182 | 9.624511*** | 21.475037*** | 21.475037*** | 5.066294* | 5.958144*** | 1.071711 | 11.693131*** |
| $H_2$: $a_{41} = b_{41} = 0$ | 12.196551*** | 2.351058 | 2.877917 | 6.851960*** | 6.851960*** | 1.350971 | 6.756132** | 0.369474 | 22.860509*** |
| cnh-eur         |         |         |           |           |           |           |           |           |           | |
| $H_0$: $a_{15} = b_{15} = a_{53} = b_{31} = 0$ | 70.367460*** | 2.542395 | 37.410010*** | 42.366321*** | 42.366321*** | 37.920767*** | 119.144649*** | 17.435166*** | 12.655162*** |
| $H_1$: $a_{15} = b_{15} = 0$ | 9.537302*** | 1.407074 | 19.228216*** | 22.704286*** | 22.704286*** | 5.267261* | 20.034193*** | 17.219377*** | 8.204821*** |
| $H_2$: $a_{53} = b_{31} = 0$ | 53.041864*** | 1.422392 | 25.383125*** | 22.875793*** | 22.875793*** | 5.267261* | 22.034193*** | 17.219377*** | 8.204821*** |
| cnh-gbp         |         |         |           |           |           |           |           |           |           | |
| $H_0$: $a_{16} = b_{16} = a_{61} = b_{15} = 0$ | 37.118203*** | 187.419835*** | 17.047020*** | 95.961877*** | 95.961877*** | 54.814951*** | 69.945648*** | 6.818554 | 162.861529*** |
| $H_1$: $a_{16} = b_{16} = 0$ | 4.419726 | 181.014348*** | 10.007227 | 65.560800*** | 65.560800*** | 39.468794*** | 46.410460*** | 1.411034 | 135.359765*** |
| $H_2$: $a_{61} = b_{15} = 0$ | 35.399646*** | 8.643251*** | 11.695451*** | 15.947251*** | 15.947251*** | 42.101970*** | 12.802862*** | 2.388738 | 1.249839 |
| cnh-aud         |         |         |           |           |           |           |           |           |           | |
| $H_0$: $a_{17} = b_{17} = a_{71} = b_{15} = 0$ | 29.531316*** | 43.612448*** | 68.194895* | 202.640003*** | 202.640003*** | 192.174858*** | 668.154496*** | 33.967103*** | 82.120205*** |
| $H_1$: $a_{17} = b_{17} = 0$ | 0.273155 | 33.156255*** | 34.655473*** | 167.778803*** | 167.778803*** | 181.361715*** | 266.793145*** | 31.840208*** | 70.369592*** |
| $H_2$: $a_{71} = b_{15} = 0$ | 29.498775*** | 11.183556*** | 8.060549*** | 1.343484 | 1.343484 | 79.472948*** | 257.645579*** | 24.355572*** | 2.999000 |

Note: The table lists the chi-squared statistics of the Wald test, with ***p < 0.01, **p < 0.05, and * p < 0.1.
Table 8
Result of auxiliary regression.

|       | Explanatory Variable | RUSDX | D1    | D2    | D3    | D4    | D5    | D6    | D7    | D8    |
|-------|----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| RCNH  | No dummy variable    |       |       |       |       |       |       |       |       |       |
|       | Introducing dummy variable |       | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| RJPY  | No dummy variable    | 3.869*** |       | 0.00002 | 0.00002 | 0.00002 | 0.00002 | 0.00002 | 0.00002 | 0.00001 |
|       | Introducing dummy variable | 8.39195*** |       | 0.00002 | 0.00002 | 0.00002 | 0.00002 | 0.00002 | 0.00002 | 0.00001 |
| RCAD  | No dummy variable    | 0.05765*** |       | 0     | 0     | -0.0001*** | 0     | 0     | 0     | 0     |
|       | Introducing dummy variable | -0.0291*** |       | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| RCHF  | No dummy variable    | 0.09410*** |       | 0.00001*** | 0.00001*** | 0.00001*** | 0.00001*** | 0.00001*** | 0.00001*** | 0.00001*** |
|       | Introducing dummy variable | 0.02911*** |       | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| REUR  | No dummy variable    | 0.8655*** |       | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
|       | Introducing dummy variable | 0.76999*** |       | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| RGBP  | No dummy variable    | 0.6114*** |       | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
|       | Introducing dummy variable | 0.37626*** |       | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| RAUD  | No dummy variable    | 0.2704*** |       | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
|       | Introducing dummy variable | -0.11461*** |       | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
first stage, there was only a unidirectional ARCH effect from the Australian dollar to the offshore RMB. In the second stage, the bidirectional volatility spillover effect between the offshore RMB and the Australian dollar was highly significant, and the continuity was very strong. In the third and fourth stage, there was bidirectional GARCH volatility spillover between the offshore RMB and the Australian dollar and a unidirectional ARCH volatility spillover from the Australian dollar to the offshore RMB which disappeared in the fifth stage, indicative of an increase in independence between the two currencies.

The Wald test result (Table 7) indicates a bidirectional volatility spillover effect between the Australian dollar and the offshore RMB in terms of independent yield. Between the yen and offshore RMB, the bidirectional volatility spillover effect disappeared only in the fourth stage; the bidirectional volatility spillover effects from the Swiss Franc and the euro to the offshore RMB disappeared in the second stage, while effects from the British pound and the Canadian dollar to the offshore RMB disappeared in the fifth stage.

As shown in Tables 6 and 7, the changes in the volatility spillover between the offshore RMB and other non-USD currencies in terms of independent yield can be divided into the following 3 types.

In the first type, there are structural changes to the characteristics of the volatility spillover effect (mainly with respect to the Swiss franc and the euro). Before the outbreak of COVID-19, there were bidirectional volatility spillover effects between the offshore RMB’s independent yield and that of the Swiss franc and the euro. However, as the pandemic was unfolded at home, the bidirectional volatility spillover effect disappeared which suggests that the outbreak has had a cut-throat impact. Then, the trend continued to go down after the third stage recovery.

In the second type, there is a significant volatility spillover effect with a waning influence of other currencies (mainly the British pound, the Japanese yen and the Australian dollar). In the second stage, there were significant bidirectional volatility spillover effects between the offshore RMB and other currencies. As COVID-19 spread internationally, however, this characteristic clearly disappeared, and the RMB became relatively independent.

Under the final type, a significant volatility spillover effect is observed with an enhanced influence of the offshore RMB (mainly with respect to the Canadian dollar). Before the outbreak of COVID-19, there were unidirectional ARCH volatility spillover effects from the Canadian dollar to the offshore RMB in terms of independent yield. However, as the pandemic was brought under control at home and spread more than expected abroad, the bidirectional GARCH volatility spillover effect between the offshore RMB and the Canadian dollar and a unidirectional ARCH volatility spillover effect from the Canadian dollar was significant. This indicates that the Canadian dollar’s influence over the offshore RMB increased.

5. Continuous Wavelet Transform

5.1. Econometric model specifications

Next, we used wavelet to test the above conclusions. Wavelet theory has its origins in Fourier analysis, but there are important differences. Wavelets allow data to be split into different frequencies for separate analysis. This scale decomposition opens a whole new way of processing data. Upon its completion in the late 1980s, wavelets began to enter the field of applied science, as a completely new way of processing data. One of their earliest applications was in earthquake prediction. Wavelets provide a temporal dimension to non-stationary seismic signals that is lacking in Fourier analysis (Schleicher, 2002). In addition, their ability to capture both long-term motion and high-frequency detail is useful when dealing with non-stationary and complex functions, so they are also widely used in economics. Wavelets have two main applications in economics, one is to split time series and the other is to look at the correlation of two time series under mixing (Conraria & Soares, 2011). In this study we have taken the first application. The following are the low frequency empirical results after wavelet filtering.

As the low frequency data did not pass the unit root test, we used the difference method to eliminate the unit root and finally passed the ADF test.

The results of the auxiliary regression from the low-frequency data (Table 8) show a non-significant but positive impact of COVID-19 on the Swiss franc, while most other currencies suffered a negative impact. This is the same as the auxiliary regression results for the high frequency data. Before and after the introduction of the dummy variable, the coefficients of the US dollar yield against the offshore RMB also changes the least, suggesting that the offshore RMB is least affected by the US dollar. However, it is worth noting that there are findings in the low-frequency data that are inconsistent with the results of the high-frequency data, such as the sign of the US dollar yield coefficient for the offshore RMB in low frequency being negative, in contrast to the high frequency.

To analyse the reason behind this, we use the low-frequency RMB data as the explanatory variable and the low-frequency and high-frequency USD data as the explanatory variables, as shown in the following formula:

\[ \text{Rcnh} \sim \text{Rusdx(high)} + \text{Rusdx(low)} \]

Table 9 shows that the coefficient of the low-frequency US dollar is negative and significant while the coefficient of the high-frequency US dollar is positive and insignificant, which means that the negative coefficient of the US dollar against the offshore

| Table 9 |
| Coefficients of rusdx. | Estimate |
|----------------------|---------|
| Rusdx(high)          | 0.00000001702 |
| Rusdx(low)           | -0.1348*** |

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RMB in low-frequency is caused by the low-frequency US dollar data.

For further verification, we apply an auxiliary regression to the following formula:

\[ Rcnh(\text{high}) \sim Rcnh(\text{low}) + Rusdx(\text{high}) + Rusdx(\text{low}) \]

The coefficient of the high-frequency US dollar in Table 10 is significantly positive. It means that it is the wavelet that filters out the useful information which results in a positive coefficient of the US dollar in the high frequency data.

Therefore, we modify equation (1) as follows:

\[ R_{it}(\text{low}) = C + R_{it}(\text{high}) + Rusdx_t(\text{high}) + \sum_{i=1}^{8} D_i + r_i \]

Consistent with the treatment of the high-frequency data, the residuals from the auxiliary regression were fitted using a VAR-BEKKGARCH model.

As the low frequency data did not pass the unit root test, we used the difference method to eliminate the unit root and finally passed the ADF test.

5.2. Auxiliary regression analysis

The auxiliary regression analysis results (Table 11) show that most of the findings of the auxiliary regressions are consistent with the high-frequency data, with the following additional differences in the auxiliary regressions for the low-frequency data to the high-frequency data: (i) the coefficients on the offshore RMB dummy variables all turn out to be insignificant; (ii) apart from the Swiss franc, the Japanese yen also suffers from insignificant but positive shocks in all phases of the pandemic. In general, the coefficient results for the different phases of the pandemic on non-US currency yields tend to be close to zero and insignificant, and the trend analysis is not clear, indicating that there is information in the high frequency data that cannot be captured by the low frequency data.

5.3. Analysis of mean spillover effect

We used the residuals of the regression to fit the VAR-BEKKGARCH model. Ljung-Box test proves that the residuals after fitting the VAR model to the data are white noise, indicating that the selection of 1 as the lag coefficient is reasonable.

The results of the mean equation (Table 12) show taking the offshore RMB as explained variable and comparing it to the results of the high frequency data, frequency, the offshore RMB results are almost identical to the high frequency data; the Japanese yen only generates a negative spillover to the offshore RMB in the fourth stage; the spillover effect of the Canadian dollar disappears; the Swiss franc still generates a positive spillover to the offshore RMB, but occurs in the third stage; the euro only maintains a negative spillover in the fourth stage compared to high frequency data; the British pound spillover effect disappears; and the Australian dollar adds a positive spillover in the fifth stage. Overall, the low-frequency results remain consistent with the high-frequency results in terms of the direction of spillover, with acceptable errors in the stages.

The results of the mean equation (Table 13) shows that taking the offshore RMB as the explanatory variable, the low-frequency data results are almost identical to the high-frequency data results; the offshore RMB increases the positive spillover effect against the Japanese yen in the first stage; the offshore RMB increases the positive spillover against the euro in the fifth stage; the offshore RMB increases the negative spillover against the British pound in the first stage, and the offshore RMB remains consistent with the high-frequency results against the Canadian dollar, the Swiss franc and the Australian dollar. Overall, the low-frequency results remain consistent with the high-frequency results in the direction of the spillover, with acceptable errors in the stages.

5.4. Analysis of the volatility spillover effect

The results of the volatility spillover effect (Table 14) show that in contrast to the high frequency results, we can observe the following features: (i) the absence of the volatility spillover effects between the euro and Swiss franc and the offshore RMB in the second stage, but the disappearance of the bidirectional volatility spillover effects between the British pound and the offshore RMB. (ii) In the fifth stage, the unidirectional volatility spillover effects of the RMB against the euro, the Canadian dollar and the British pound disappear, reflecting the trend towards the independence of the offshore RMB. (iii) In the fifth stage, the volatility spillover effect from the offshore RMB against the Japanese yen turns from positive to negative, indicating a strengthening of the offshore RMB’s negative influence on the Japanese yen, contrary to the high frequency results. Although we observe a greater variation in the volatility spillover effect for the low frequency data, we focus on the high frequency data results as the information missing from the low frequency data

| Table 10 |
| --- |
| Coefficients of rcnh and rusdx. |
| | Estimate |
| Rcnh(low) | 1.097 |
| Rusdx(high) | 0.3315*** |
| Rusdx(low) | 1.650 |
|       | Explanatory Variable | RUSDX | D1    | D2    | D3    | D4    | D5    | D6    | D7    | D8    |
|-------|----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| RCNH  | No dummy variable    | 0.3315*** | −0.0000545 | 0.0000178 | −0.0000467 | −0.0000394 | −0.0000304 | −0.0000307 | −0.0000389 | −0.0000483 |
|       | Introducing dummy variable | 0.3314701*** | 0.00017 | 0.000311 | 0.000261 | 0.000273 | 0.000201 | 0.000233 | 0.000274 | 0.000203 |
| RJPY  | No dummy variable    | 0.5583*** | 0.00017 | 0.000311 | 0.000261 | 0.000273 | 0.000201 | 0.000233 | 0.000274 | 0.000203 |
|       | Introducing dummy variable | 0.558326*** | 0.00017 | 0.000311 | 0.000261 | 0.000273 | 0.000201 | 0.000233 | 0.000274 | 0.000203 |
| RCAD  | No dummy variable    | 0.6699*** | −0.0001557 | 0.0000011 | −0.0001264 | −0.0001059 | −0.0000974 | −0.0000920 | −0.0001565 | −0.0000888 |
|       | Introducing dummy variable | 0.6699038*** | −0.0001557 | 0.0000011 | −0.0001264 | −0.0001059 | −0.0000974 | −0.0000920 | −0.0001565 | −0.0000888 |
| RCHF  | No dummy variable    | 0.8622*** | 0.0000011 | 0.0000231 | 0.0000415 | 0.000089  | 0.0000436 | 0.0000148 | 0.0000352 | 0.0000108 |
|       | Introducing dummy variable | 0.8621987*** | 0.0000011 | 0.0000231 | 0.0000415 | 0.000089  | 0.0000436 | 0.0000148 | 0.0000352 | 0.0000108 |
| REUR  | No dummy variable    | 1.084***  | 0.0000039 | 0.0000051 | −0.000092  | −0.000107  | 0.000059  | −0.000007  | −0.000017  | −0.000017  |
|       | Introducing dummy variable | 1.0835062*** | 0.0000039 | 0.0000051 | −0.000092  | −0.000107  | 0.000059  | −0.000007  | −0.000017  | −0.000017  |
| RGBP  | No dummy variable    | 1.008***  | 0.0001292 | −0.0000774 | 0.0000794  | 0.0000607  | 0.0000461 | 0.0000592  | 0.0000647  | 0.0000489  |
|       | Introducing dummy variable | 1.0084346*** | 0.0001292 | −0.0000774 | 0.0000794  | 0.0000607  | 0.0000461 | 0.0000592  | 0.0000647  | 0.0000489  |
| RAUD  | No dummy variable    | 1.128***  | 0.000172  | −0.00031  | −0.000027  | −0.0000338 | −0.0000114 | −0.0000287 | −0.0000448 | −0.0000363 |
|       | Introducing dummy variable | 1.128253*** | 0.000172  | −0.00031  | −0.000027  | −0.0000338 | −0.0000114 | −0.0000287 | −0.0000448 | −0.0000363 |

Note: ***, ** and * represent significance levels of 10%, 5% and 1%, respectively.
Table 12
Regression results of the mean equation (CNH as explained variable).

|        | Stage 1 | Stage 2 | Stage 3-1 | Stage 3-2 | Stage 3-3 | Stage 4-1 | Stage 4-2 | Stage 5-1 | Stage 5-2 |
|--------|---------|---------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| L1.rcnh| -0.55412*** | -0.60827*** | -0.5357*** | -0.56474*** | -0.53574*** | -0.52115*** | -0.5099*** | -0.52225*** | -0.51995*** |
| L1.rjpy| -0.02037 | -0.02261 | 0.014405 | -0.00417 | -0.00614 | -0.02958** | -0.00056 | -0.00913 | 0.004214 |
| L1.rcad| -0.0439 | -0.02978 | 0.01661 | -0.00129 | 0.01733 | 0.004497 | -0.00194 | -0.00023 | 0.015828 |
| L1.rcnh | 0.02736 | 0.003444 | 0.052636* | -0.01098 | 0.00528 | 0.00314 | 0.008091 | 0.006285 | -0.00016 |
| L1.reur | -0.05365 | 0.034979 | 0.052937 | -0.02002 | -0.01832 | 0.001424 | -0.04439* | -0.05454 | -0.02311 |
| L1.rgbp | -0.01641 | -0.01572 | 0.017209 | -0.00554 | 0.00405 | -0.00526 | -0.00659 | -0.01414 | -0.0142 |
| L1.raud | 0.030454 | 0.08471*** | -0.01277 | 0.01767 | -0.01792** | 0.002557 | 0.030454 | 0.08471*** | -0.01277 |

Note: ***, ** and * stand for significance levels of 10%, 5% and 1%, respectively. Due to limited space, this table lists only the mean value model outcomes with the offshore RMB (CNH) as the explained variable.
policy should be focused mainly on the fundamentals of the domestic economy instead of providing yields to the outside world to

and the Australian dollar); the third is a significant volatility spillover effect is observed with an enhanced influence of the offshore

impacted by the negative spillover effect of offshore RMB during the second/third stage of the outbreak. Nevertheless, the RMB

second is a significant volatility spillover effect with a waning influence of other currencies (mainly the British pound, the Japanese yen

significant negative spillover effects on the offshore RMB in the fourth and fifth stages only. Meanwhile, non-USD currencies were also

progress of internationalization will inevitably become sluggish, putting the stability of the RMB exchange rate at risk. Interest rate

unsustainable for China to maintain positive spreads with other economies. Once the positive spreads begin to recede or fade, the

such uncertain risks to onshore markets, to which end liquidity management in offshore markets is imperative.

is the first time we observe such tendency during the decade of RMB internationalization. Whether this RMB independence will last

more independent afterwards. This independence trend results in the marginalization of RMB in the global currency ecosystem, which

Note: ***, ** and * stand for significance levels of 10%, 5% and 1%, respectively. Due to limited space, this table lists only the mean value model

Table 13
Regression results of the mean equation (CNH as the explanatory variable).

| Stage 1 | Stage 2 | Stage 3-1 | Stage 3-2 | Stage 3-3 | Stage 4-1 | Stage 4-2 | Stage 5-1 | Stage 5-2 |
|---------|---------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| L1.rjpy | 0.0961* | 0.177061*** | 0.021949  | -0.00024  | 0.021734* | 0.007443  | 0.052945*** | -0.00173  | -0.04504** |
| L1.rcad | -0.0108  | -0.092905*** | -0.05863  | 0.05379   | 0.016983  | 0.011299  | -0.0421*   | -0.02281  | -0.01865  |
| L1.rchf | 0.0681   | 0.097454*** | -0.0381*  | -0.04375  | 0.018355* | -0.02138  | -0.01281   | -0.0242   | -0.01869  |
| L1.reur | -0.0037  | -0.03372*** | -0.02843  | 0.003475  | 0.006088  | -0.00369  | -0.00834   | -0.00127  | 0.013085* |
| L1.rgbp | -0.1131* | 0.009304   | -0.03333  | -0.02468  | -0.04821* | 0.012807  | 0.021211   | 0.011088  | -0.01341  |
| L1.raud | -0.0497  | -0.4239***  | -0.11927  | -0.04751  | 0.01579   | 0.004935  | -0.03081   | 0.008957  | -0.02602  |

compared to the high frequency data have a greater impact in this model.

6. Conclusion and implication

This paper aims to study changes in the characteristics of the relationship between the RMB and major non-USD currencies at five

stages of the COVID-19 pandemic by means of auxiliary regression analysis with a VAR-BEKK-GARCH model. From the empirical

results, we observe that in the beginning period of pandemic, the influence of RMB on the global currency market significantly

increased compared with the period before COVID-19. Nevertheless, as the pandemic progressed, this influence quickly declined

among most of the non-USD currencies while in the later stage of pandemic, the RMB suffered significant negative spillover effects

from the British pound and the euro, as well as the significantly negatively affected on Japanese yen. This changing process of currency

influence of RMB can be further broken down as below.

First, the offshore RMB’s independent yield has been subject to a positive impact at five stages of the pandemic, and the RMB has

depreciated to a certain extent under direction quotation. After we introduce dummy variables, the absolute value of the change in the

onshore RMB coefficient is the smallest among the considered currencies, while those of the yen are the largest. This indicates that after

the outbreak of COVID-19, the influence of the dollar’s yield on the offshore RMB’s yield has been more stable than other non-USD

currencies, and there has been no significant change.

Second, as pandemic progressed, the non-USD currencies influenced the RMB in the following ways: yields of Japanese yen and Swiss

franc have significant spillover effects on the offshore RMB in the first and second stages only; yields of Canadian dollar and Australian

dollar have significant spillover effects on the offshore RMB lasting until the third stage; yields of the British pound and the euro have

significant negative spillover effects on the offshore RMB in the fourth and fifth stages only. Meanwhile, non-USD currencies were also

impacted by the negative spillover effect of offshore RMB during the second/third stage of the outbreak. Nevertheless, the RMB’s

spillover effect on other currencies’ yields gradually declined as we move into the fifth stage of pandemic, suggesting that the influence

of the RMB declines in the latter stages of the pandemic. The declining influence of RMB also suggests its growing independence in the

global currency market. Interestingly, we noticed that the RMB spillover effect on the Japanese yen dramatically turned from positive

in earlier stages to significantly negative in latter stages, which may request extra attention in the currency market.

Third, three types of changes in the volatility shows spillover between the offshore RMB and other non-USD currencies: the first is

structural changes to the characteristics of the volatility spillover effect (mainly with respect to the Swiss franc and the euro); the

second is a significant volatility spillover effect with a waning influence of other currencies (mainly the British pound, the Japanese yen

and the Australian dollar); the third is a significant volatility spillover effect is observed with an enhanced influence of the offshore

RMB (mainly with respect to the Canadian dollar).

In conclusion, changes in the mean spillover effect, volatility spillover effect and volatility continuity prove that the COVID-19

pandemic has, to a certain extent, improved the RMB’s global influence when the pandemic was first spreading in China and thus

opened a favourable window for RMB internationalization, but the influence faded as the pandemic progressed and the RMB became

more independent afterwards. This independence trend results in the marginalization of RMB in the global currency ecosystem, which

is the first time we observe such tendency during the decade of RMB internationalization. Whether this RMB independence will last

depends on the future currency fundamentals of China and monetary policy interaction between China and other major economies. It,

thus, becomes clearer that the China government needs to adjust its policy of RMB internationalization and avoid related risks.

The first policy suggestion based on this study would be to enhance RMB liquidity management in offshore markets. Our empirical

research shows that the pandemic has made the offshore RMB relatively independent, yet there is a tendency for it to be influenced by

non-USD currencies with a larger SDR share. It is important for the prevention of overseas risk contagion to reduce the transmission of

such uncertain risks to onshore markets, to which end liquidity management in offshore markets is imperative.

Secondly, we are aware of the negative impact of high spreads between yields at home and abroad on RMB internationalization.

Since the pandemic began, major economies have adopted unconventional monetary policy, and the combined effect of the favourable

interest rates on domestic bond markets and the quick recovery of China’s economy ahead of the rest of the world has spurred strong

interest of foreign investors in China’s bond markets. Although the fundamentals of China’s economy have further improved, it is

unsustainable for China to maintain positive spreads with other economies. Once the positive spreads begin to recede or fade, the

progress of internationalization will inevitably become sluggish, putting the stability of the RMB exchange rate at risk. Interest rate

policy should be focused mainly on the fundamentals of the domestic economy instead of providing yields to the outside world to
Table 14  
Estimates of volatility spillover effect.

|       | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 | Stage 7 |
|-------|---------|---------|---------|---------|---------|---------|
| cnh-jpy |         |         |         |         |         |         |
| a12   | -0.11452466** | -0.16236370 | -0.01791468 | -0.013396200 | -0.032486234** | -0.002441164 | -0.060377722*** | -0.047052911 | 0.048239256** |
| b12   | 0.20299735*** | 0.023422370 | 0.014457770*** | 0.009089715 | 0.012304293 | -0.008041732 | 0.024430401 | -0.006458082 | 0.008573345 |
| b21   | -0.053071099 | -0.006651708** | -0.006651708** | -0.010615702 | -0.034568915** | -0.014190733 | -0.074647295*** | -0.00447478 | -0.040178672*** |
| cnh-cad |         |         |         |         |         |         |
| a12   | 0.016057193 | 0.021257987 | 0.012831936 | 0.023780637 | 0.021121113 | 0.006380897 | 0.04317644** | 0.080127945** | 0.025849804 |
| b12   | 0.044560294 | 0.053192859** | 0.0294794659** | 0.001217904*** | 0.002586822 | 0.003614351 | 0.001269109 | 0.008573874 | 0.008040334 |
| b21   | -0.013721098 | -0.002846622 | -0.013715379 | -0.000225057 | -0.008942153 | -0.0003922369 | -0.007438987 | -0.005710987 | -0.007438987 |
| cnh-chf |         |         |         |         |         |         |
| a12   | 0.036281093 | 0.002895465 | 0.019035806 | 0.039599543 | 0.011503291 | 0.007236562 | -0.002506499 | 0.026742697 | 0.006434274 |
| b12   | -0.039673065 | -0.020417477 | -0.075659050** | 0.005757120 | 0.008092365 | -0.0467398 | -0.013470919 | 0.004707497 | 0.003157232 |
| b21   | 0.112682799** | -0.015466152 | -0.024609353 | -0.045343617 | 0.002946202 | 0.022714262 | 0.041616175** | -0.014058435*** | -0.007418242 |
| cnh-gbp |         |         |         |         |         |         |
| a12   | -0.013724192 | -0.009394153 | 0.009911304*** | -0.0022170625 | 0.002391039 | 0.002387881 | -0.005279001 | -0.06437416 | -0.022673929** |
| b12   | 0.138441468 | -0.010353323 | -0.021367144 | -0.009672468 | 0.00882510 | -0.003846386 | 0.000232158 | 0.006973229 | -0.014032571* |
| b21   | -0.046526217*** | -0.000494284 | -0.006664180 | 0.003363634 | 0.018776713** | 0.0004306133 | 0.007779004 | 0.001510162 | 0.008501557 |
| cnh-aud |         |         |         |         |         |         |
| a12   | 0.062732792 | -0.037267653 | 0.065717761 | 0.073558244 | -0.036646662 | -0.046532800 | -0.076831548*** | 0.031694642 | -0.048389455 |
| b12   | 0.136374955*** | -0.002473165 | -0.024606712 | 0.018531172 | 0.000170340 | 0.000700327 | 0.016131429 | 0.010203233 | 0.007551312 |
| b21   | 0.039674636 | 0.008512359 | 0.027181475** | 0.024032858* | -0.006510300 | 0.020007731 | 0.005845484 | 0.027744732* | 0.021292060* |
| cnh-aud |         |         |         |         |         |         |
| a12   | -0.070502074 | -0.001551018 | 0.055155215 | 0.005921570 | 0.066399708*** | -0.064289901*** | -0.031201344 | 0.0167128994 | -0.001799198 |
| b12   | -0.014436479 | -0.002948697 | 0.026813617** | 0.003143153*** | 0.008379327 | 0.030119090*** | -0.002203331 | -0.014756228 | 0.003998662 |
| b21   | 0.074515946 | 0.037299993 | 0.269709344** | 0.048123556 | -0.003460471 | 0.035296145 | 0.061002266 | 0.044582988 | 0.050034550** |
| cnh-aud |         |         |         |         |         |         |
| a12   | -0.048222913 | -0.034683166** | 0.010210470 | -0.01508867* | 0.018195148* | 0.019469790 | 0.010298094 | 0.006792468 | 0.004373780 |
| b12   | -0.208573470*** | -0.013856044*** | 0.05215325 | -0.022974414 | -0.001995386 | 0.026229581 | 0.041334275 | 0.03204634 | 0.139793272** |
| b21   | 0.033749149 | -0.002886512 | -0.013647477 | 0.003290179** | -0.016054307 | 0.024573658** | 0.021552798*** | -0.028245605*** | -0.005423297 |

Note: Nonmain diagonal elements: a12 is the ARCH volatility effect from the offshore RMB’s independent yield to the yen’s, and a21 is the opposite; b12 is the GARCH volatility effect from the offshore RMB’s independent yield to the yen’s, and b21 is the opposite one.
promote internationalization.

Thirdly, enhance the RMB’s overseas liquidity and expand demand for the RMB. Expanding demand for the RMB is an important prerequisite to keeping the RMB’s overseas influence stable. Though the RMB has been consistently among the top six in the currency ranking for global payments, it still has a relatively small market share, while the US dollar remains the most important currency for payments. Steadily expanding overseas demand for the RMB is key to keeping the RMB’s influence stable, for example, by expanding the scale of currency swaps between central banks, mapping out more RMB cross-border settlement networks, and increasing overseas RMB loans through institutions such as the Asian Infrastructure Investment Bank (AIIB).

In addition, we hope to make the following recommendation to global investors. In the fifth stage, we can observe a tendency for the offshore RMB to show independence and the negative spillover effects from the British pound and the euro, a phenomenon that does not reflect the stability and safety of offshore RMB yields. Therefore, for global investors, there is still a need for diversification when faced with the need to hedge against exchange rate risk with extra caution in expanding investment in RMB assets.

Besides the significant impact of COVID-19 and potential change in China’s monetary policy, dramatic geopolitical incidents such as the Russian-Ukrainian war also bring great uncertainty in the RMB currency structure. In the face of the turmoil in global financial markets caused by superposition factors including pandemic, economic uncertainty and the Russian ruble being kicked out of SWIFT, our follow-up research would like to focus on the interaction and relationship between geopolitical affairs and the spillover effect of RMB, in order to further complete the picture of the changing global currency market.

Author statement

Conceptualization - Chang Rong, LU Funding acquisition - Chang Rong, LU Project administration - Chang Rong, LU Supervision - Chang Rong, LU Writing - original draft - Chang Rong, LU & Fandi, YU Review and editing - Chang Rong, LU & Fandi, YU Data curation - Fandi, YU Investigation - Fandi, YU Methodology - Chang Rong, LU & Jia Xiang, LJ Formal analysis - Jia Xiang, LJ Software and programming - Jia Xiang, LI Validation - Jia Xiang, LI Visualization - Jia Xiang, LI Resources - Lian, LIU Advice - Lian, LIU.

Data availability

The data that has been used is confidential.

Acknowledgement

This paper is recognized and sponsored by the funding as below: Youth projects of National Social Science Foundation, and currently presiding over the topic of “Study on the Global RMB Supply-Demand Mechanism from the Perspective of International Financial Public Goods” (Project No.: 19CGJ045); Youth Project for Humanities and Social Sciences Research of Chinese Ministry of Education 2017: Research on the Dilemma of Supply and Demand of International Financial Public Products – taking global dollar liquidity as an object of study (ID: 17YJCZH117) and General program of Shanghai Social Science Project 2017: A Research on RMB internationalization Path Selection within the New Normalcy – A Focus on Relationship between Supply and Demand of International Financial Public Goods (ID: 2017EGJ002).

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