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Abstract

The paper dynamically analyzes the recent RMB internationalization development. Unlike previous studies, we study the level of currency internationalization using explanatory factor analysis and rolling correlation calculation and report evidence that the Chinese RMB is still not a completely internationalized currency, but overall is internationalizing with a positive trend. Moreover, based on a Bayesian-based causal impact analysis, we study the effect of the COVID-19 pandemic on the process of RMB internationalization.

Keywords: RMB internationalization; Factor analysis; COVID-19 pandemic; Bayesian Causal impact

JEL Classification: C11, C32, C58, F31

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1 Introduction

During the Second World War, the US Dollar (USD) became the world's most powerful currency and is still of central status. However, after the collapse of the Bretton Woods System[1] in 1973 and the global recession triggered by the US subprime loan crisis from the end of 2007 to 2009, people started to realize that there are problems in the USD-centered system and this powerful currency might not be as stable as they thought (Cooper et al., 2009; Goldberg, 2010; Kim, 2011; Wyplosz, 2010). Meantime, China overtook Japan and became the world's second-largest economy. Chinese economy developed so rapidly that scholars turned their focal point to China's currency, the Yuan (RMB). The Chinese government has also mapped out strategies, projects, and policies to promote RMB internationalization. For example, the Belt and Road Initiative Project, also called "One Belt One Road (OBOR)", was proposed by President Xi Jinping in 2013, aiming at promoting international trade and investments in nearly 70 countries often located near China. As a result, International Monetary Fund (IMF) included RMB into the Special Drawing Rights (SDR) basket[2] in 2016, admitting its global impact on the world's economy. According to the reported currency SDR value from Bank for International Settlement (BIS), RMB is weighted 10.92% in the currency basket, ranking in third place in 2015. Considering these backgrounds, discussing the strategy and policy choices for promoting the RMB to become an internationalized currency is meaningful.

We examine the recent situation of currency internationalization and the impact of a recent pandemic (COVID-19) on RMB internationalization, with the Exploratory Factor Analysis (EFA) and the Causal Impact (CI) Analysis. A fall in global trade caused by COVID-19 is expected to reduce the use of foreign exchanges such as the RMB. But since the determination of settlement currencies requires agreement between traders through a legal process, RMB internationalization may have been affected little. Therefore, we clarify if there are any changes in RMB internationalization using advanced time-series techniques.

The paper is written based on several theories and previous empirical works. According to the standard economic theory, a currency is defined as money with functions including the unit of account, the medium of exchange, and the store of value. Nor-

[1]The Bretton Woods System is a monetary management system established after the signing of the Bretton Woods Agreement in 1944 among the United States (US), Canada, Western European countries, Australia, and Japan.

[2]The Special Drawing Rights (SDR) was created by the International Monetary Fund (IMF) in 1969. SDRs are units of account for the IMF and represent a claim to currency held by IMF member countries for which they may be exchanged. The SDR weights and values are calculated every five years.

rlof (2009) expands this definition specifically for the world's key currencies with the private and public sectors. We use a factor model in the empirical analysis to obtain a proxy for key currencies from major exchange rates assumed to possess these three functions for key currencies and infer the underlying factors behind currency internationalization. The next section reviews previous studies to clarify our contributions to existing literature.

2 Literature Review

While the discussion on currency internationalization started very early, RMB internationalization became a popular topic after 2010. Most researches were qualitative and discussed the possibility of RMB internationalization or whether RMB was an internationalized currency at their time. These studies often concluded that RMB is not yet an internationalized currency, but it can become one (Dobson and Masson, 2009; Huang and Lynch, 2013; Nakagawa, 2004; Tung et al., 2012).

After 2013, different topics and more quantitative research appeared, while some researchers continue to study whether the RMB is already an internationalized currency since little evidence has been provided to support the complete internationalization of the RMB(Campanella, 2014). One popular topic is the analysis of influential factors of RMB internationalization. Factors such as economic size (Chen, 2018; Peng and Tan, 2017), economic degree of freedom and financial openness (Jin and Du, 2014; Lyratzakis, 2014; Peng and Tan, 2017; Wu and Tang, 2018; Zhang, 2013), the volume of international trade and investments (Wu and Tang, 2018; Zhang, 2017), and the stability of exchange rate and its system (Fan et al., 2015; Wu and Tang, 2018) are most highly mentioned. Other scholars analyze the relationship between RMB internationalization and specific events such as constructing RMB offshore market in Hong Kong (Maziad and Kang, 2012), proposing the Belt and Road Initiative (Wu and Tang, 2018; Yu and Cao, 2015; Zhang et al., 2017), being included in Special Drawing Right (Wei, 2020), and promoting RMB international invoicing (Lai and Yu, 2015). These factors are selected based on the criteria for key currencies.

Norrlof (2009) summarizes the key currency definition and functions that can be used to assess currency internationalization. As the function of the unit of account, a currency should be able to indicate prices of goods and services (e.g., export and import). In this respect, market size and currency stabilization can become factors in determining payment currencies. The function of medium of exchange serves as a payment means for individuals and officials when trading. This may be reflected in the share of a currency in the world's trading activity. As the function of store of value, the definition is highly related to exchange rate stability. The currency's value should not decline excessively over time if it has a high store of value.

Among quantitative research, constructing index models is most commonly used to measure the RMB internationalization degree. Currently, the most authoritative index specifically for the Chinese Yuan is called "RMB Internationalization Index (RII)" developed by a group of scholars from the International Monetary Institution, Renmin University of China (Tu et al., 2013). Other scholars construct indexes or economic models to measure the internationalization degree from different aspects. For example, Dobson and Masson (2009) measure the RMB internationalization degree with an index called Reserve Currency Ratio with IMF data simply from the reserve aspect. Tung et al. (2012) construct a currency internationalization degree index with Principal Component Analysis (PCA) to measure current RMB internationalization status. Zhang (2017) creates a macroeconomic model with three sectors, including household, enterprise, and government to measure the RMB internationalization degree. Cheng et al. (2018) examine the internationalization degree under trading patterns with a model including trading volume, trading value, market concentration, and trading network.

Few researchers study RMB internationalization, specifically the relationship between the COVID-19 pandemic and RMB internationalization. Most of them focus on discussing the influence of the COVID-19 pandemic on other financial aspects. Wei et al. (2020) conclude that the COVID-19 outbreak in China caused the foreign exchange markets to become unstable and risky, which might have already changed the monetary system. Cristina and Ramona (2020) conclude that the COVID-19 pandemic will promote a more profound reform of the world and Chinese financial systems. But they have yet to make specific conclusions like this research.

Therefore, despite many academic works on RMB internationalization, many questions still need to be addressed. For example, scholars have yet to agree on whether the RMB has already been internationalized. Additionally, there are many ways to define RMB internationalization and its realized conditions. Tavlas (1990) and Kenen (2011) consider that the three functions of key currencies (medium of exchange, unit of account, and store of value) should be realized simultaneously so that the currency can be regarded as an internationalized currency. Zhou and Wen (2001) deem that the functions should be realized step by step following different stages, including forming exchange relations with other countries, opening currency and capital projects, and becoming other countries' storage currency. Also, Liu (2003) and Dong and Yao (1997) conclude that the process of RMB outside the home country should be considered RMB internationalization.

Against this background, we contribute to the following aspects of the currency or RMB internationalization area. First, recent situations of RMB internationalization are updated because the article covers recent data. Second, we obtain a proxy for a key currency from selected exchange rates based on the EFA and propose using rolling correlation to measure the level of currency internationalization. Finally, we conduct the CI analysis to investigate the influence of the COVID-19 pandemic on RMB internationalization using the factors from the EFA.

3 Exploratory Factor Analysis

There are several ways to find a benchmark for the key currency. Here, we use a factor model that allows us to extract common features among economic variables because currency internationalization is abstract progress. Other measurements such as the foreign reserves data from IMF Currency Composition of Official Foreign Exchange Reserve (IMF-COFER)[3] and currency international payment share data from the Society for Worldwide Interbank Financial Telecommunication (SWIFT)[4] may be more direct approaches to examine currency internationalization. COFER data order currencies with SDR basket weights as a reference to show the ranking of total foreign exchange reserves of currencies. It can, in some aspects, reflect countries' willingness to have the currency due to its power and stability. However, the data are in quarter frequency, and the time range is quite short (from 2016 to the present). The amount of observations is not enough for accurate empirical research. SWIFT data provide monthly information on RMB's value share as a global payment currency in the world's trade markets from 2012 to the present. Although the SWIFT dataset's time range is longer than that of COFER, part of RMB data are categorized as "Others" due to its low share, causing missing data. For these reasons, we estimate a proxy for key currencies using the factor model and major exchange rates.

Our approach is similar to Tung et al. (2012), who applied PCA to key determinants of currency internationalization, such as the market capitalization ratio, the GDP ratio, price stability, and exchange rate stability. However, since these data are available at low frequency but we need high-frequency data to assess the impact of the pandemic on RMB (2020–), common features are extracted from influential exchange rates and

[3]https://data.imf.org/?sk=E6A5F467-C14B-4AA8-9F6D-5A09EC4E62A4

[4]https://www.swift.com/our-solutions/compliance-and-shared-services/business-intelligence/renminbi/rmb-tracker

are used to measure the internationalization level by comparing their common features with RMB. A high correlation between the common factors and RMB implies a high internationalization level. Therefore, our approach does not directly utilize the concept of key currencies but employs currencies and exchange rates that are believed to meet the condition of key currencies. Clearly, if our proxy data positively correlate with SWIFT and COFER, then it is effective and reliable to evaluate the internationalization degree of currencies.

In the following part, we will explain how exploratory factor analysis works with mathematical details and show how the extracted factors serve a role in influencing currency internationalization. The study's variable grouping process will also convey meaningful information about potential influencing factors.

3.1 Mathematical Principles and Conditions

Exploratory Factor Analysis (EFA) is a data dimension reduction technique used to discover the latent structure and complex pattern of a set of variables (Bai et al., 2015; Yong and Pearce, 2013). In this paper, interpreting factor analysis results is a critical mission. The group clustering results, the factor scores, and the linear functions representing the relationship between underlying factors and variables varying by time can help complete this task. Researchers such as Öcal et al. (2007) and Bai et al. (2015) acquire valuable information on the data through the grouping process. According to the previous works (Yong and Pearce, 2013), two essential conditions must be fulfilled before conducting the EFA. First, the criterion of sample size should be sufficiently large. Second, the correlations among variables in the data set should not be larger than 0.9 because it indicates there might have a multicollinearity problem in the data.

The classic mathematical expression of EFA is:

$$X_j = a_{j1}F_1 + a_{j2}F_2 + \ldots\ldots a_{jm}F_m + e_j \tag{1}$$

where j = 1, 2, ..., p, p represents the number of variable, and m represents the number of underlying common factors F. The letter a denotes factor loadings, where a_{j1} means the factor loading of jth variable on the first factor. The term e is the error term and represents idiosyncratic factors.

Before conducting the EFA, several conditions should be fulfilled. The sample size should be larger than 300, and the correlations among variables should not be larger than 0.9 because this means a multicollinearity problem might exist in the data (Yong and Pearce, 2013). Additionally, the data for conducting EFA should pass the Kaiser-Meyer-Olkin (KMO) Test and the Bartlett's Test of Sphericity, with a KMO value larger than 0.5 and a p-value smaller than 0.01 (Bartlett, 1954; Kaiser, 1958). The number of factors is determined by drawing a scree plot, and those factors extracted with an eigenvalue larger than one can be used as common factors (Kaiser, 1960). Communality is another concept that can be used to judge whether a variable should be kept after conducting the factor analysis. Equation (2) denotes the mathematical expression of calculating commonality, and any variable with a commonality before rotation smaller than 0.4 should be deleted.

$$h_j^2 = a_{j1}^2 + a_{j2}^2 \ldots \cdots + a_{jm}^2 \tag{2}$$

As a data dimension reduction technique, the primary purpose of using factor analysis in this research is to find common features behind internationalized and key currencies and then extract these features as influential factors of currency internationalization. One of the main tasks of the research is to find out the gaps between the RMB and other internationalized currencies; thus, it is necessary to acquire influential factors, which are the factors extracted among internationalized and key currencies, that influence currency internationalization and guide the development of RMB internationalization. Besides, exchange rate data can provide information about a country's economic conditions, international competitiveness, and even domestic consumer market situations. Extracted common factors can generalize the information wanted, but the disadvantage is that interpreting the factors is always challenging in the factor analysis, even when most of the information has been extracted. Therefore, we shall conduct factor analysis with several groups of exchange rates believed to be relatively important in the global market.

3.2 Data Description, Eligibility & Results

Eleven influential currencies are selected for EFA, divided into internationalized and internationalizing currencies. According to the turnover report of currency foreign exchange instruments from the BIS[5], internationalized currencies include US Dollar (USD), Euro (EURO), Japanese Yen (JPY), Pound Sterling (GPB), Canadian Dollar (CAD) and Australian Dollar (AUD). Another internationalized currency, the Swiss Franc (CHF), is performed as a benchmark of the nominal exchange rate data. Other five internationalizing currencies come from BRICS countries, including the Chinese Yuan (RMB), Russian Ruble (RUB), Brazilian Real (BRL), Indian Rupee (INR), and South Africa Rand (ZAR). The frequency of the data is monthly, and the time range is from January 1999 to December 2021, acquired from FxTop historical exchange rate

[5] https://stats.bis.org/statx/srs/table/d11.3

database.[6] All exchange rates are in natural logarithmic form and first difference. Data description details and graphs are shown in Table 1 and Figures 1 and 2. In total, there are 276 observations under each currency.

Moreover, Table 2 presents a correlation matrix. The correlations of INR, BRL, and ZAR with other currencies are mostly low. Thus, they can be deleted for conducting EFA without losing vital information required for the accuracy of the factor extraction. After deleting these currencies, the new data set should pass the KMO and Bartlett's Test. The rotation technique is called "*Varimax*", meaning the number of variables with high loadings on each factor has been minimized, and the number of variables with smaller loadings is smaller (Yong and Pearce, 2013). Before rotation, all variables were clustered under one factor. After rotation, variables should be clustered under several factors, which will help to interpret the results easily.

Then, factor analysis is conducted three times with different variables and purposes. The first-factor analysis is performed with eight currencies. The second-factor analysis is conducted just among the six internationalized currencies, including USD, EURO, JPY, GPB, CAD, and AUD. This is to examine how these key currencies are grouped. These results will detect some potential influencing factors of currency internationalization. The third-factor analysis is conducted among the three strongest currencies (USD, EURO, and GPB), extracting only one factor that will include the most information on internationalized currencies. The standard of picking the strongest currencies is based on the turnover report of currency foreign exchange instruments from the BIS mentioned previously. Although it shows that JPY surpassed GPB around 2016 to be the third strongest currency, overall, GPB has a longer period to be the third place. Thus, the three strongest currencies in the paper are USD, EURO, and GPB. After acquiring this single factor, an estimated exchange rate time series data can be formed for the next step. Table 3 indicates that all data with different variable combinations have passed the KMO and Bartlett's tests.

Table 4 and the left part of Figure 6 show factor analysis results with eight currencies. The USD, JPY, and RMB are clustered under Factor 2, and the rest of the currencies are under Factor 1. In total, the two factors explain 60% of the whole data set. After deleting the data of RMB and RUB, Table 5 and the right part of Figure 6 indicate the results of 6 currencies, where CAD and AUD are under Factor 1, USD and JPY are under Factor 2, and EURO and GPB are under Factor 3. In total, the three factors explain 70% of the whole data.

The correlation matrix in Table 2 shows that the correlation values among USD,

[6] https://fxtop.com

RMB, and JPY are high, relatively, 0.6034, 0.7914, and 0.5006. This is probably the reason for their clustering with each other in the grouping process. The correlation value between GPB and USD is 0.6110, and almost 0.5 between GPB and RMB. However, GPB does not cluster with USD and RMB but with EURO and RUB, even though the correlation between RUB and GPB is slightly lower. According to the World Bank's GDP ranking, the economic size of the United Kingdom is closer to that of Russia, and the United States, China, and Japan are the three top economies in the world. Thus, economic size can be another reason for this grouping results. Also, in Table 2, it is evident that RMB has relatively low correlations with countries that are far away from it, such as EURO (0.3474), CAD (0.4625), AUD (0.2437), and RUB (0.3620). Not just RMB, JPY has a similar situation (EURO 0.3565, CAD 0.3640, AUD 0.2536, RUB 0.2138). These results might be evidence that, except for economic size, geographical location could be another important, influential factor for the determination of particular currencies used in the payment system, which is consistent with previous studies (He et al., 2016; Korhonen et al., 2015; Xueyan, 2017) and provides indirect evidence that the Belt and Road Initiative project has become a driving force of RMB internationalization.

As Factor 1 extracted most information from the data, significant tests for Factor 1 from factor analysis with six currencies and three world's strongest currencies are conducted to see whether the results are significant to all included currencies and the RMB. For the factor analysis with three currencies, since only one factor was extracted, there is no need to rotate. The factor loadings under the sole factor are 0.64, 0.57, and 0.96 relative to USD, Euro, and GPB. According to Table 6, no matter which Factor 1 is, the results are all significant, meaning the factor analysis results are meaningful and reliable. Thus, according to the linear function of factor analysis, estimated time series exchange rate data can be acquired, representing the exchange rates influenced by the factor extracted. The rolling correlations with a moving window size of 3 are calculated between the original exchange rate data and the estimated data.

Since RMB internationalization progress is a dynamic process changing over time, the rolling correlation data of RMB should expect to be significant to the time change. Here, natural numbers starting from 0 represent the time change. Results can be seen in Table 7. In the left part, the rolling correlations are calculated with Factor 1 from all six internationalizing currencies, where only USD and RMB results are significant. Results in the right part show that Factor 1 extracted from 3 currencies' factor analysis is most significant to RMB but less significant to USD and EURO and not significant to GPB. Since Factor 1 from 6 currencies includes more information on internationalization and the results of time trend are significant, the rolling correlation calculated with this Factor 1 of RMB can represent the internationalization process and will be used as the data set for the causal impact analysis. Figure 4 and Figure 5 plot the rolling correlation of all internationalized currencies and RMB. Comparing the figures indicates that for internationalized currencies, dots are mostly clustered near the top of the graph with values closer to 1. That makes the trend line flatter. The dots in the RMB graph spread over the panel, and the trend line slope is much steeper. Thus, RMB has not been completely internationalized yet. Still, since the trend line slope is positive and the dots start to get close to value 1, this ongoing process is positive, and finally, the RMB will be an internationalized currency.

The reason for selecting the exchange rate as a concrete measurement of currency internationalization is mainly based on related economic theories and previous research (Ding et al., 2020; Wang et al., 2022; Xun et al., 2019). As a key currency, the currency must serve as a medium of exchange, a unit of account, and a store of value. The exchange rate is an important standard for conveying these functions. According to Norrlof (2009) and Hartmann and Issing (2002), a key currency, or an internationalized currency, should have the ability to maintain price stability, and the price of the currency refers to the exchange rate. Thus, examining currency exchange rates is reasonable for measuring whether a currency is internationalized.

Finally, to demonstrate their similarity with our proxy for currency internationalization, we show their correlation in Table 8. We use three-month averages as quarterly data for SWIFT and rolling correlation data and find that our proxy for currency internationalization positively correlates with COFER and SWIFT (0.4537 and 0.2282). A positive correlation means that our proxy of currency internationalization shares similar information with COFER and SWIFT in some aspects, and since the correlation with COFER is higher than that with SWIFT, our proxy for currency internationalization is more in line with COFER that records the currency composition of holdings of foreign exchange reserves.

4 COVID-19 Impact on RMB Internationalization

On January 31st, 2020, the World Health Organization (WHO) Emergency Committee announced the COVID-19 pandemic had become a worldwide health emergency based on the growing cases in different places (Velavan and Meyer, 2020). From the news on TV and the Internet, it is claimed that this worldwide health emergency is the cause of the economic downturn, but it has no academic evidence. Thus, it is necessary to explore the impact of the COVID-19 pandemic. The world's economy and financial market have been hugely influenced since the COVID-19 pandemic. During the COVID-19 pandemic in China, companies and factories stopped working; people were locked down at home in many cities. The crash risk of the stock and bond market in China was more strongly affected by the pandemic (Liu et al., 2021); the expected results of the COVID-19 pandemic causal analysis should be negative.

Previously, pandemics such as Severe Acute Respiratory Syndrome (SARS) and Swine Flu (H1N1) have been proven by researchers that such worldwide pandemics have a negative impact in the short term. For example, Fan (2003) concludes that the appearance of the short-term negative impact of SARS on the economy is reducing demand. She also considers that the so-called long-term effect of SARS is on the strategy of preventing the pandemic. Hai et al. (2004) stress that SARS negatively influenced the Chinese economy in the short term and hit the tourism sector the most. Beutels et al. (2009) has similar conclusions, but the research object is Beijing City. Research related to H1N1 is mainly conducted with single-country samples, but the findings also have a short-term negative impact on the economy and financial sectors. Tracht et al. (2012) confirm that the H1N1 pandemic has caused short-term economic loss due to the wide use of face masks. Rassy and Smith (2013) conclude that the negative impact of H1N1 on Mexico's pork and tourism sector lasts around five months.

Another reason for the hypothesis is that existing researches and facts prove that the COVID-19 pandemic can negatively influence RMB internationalization through different channels shortly. According to researchers such as Wei et al. (2020) and Gunay (2021), the COVID-19 pandemic has induced disturbances and shocks in financial markets. Besides, according to Batten and Szilagyi (2016) and Ming and Zhang (2017), international trade or cross-border trade is an important channel to promote RMB internationalization. Researchers such as Gruszczynski (2020) and Hayakawa and Mukunoki (2021) have proved with empirical methods that COVID-19 has a short-term negative impact on international trade in most industries. During the pandemic, the Chinese government has closed many factories and shops, canceled multiple transportation lines, and stopped international trade to prevent the virus from infecting more people. Thus, it is not surprising to see that the pandemic has influenced RMB internationalization in some aspects, and the negative impact lasted for a while due to the timeline of restrictions from the government.

4.1 Causal Impact Methodology

Brodersen et al. (2015) developed the causal impact technique to analyze the impact of an intervention with time series data. They defined the causal impact as the difference between the reality (observed data) and the counterfactual. The counterfactual data can be acquired through direct estimation with the observed data, data with similar behavior, and models with prior knowledge. The data before and after the event time point is relatively called pre-period data and post-period data.

The most commonly used approach to infer a causal relationship before and after an intervention is the Difference-in-Differences (DID) method with a cross-sectional data set. However, the standard DID is often static and only considers two-time points (before and after the intervention). Thus, the Bayesian Structural Time Series (BSTS) model has been developed to address these limitations. In causal impact analysis, the relationship before the event is modeled with BSTS models. In short, the BSTS models illustrate that the observed data, in reality, is determined by the latent state that evolves with a Markov Chain Monte Carlo (MCMC) process.

A basic structural model contains a local linear trend component, a seasonality component, and a regression component, and the function could be written as:

$$y_t = \mu_t + \tau_t + \beta^{\mathrm{T}} \mathbf{x}_t + \varepsilon_t \tag{3}$$

In the above equation, y_t represents the observed data, and ε_t represents the error term of the linear equation. μ_t, and τ_t represent the local linear trend and seasonality. Term $\beta^{\mathrm{T}} \mathbf{x}_t$ is the regression component, including regression coefficients and a set of trend verticals. Since each component has its way of calculating, writing them separately can be tedious and complex. Thus, α, the unobserved latent state, is used to represent these components in a state space model to include them and can be written as:

$$y_t = Z_t^{\mathrm{T}} \alpha_t + \varepsilon_t \left(\varepsilon_t \sim \mathcal{N}\left(0, \sigma_t^2\right)\right) \tag{4}$$

$$\alpha_{t+1} = T_t \alpha_t + R_t \eta_t \quad \left(\eta_t \sim \mathcal{N}\left(0, Q_t\right)\right) \tag{5}$$

In the above equation pair, Equation (4) is called the observation equation, which links the observed data y_t with the unobserved latent state α, and Equation (5) is called the transition equation, which defines the latent state with the change of time. The capital letters, Z_t, T_t, and R_t are matrices that contain known values and unknown parameters. Term $R_t \eta_t$ is another format of the error term in transition equation (Scott and Varian, 2014).

The parameters of the linear function of Bayesian linear regression, unlike those of regression based on the regular Ordinary Least Squares (OLS), come from distribution sampled from thousands of times of simulations. The spike and slab selection method is helpful to make use of the prior knowledge of the regression model, where “spike” refers to the probability of a particular coefficient of the model to be zero, and “slab” refers to the prior distribution of regression coefficient values. A spike and slab prior can be expressed as the following:

$$p\left(\beta, \gamma, \sigma^{-2}\right) = p(\gamma) p\left(\sigma^2 \mid \gamma\right) p\left(\beta_\gamma \mid \gamma, \sigma^2\right) \tag{6}$$

where:

$$\gamma \sim \prod_{k=1}^{K} \pi_k^{\gamma_k} \left(1 - \pi_k\right)^{1-\gamma_k} \tag{7}$$

and:

$$\beta_\gamma \mid \sigma^2 \sim N\left(\mathbf{b}_\gamma, \sigma^2 \left(\Sigma_\gamma^{-1}\right)^{-1}\right) \tag{8}$$

$$\sigma^{-2} \sim G\left(\frac{\nu}{2}, \frac{s}{2}\right) \tag{9}$$

In the above expressions, Equation (7) is a Bernoulli distribution representing the spike part, and Equation (8) and (9) is a conditionally conjugate slab prior. The small π in Equation (7) is the prior probability of the regressor in the model, and its value can be determined by examining the expected model size M, where π equals M divided by K. Vector $\mathbf{b}$ in Equation (8) is usually set as 0, and Σ^{-1} is the prior precision over β in the model. Σ is calculated as:

$$\Sigma^{-1} = \frac{g}{n} \left\{ w X^{\mathrm{T}} X + (1 - w) \operatorname{diag}\left(X^{\mathrm{T}} X\right) \right\} \tag{10}$$

where g is the number of observations that contain the worth of information, and w is the probability. X is the covariates. Prior parameters in Equation (9) follow a Gamma Distribution and can be elicited by examining the expected R^2 value and the number of observations worth of weight v. Thus, prior sum of squares s can be calculated as:

$$s = v\left(1 - R^2\right) s_y^2 \tag{11}$$

In this research, θ represents a set of the model parameters, and the prior distribution can be expressed as $p(\theta)$, indicating all possible model parameters based on the initial guess on the situation of the data set. The prior distribution also describes the beliefs about the researcher’s expectations of the model and likelihood relationship. The model will be estimated by sampling the posterior distribution of the parameters with the Markov Chain Monte Carlo (MCMC) algorithm. The posterior distribution is the proportion of the product of prior and likelihood, written as:

$$p(\theta \mid D) \propto p(D \mid \theta) \cdot p(\theta) \tag{12}$$

where D is the data set used for analysis. The causal impact analysis in this research will use defaulted values in programming software R, where R^2 is set as 0.5, π equals 0.5 for each regressor, v equals 0.01 and w when calculating Σ^{-1} is 0.5. The inference will be performed following these steps: First, a draw of θ and latent state α will be simulated given the observed data y within the historical data before the event time point. With the MCMC technique, this goal can be easily reached. The algorithm of MCMC is as follows. Let E be the set of latent state α and other model parameters including θ, β and σ^2. Relatively, simulate latent state α and model parameter θ given data y within the training period. Then, simulate other parameters from the Markov Chain with a stationary distribution $p(E \mid y)$. After repeating simulations thousands of times (3000 times in this research), a sequence of drawing E_1, E_2,... forms. Then, the posterior simulations will be used to simulate the posterior predictive distribution over the counterfactual data. Finally, these posterior predictive samples will be used for calculating the differences to get the cumulative impact of the distribution.

4.2 COVID-19 Pandemic and RMB Internationalization

Due to the particularity of the COVID-19 pandemic data, the only reliable way to find its counterfactual data is to estimate based on the data itself. To examine whether the COVID-19 pandemic effect is a robust short-term negative one, two methods, including a simple naive forecasting method and a moving average forecasting method, are conducted to simulate different counterfactual data. Besides, a comparison of results between a longer counterfactual period (from February 2020 to December 2021) and a shorter counterfactual period (from February 2020 to December 2020) is made to confirm whether the impact is a long-term one or a short-term one.

The mathematical expression for the simple naive method is as follows: the asterisk means the estimated value, and t is time.

$$y_t^* = y_{t-1} \tag{13}$$

The mathematical expression of the moving average method is:

$$y_n = \frac{y_{n-12} + y_{n-11} + \cdots + y_{n-1}}{12} \tag{14}$$

The moving size selected is 12 because of the monthly data. The forecast value can be acquired from the average of the previous 12 values. With these two methods, simulated counterfactual data are plotted in Figure 7 and Figure 8.

Based on the causal impact methodology described in the previous part, each part of Equation 6 can be clearly explained. The prior distribution is the guess of the trained model parameters and comes from the simulations with the actual historical data before the event. The likelihood is the response features given the trained model, which is expressed as the probability of the data analyzed (both reality and counterfactual) given the trained model. Thus, the product of these two is the posterior of the model parameters used for the causal impact analysis. The causal impact results can be numerical (Tables 9 and 10) and graphical (Figures 9 and 10). According to the results in Table 9, under the naive method, the absolute average effect is -82%, and the absolute cumulative effect is -165%. The relative effect for both methods is -179%. The moving average method shows that the absolute effect is -47% and the cumulative effect is -435%. However, the relative effect for both average and cumulative is -47%. Both methods' p-value is smaller than 0.01, meaning the magnitude of the negative impacts observed is statistically significant. According to the results in Table 10, under the naive method, the absolute average effect is -4%, and the absolute cumulative effect is -44%. The relative effect for both methods is -253%. The moving average method shows that the absolute effect is -15% and the cumulative impact is -41.6%. However, the relative effect for both average and cumulative is -14%. Both methods' p-value is smaller than 0.01, meaning the magnitude of the negative impacts observed is statistically significant.

In Figure 9, the shapes of a point-wise part are similar. Although line shapes are slightly different in the cumulative panel, the total trend is still negative. Also, they both show a relatively short trend of increase of the negative effect but then a long trend of decrease, meaning the COVID-19 pandemic's negative impact only lasts shortly. As in Figure 9, line shapes in point-wise panels of Figure 10 are similar. In the cumulative panel, the total trend is negative, and there is a short-term increase in the negative impact, but then the impact decreases. Therefore, the COVID-19 pandemic impact is negative but only lasts in the short term. All these results mean that the COVID-19 pandemic presents a much stronger negative effect in a shorter period, and it keeps decreasing over time. Though the relative effect of the naive forecasting method of 2020 is smaller than that of 2021, the result is still negative. All four parts have a p-value smaller than 0.01, meaning the negative effect is statistically significant, and the results are robust.

Literature previously mentioned the relationship between exchange rate and the COVID-19 pandemic in Section 4 concludes that COVID-19 influences exchange rate spillover differently. Wei et al. (2020) claim that the pandemic triggers the changes of exchange rate spillover, while Gunay (2021) considers the influence on spillover varies from country to country. However, they only confirm that the COVID-19 pandemic can affect exchange rates from some channels but do not conclude any causal or another type of relationship. But similarly, when comparing with Wei et al. (2020)'s results, when the pandemic hits, there is an apparent sudden change in the graph, meaning the COVID-19 pandemic significantly affects the exchange rate market. However, the conclusion from Wei et al. (2020)'s paper is only to confirm the influence, not define its nature. But in this paper, a clear causal relationship conclusion is drawn based on empirical results from the causal impact analysis, and it should be considered an improvement in this area.

5 Conclusions

We have examined the dynamic process of currency internationalization and the relationship between the COVID-19 pandemic and RMB internationalization. Using rolling correlation, our proxy for currency internationalization shows that RMB is approaching complete internationalization; the trend is positive as an internationalizing currency. Moreover, the results of the causal analysis indicate that the COVID-19 pandemic can significantly and negatively affect the process of RMB internationalization, confirming a close relationship between international trade and currency internationalization. However, this effect lasted just a short time. A short-term impact of COVID-19 implies that the pandemic has not resulted in institutional changes, such as alternation in settlement currencies. As a result, traders still view RMB as an important payment currency in the global market.

	Original				1st Difference			
	Mean	**Median**	**Std.**	**UR p-value**	**Mean**	**Median**	**Std.**	**UR p-value**
USD	1.1443	1.0218	0.2539	0.7876	-0.0007	-0.0003	0.0125	0.0100
EURO	1.3469	1.3647	0.2096	0.6354	-0.0007	-0.0002	0.0077	0.0100
GPB	1.8027	1.5879	0.4798	0.6279	-0.0010	-0.0006	0.0119	0.0100
JPY	1.0708	1.0609	0.1984	0.2709	-0.0007	-0.0012	0.0134	0.0100
CAD	0.9175	0.9374	0.1423	0.1738	-0.0004	0.0007	0.0141	0.0100
AUD	0.8534	0.8799	0.1139	0.3711	-0.0008	-0.0001	0.0270	0.0100
RMB	0.1576	0.1519	0.0194	0.4855	-0.0002	0.0003	0.0124	0.0100
RUB	0.0339	0.0328	0.0157	0.5116	-0.0025	0.0000	0.0176	0.0100
INR	0.0225	0.0219	0.0081	0.6103	-0.0015	0.0000	0.0104	0.0100
BRL	0.4755	0.4653	0.1972	0.4322	-0.0028	-0.0011	0.0195	0.0100
ZAR	0.1331	0.1314	0.0588	0.4027	-0.0022	-0.0006	0.0160	0.0100

Note: USD - US Dollar; GPB - Pound Sterling; JPY - Japanese Yen; CAD - Canadian Dollar; AUD - Australian Dollar; RMB - Chinese Yuan; RUB - Russian Ruble; INR - Indian Rupee; BRL - Brazilian Real; ZAR - South African Rand.

Table 1: Data Description

	USD	**EURO**	**GPB**	**JPY**	**CAD**	**AUD**	**RMB**	**RUB**	**INR**	**BRL**	**ZAR**
USD	**1.0000**										
EURO	0.3608	**1.0000**									
GPB	0.6110	0.5449	**1.0000**								
JPY	0.6034	0.3565	0.3786	**1.0000**							
CAD	0.6145	0.5292	0.5982	0.3640	**1.0000**						
AUD	0.3022	0.5222	0.4383	0.2536	0.6811	**1.0000**					
RMB	0.7914	0.3474	0.4988	0.5006	0.4625	0.2437	**1.0000**				
RUB	0.4396	0.4129	0.4778	0.2183	0.5560	0.4784	0.3620	**1.0000**			
INR	0.4268	0.2361	0.2348	0.1857	0.3264	0.2760	0.5108	0.2913	**1.0000**		
BRL	0.1895	0.1863	0.2296	0.0542	0.2965	0.4029	0.2451	0.2878	0.4858	**1.0000**	
ZAR	0.1287	0.1408	0.1729	0.0655	0.3426	0.3426	0.2074	0.2709	0.4852	0.4064	**1.0000**

Table 2: Correlation Matrix

1st Factor Analysis		**2nd Factor Analysis**		**3rd Factor Analysis**	
	KMO Value		KMO Value		KMO Value
Overall	0.83	Overall	0.76	Overall	0.63
USD	0.77	USD	0.69	USD	0.64
EURO	0.86	EURO	0.85	EURO	0.69
GPB	0.89	GPB	0.81	GPB	0.59
JPY	0.83	JPY	0.69		
CAD	0.84	CAD	0.77		
AUD	0.78	AUD	0.72		
RMB	0.80				
RUB	0.94				
Bartlett's Test		**Bartlett's Test**		**Bartlett's Test**	
Chi-square	1250.029	Chi-square	747.851	Chi-square	223.542
p-value	3.55E-239	p-value	1.16E-149	p-value	3.44E-48
DF	36	DF	15	DF	3

Table 3: KMO and Bartlett's Test Results

	Before			After		
	FA 1	FA 2	Communality	FA 1	FA 2	Communality
EURO	0.60	0.30	0.46	**0.65**	0.19	0.46
GPB	0.73	0.08	0.54	**0.59**	0.43	0.54
CAD	0.83	0.24	0.74	**0.77**	0.38	0.74
AUD	0.62	0.50	0.64	**0.80**	0.05	0.64
RUB	0.61	0.20	0.41	**0.58**	0.27	0.41
USD	0.87	-0.48	0.99	0.32	**0.94**	0.99
JPY	0.49	-0.36	0.47	0.12	**0.60**	0.47
RMB	0.71	-0.38	0.65	0.26	**0.76**	0.65
Eigenvalue	4.80	1.20		3.20	2.80	
Explained %	48%	12%		32%	28%	
Cumulative %	48%	60%		32%	60%	

Table 4: Factor Analysis Results of 8 Currencies

	Before Rotation				**After Rotation**			
	FA 1	FA 2	FA 3	Communality	FA 1	FA 2	FA 3	Communality
CAD	0.84	-0.13	0.14	0.74	**0.67**	0.24	0.34	0.74
AUD	0.69	-0.52	0.25	0.81	**0.87**	0.08	0.19	0.81
USD	0.80	0.52	0.06	0.92	0.18	**0.86**	0.37	0.92
JPY	0.46	0.42	0.20	0.43	0.10	**0.65**	0.07	0.43
EURO	0.62	-0.25	-0.13	0.46	0.29	0.12	**0.45**	0.46
GPB	0.79	0.00	-0.44	0.82	0.30	0.30	**0.80**	0.82
Eigenvalue	5.10	1.30	0.06		2.60	2.40	1.90	
Explained %	51%	13%	6%		26%	24%	19%	
Cumulative %	51%	64%	70%		26%	51%	70%	

Table 5: Factor Analysis Results of 6 Currencies

6 Internationalized Currencies					**3 Key Currencies**				
US Dollar	Est.	Std.	t-value	p-value		Est.	Std.	t-value	p-value
Intercept	-0.0007	0.0004	-1.7090	0.0885	Intercept	-0.0007	0.0006	-1.2270	0.2210
Factor 1	0.0106	0.0004	24.2310	2e-16 ***	Factor 1	0.0085	0.0006	14.5110	2e-16 ***
Euro									
Intercept	-0.0007	0.0004	-1.9840	0.0482 *	Intercept	-0.0007	0.0004	-1.8530	0.0650
Factor 1	0.0050	0.0004	13.6500	2e-16 ***	Factor 1	0.0047	0.0004	12.0260	2e-16 ***
Pound Sterling									
Intercept	-0.0010	0.0004	-2.4850	0.0135 *	Intercept	-0.0010	0.0001	-16.9800	2e-16 ***
Factor 1	0.0100	0.0004	23.2250	2e-16 ***	Factor 1	0.0123	0.0001	199.6400	2e-16 ***
Japanese Yen									
Intercept	-0.0007	0.0007	-0.9800	0.3280					
Factor 1	0.0065	0.0007	8.8750	2e-16 ***					
Canadian Dollar									
Intercept	-0.0004	0.0003	-1.0400	0.2990					
Factor 1	0.0125	0.0004	28.0500	2e-16 ***					
Australian Dollar									
Intercept	-0.0009	0.0011	-0.7700	0.4420					
Factor 1	0.0198	0.0012	16.7700	2e-16 ***					
Chinese RMB									
Intercept	-0.0003	0.0006	-0.4750	0.6350	Intercept	-0.0002	0.0006	-0.3850	0.7000
Factor 1	0.0084	0.0006	14.5150	2e-16 ***	Factor 1	0.0069	0.0007	14.6100	2e-16 ***

Table 6: The Significance Between Factor and Currency

	6 Internationalized Currencies					3 Key Currencies			
US Dollar	Est.	Std.	t-value	p-value		Est.	Std.	t-value	p-value
Intercept	9.22e-01	6.75e-03	136.67	2e-16 ***	Intercept	0.7097	0.0661	10.7410	2e-16 ***
Time	1.90e-04	4.29e-05	4.43	1.37e-05 ***	Time	-0.0012	0.0004	-2.8380	0.0049 **
Euro									
Intercept	0.1750	0.0847	2.0650	0.0399 *	Intercept	0.2359	0.0813	2.9010	0.0040 **
Time	0.0011	0.0005	1.9510	0.0521	Time	0.0011	0.0005	2.2170	0.0275 *
Pound Sterling									
Intercept	0.7540	0.0550	13.7040	2e-16 ***	Intercept	0.9787	0.0096	101.4330	2e-16 ***
Time	-0.0004	0.0004	-1.2220	0.2230	Time	0.0000	0.0001	0.5240	0.6010
Japanese Yen									
Intercept	5.48e-01	6.68e-02	8.207	9.27e-15 ***					
Time	2.84e-05	4.25e-04	0.067	0.9470					
Canadian Dollar									
Intercept	0.8000	0.0548	14.6050	2e-16 ***					
Time	-0.0005	0.0003	-1.4840	0.1390					
Australian Dollar									
Intercept	0.6799	0.0659	10.3220	2e-16 ***					
Time	-0.0007	0.0004	-1.6570	0.0986					
Chinese RMB									
Intercept	0.4067	0.0410	9.9280	2e-16 ***	Intercept	0.0042	0.0776	0.0540	0.9570
Time	0.0024	0.0003	9.2210	2e-16 ***	Time	0.0026	0.0005	5.1800	4.34e-07 ***

Table 7: The Significance Between Rolling Correlations and Time Trend

	COFER	**SWIFT**	**ROLLING**
COFER	1		
SWIFT	0.4612	1	
ROLLING	0.4537	0.2282	1

Table 8: Correlation Matrix (COFER, SWIFT, and Rolling Correlation)

	Naive Method		**Moving Average**	
	Average	Cumulative	Average	Cumulative
Actual	-0.36	-7.31	0.24	4.85
Prediction	0.46 (0.042)	9.2 (0.861)	0.46 (0.042)	9.20 (0.848)
95% CI	[0.37, 0.54]	[7.48, 10.89]	[0.38, 0.54]	[7.59, 10.86]
Absolute	-0.82 (0.043)	-16.5 (0.861)	-0.22 (0.042)	-4.35 (0.848)
95% CI	[-0.91, -0.74]	[-18.19, -14.78]	[-0.3, -0.14]	[-6.0, -2.74]
Relative	-179% (9.4%)	-179% (9.4%)	-47% (9.2%)	-47% (9.2%)
95% CI	[-198%, -161%]	[-198%, -161%]	[-65%, -30%]	[-65%, -30%]
p-value		0.00101	p-value	0.00201
Prob.		0.999	Prob.	0.999

Note: In the above table, "Average" and "Cumulative" are the average across time during the training period and the sum of individual time points. "Actual" means the actual value examined. "Prediction" means the predicted value. Values in the brackets are standard deviations. CI is short for Credible Interval, referring to the interval that the real parameters of estimation could be in.

Table 9: Causal Impact Analysis Results (Till Dec. 2021)

	Naive Method		Moving Average	
	Average	Cumulative	Average	Cumulative
Actual	0.33	3.64	0.33	3.64
Prediction	-0.22 (0.049)	-2.38 (0.543)	0.18 (0.049)	2.02 (0.536)
95% CI	[-0.32, -0.12]	[-3.47, -1.36]	[0.087, 0.28]	[0.955, 3.08]
Absolute	-0.04 (0.049)	-0.44 (0.531)	-0.15 (0.049)	-0.416 (0.55)
95% CI	[-0.14, 0.052]	[-1.50, 0.574]	[-0.051, 0.24]	[-0.574, 1.53]
Relative	-253% (-23%)	-253% (-23%)	-14% (-26%)	-14% (-26%)
95% CI	[-210%, -298%]	[-210%, -298%]	[-37%, 63%]	[-37%, 63%]
p-value		0.00101	p-value	0.00201
Prob.		0.999	Prob.	0.998

Table 10: Causal Impact Analysis Results (Till Dec. 2020)

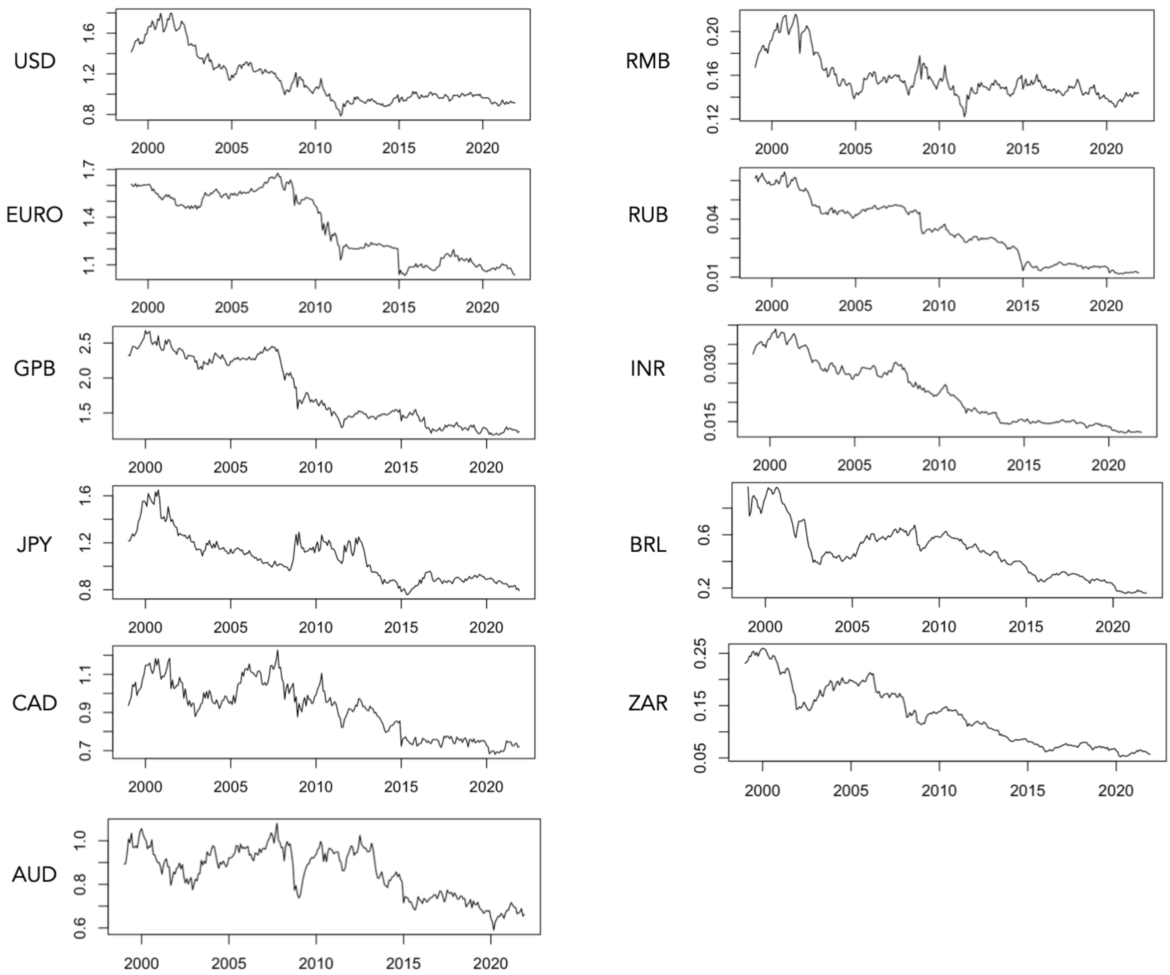


Figure 1: Original Exchange Rates

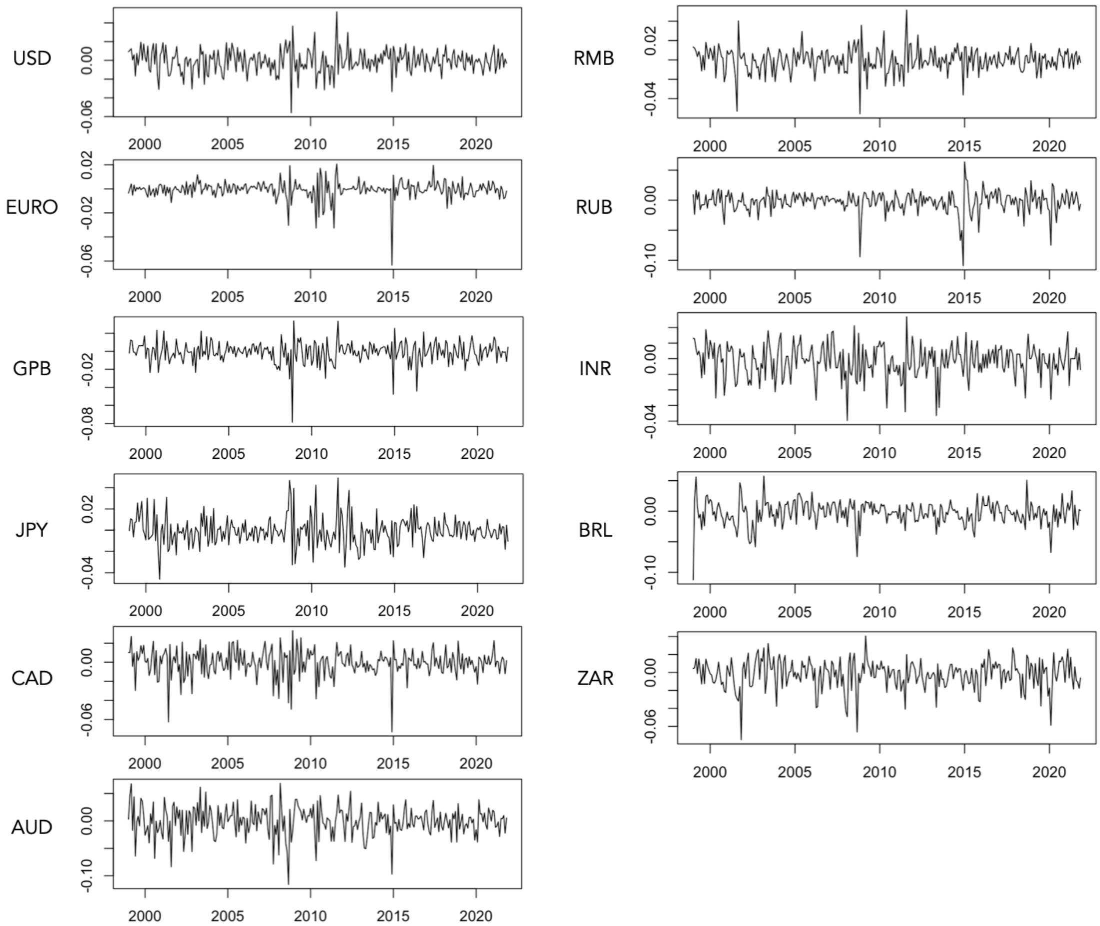


Figure 2: Stationary Exchange Rates

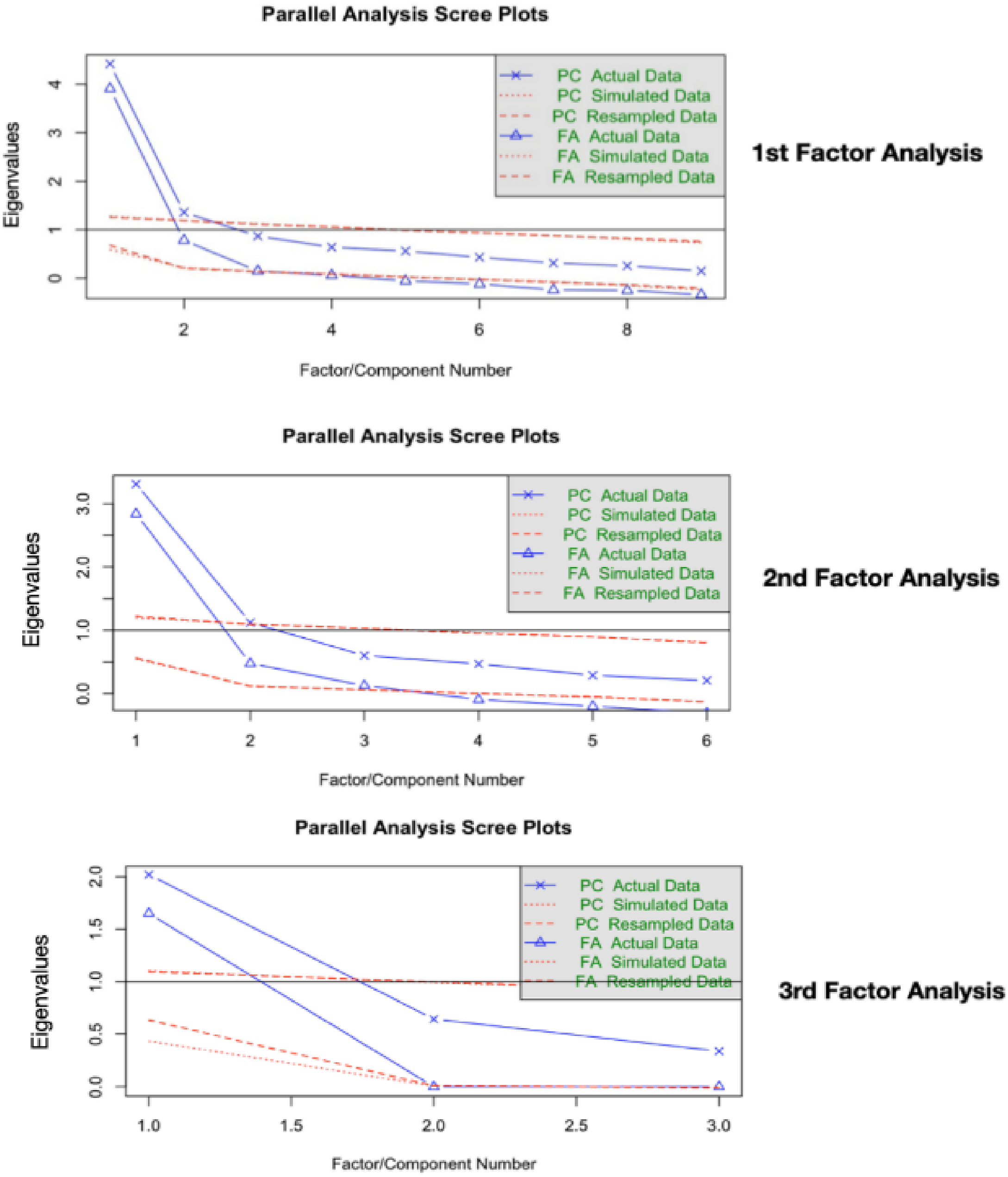


Figure 3: Scree Plots

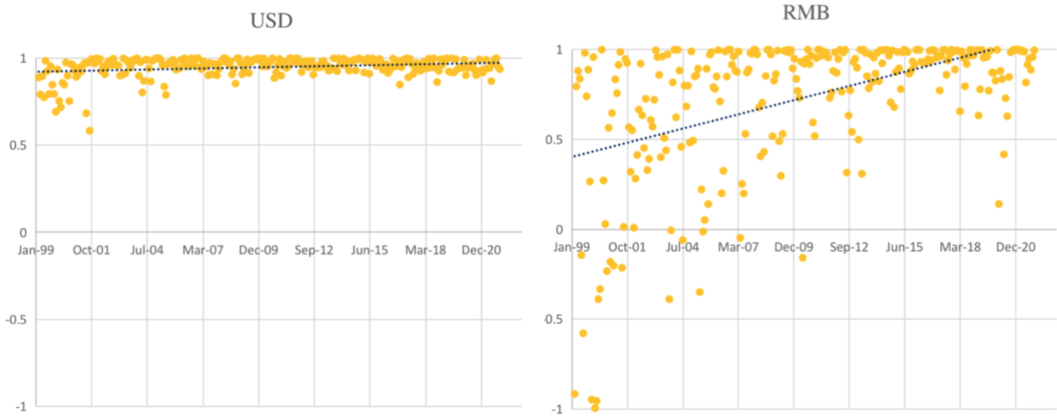


Figure 4: USD and RMB Rolling Correlations

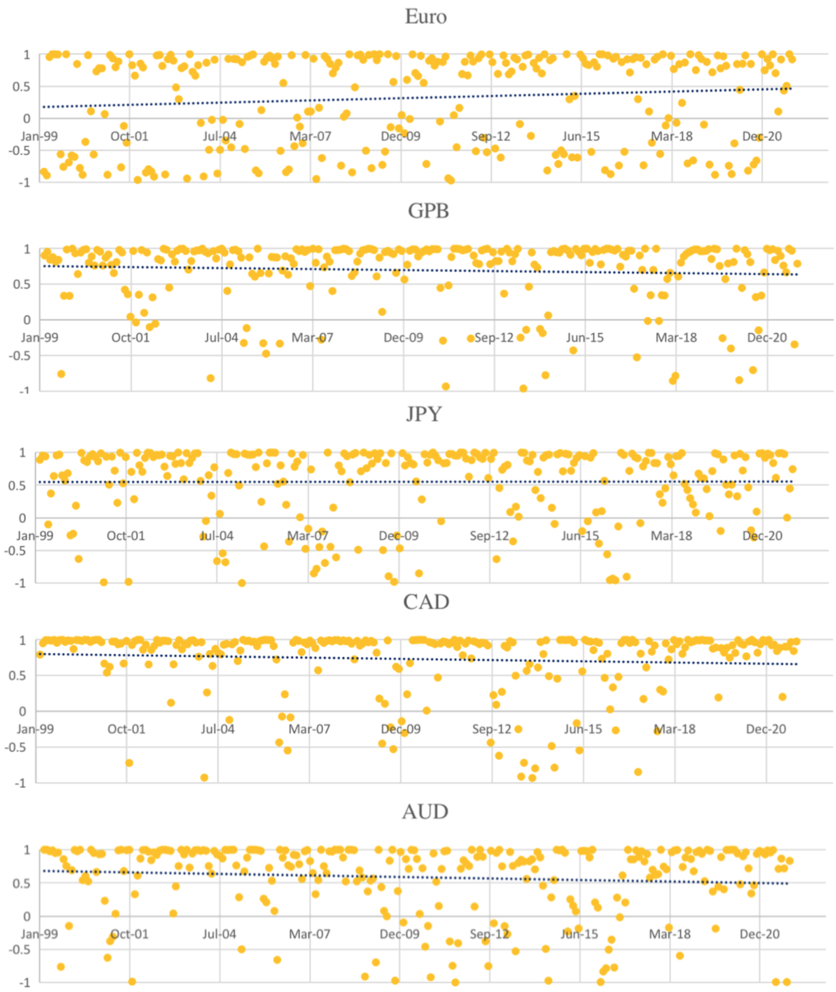


Figure 5: Other Internationalized Currencies Rolling Correlations

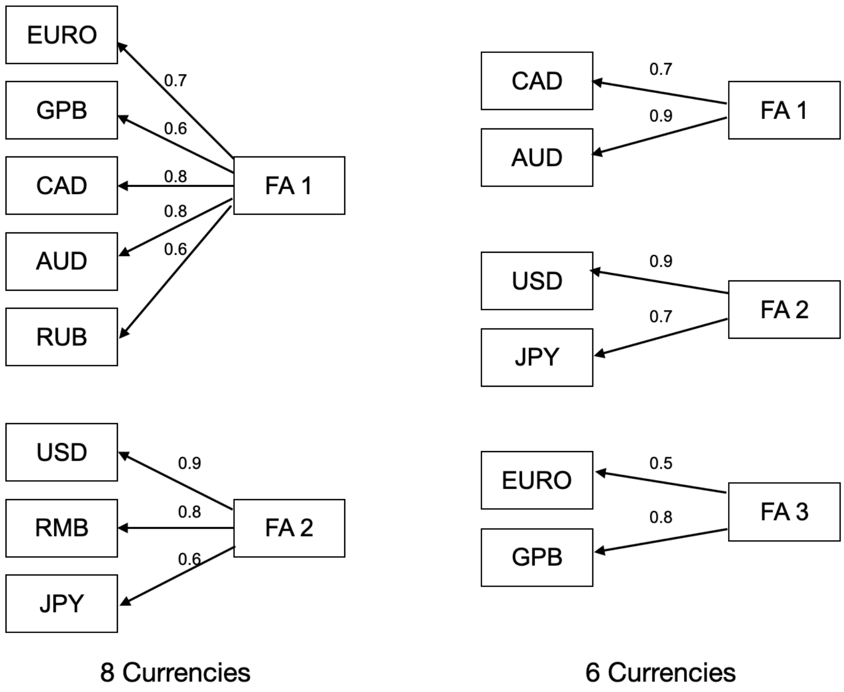


Figure 6: Factor Analysis Grouping

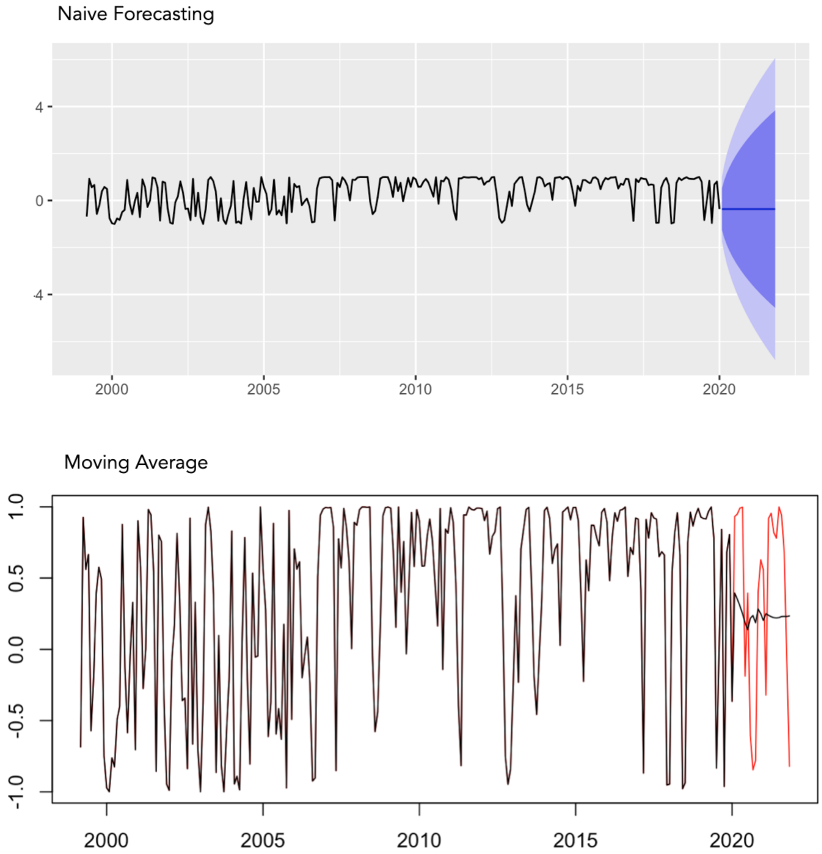


Figure 7: Counterfactual Simulation Till December 2021

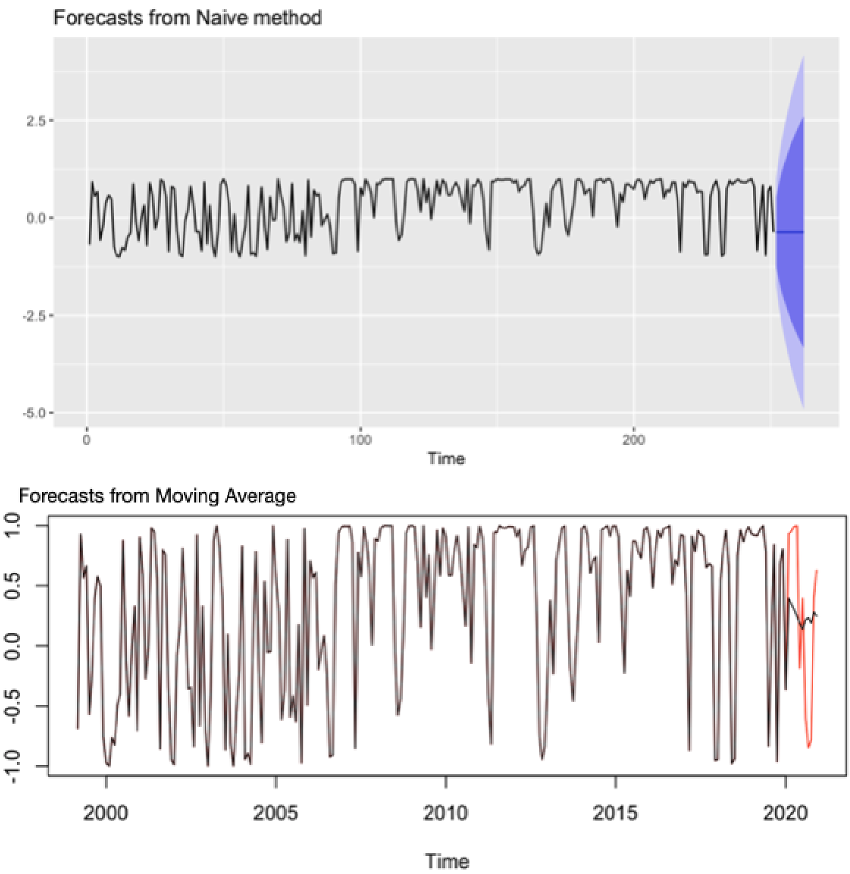
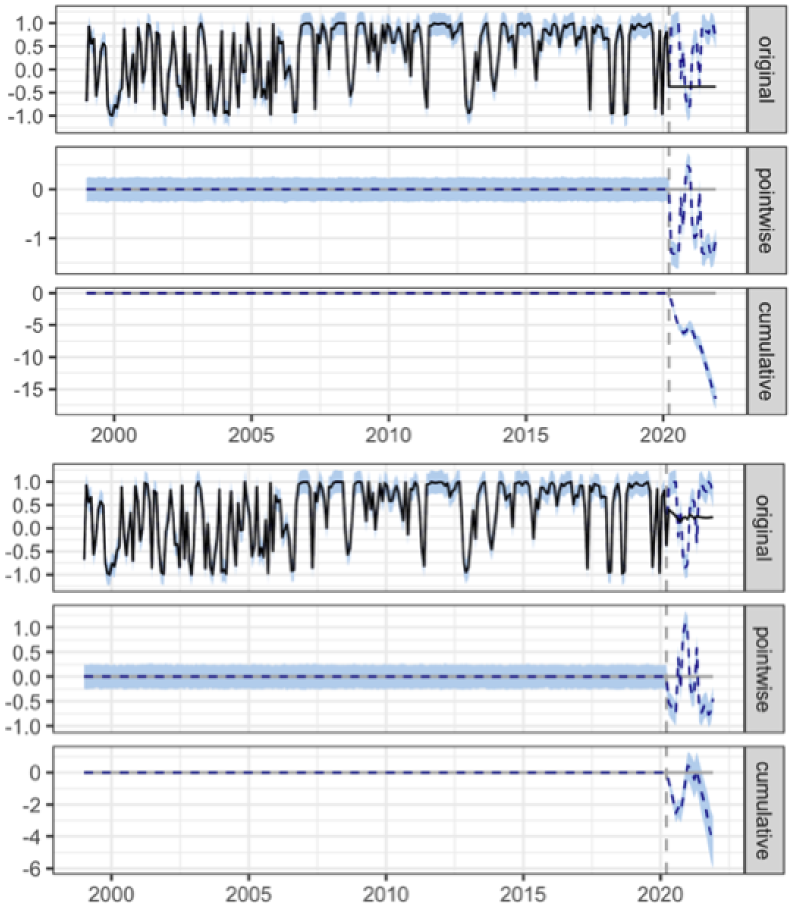


Figure 8: Counterfactual Simulation Till December 2020



Note: The original panel shows the reality data (broken line) and the counterfactual data (black line). The broken line in the point-wise panel denotes the difference between reality and the counterfactual. The cumulative panel yields the comprehensive influence of the COVID-19 pandemic.

Figure 9: Causal Impact Results (Dec 2021)

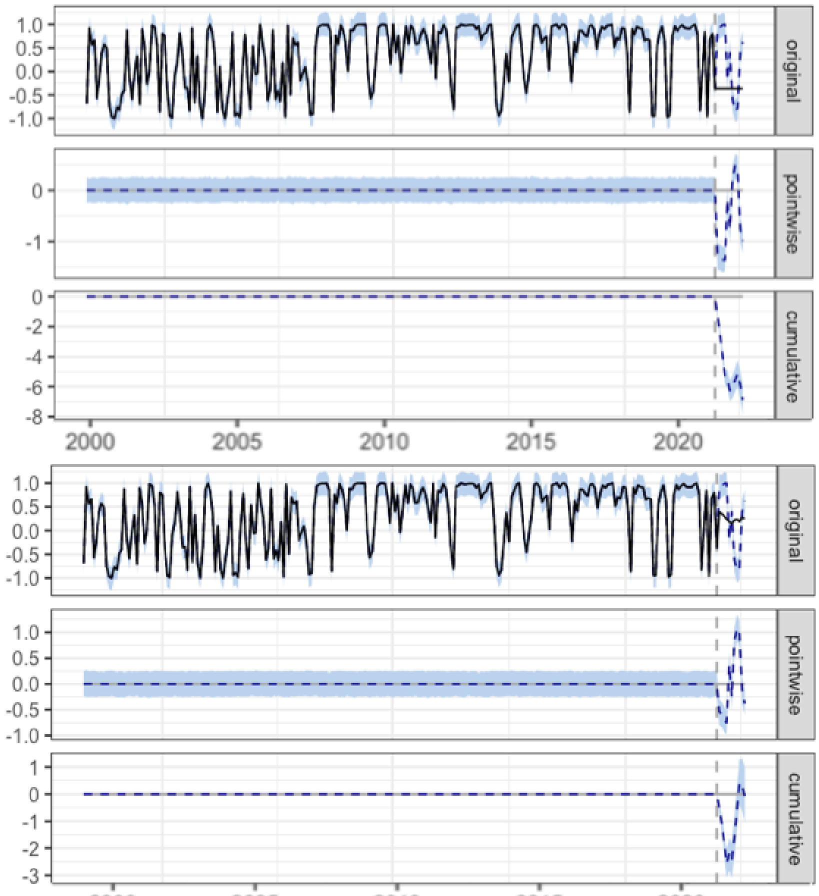


Figure 10: Causal Impact Results (Dec 2020)

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