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Climate Disaster Losses and Foreign Exchange Reserve Dynamics: Evidence of East Asia Pacific

Yawen Wang [1], Qing Wang [2] and Zhaopeng Xing [3,*]

[1] Institute of Economics, School of Economics, Xiamen University, Xiamen 361005, China
[2] Department of International Trade, School of International Economics and Trade, Jiangxi University of Finance and Economics, Nanchang 330013, China
[3] Department of Finance, School of Economics, Xiamen University, Xiamen 361005, China
* Correspondence: 15620180155357@stu.xmu.edu.cn

Abstract: This paper examines the relationship between foreign exchange reserves (FERs) and climate disaster losses (CDLs) in the East Asia Pacific region. To guide the empirical work, we use the bootstrap Granger rolling window estimation to capture the dynamic relationship between the two variables. It is suggested that CDLs positively affect the central banks' FERs in East Asia Pacific countries, but this relationship appears to be weakening recently. FERs are shown to reduce CDLs. The results are supported by the small open economy model in which the central bank decides jointly on FERs and external debt. With the balance of payments deteriorating, CDLs can lead to a sudden stop of international capital flows, which is destructive to economic development. Therefore, when severe climate disasters are anticipated, the central bank accumulates FERs in advance. If unexpected climate disasters occur, central banks may become more precautious and increase FERs. Therefore, the central bank should consider the risk of climate change and hold an appropriate amount of FERs but FERs are not the more the better; the government should strengthen infrastructure construction to resist climate disasters.

Keywords: bootstrap rolling windows; climate disaster losses; central banks; foreign exchange reserves

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1. Introduction

Climate risk has always been a huge problem in relation to economic development faced by countries all over the world. In recent years, extreme weather and natural disasters, including frequent and intense cold spells and heat waves, torrential rains, floods, droughts, hurricanes, and so on, have seriously threatened human life and health [1]. Climate changes cause huge economic losses and have attracted growing attention globally. According to a recent report from GERMANWATCH, extreme weather events led to more than 526,000 deaths and economic losses of more than USD 3.47 trillion between 1998 and 2017. This is a serious global disaster, especially in emerging market economies. As the East Asia Pacific is one of the areas with the most frequent occurrences of climate disasters [2], the economic situation and personal safety have been severely affected in this region. For example, Typhoon Haiyan, East Asia Pacific's worst climate disaster in recent years, caused more than 6,300 deaths and economic losses of at least USD 4.39 billion. In addition, climate change also causes both an indirect impact and a secondary economic risk. How to reduce the economic losses caused by climate disasters is an important issue for all countries as they seek to develop economically. In addition, due to the multi-dimensional impact of climate disasters and the huge redistribution effect, we believe that only using the direct economic losses caused by climate disasters as the proxy variable of CDLs cannot fully reflect the severity of disasters [3], and the indirect losses caused by climate disasters are also crucial to the economic and social impacts. Therefore, the definition of CDLs in this paper refers to the EM-DAT (EM-DAT data base: https://www.emdat.be/guidelines (accessed on 10 July 2021)), which includes both direct economic losses and losses indirectly related to disasters and reconstruction costs.

As one of the important tools of national macro-control, FERs play a key role in adjusting the balance of payments, stabilizing the exchange rate, etc., and have also been a concern for researchers and the monetary authorities of many countries. Under some negative shocks, other financial instruments can also play roles, such as fiscal subsidies, rediscount loans, and cash reserve ratios. They can provide liquidity, improve corporate cash flow, and play a greater role in developing countries [4,5]. However, FERs are different because they can directly affect and stabilize the exchange rate, and can directly import necessary materials in foreign currencies, which determines their strong role in the international market [6]. In the context of the increasingly serious climate change problem, we find that countries with different CDLs have different choices in the scale of FERs. Countries that are more affected by climate disasters tend to hold more FERs (such as Vietnam), while countries that are less affected by climate disasters hold fewer FERs (such as Laos). Table 1 reports the proportion of FERs in the GDP of Vietnam and Laos. Especially in this area with high climate risks, the optimal level of FERs is increasing in the area's fundamental vulnerability to sudden stops, which can occur with a natural disaster [7,8]. Furthermore, climate risks have seriously increased the risk exposure of various assets [9], so countries may need FERs to diversify risks. Based on the perspective of prudent motivation, countries with frequent natural disasters may hold relatively more FERs in advance.

Table 1. Proportion of FERs in GDP of Vietnam and Laos (According to the Global Climate Risk Index released by GERMANWATCH, Vietnam is a country with extremely high CDLs in the sample period and Laos is a neighboring country with low CDLs).

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
VIE	14.7	24.0	23.1	15.1	10.8	11.0	19.7	18.9	23.6	18.3	22.3	28.0	29.5
LAO	6.6	9.8	10.7	10.9	11.3	9.8	9.8	8.2	9.2	10.2	8.0	9.2	7.5

Data sources: World Bank.

FERs and CDLs interact in many ways. As shown in Figure 1. First, when a disaster occurs, the country must consume FERs to stabilize prices and smooth consumption [7]. The occurrence of climate disasters has also led to reductions in private and public capital [10]. A reduction in private capital brings about a reduction in expected output, while a reduction in public capital makes the problem worse [11]. Public capital and private production factors show complementary characteristics. Therefore, the destruction of public capital by natural disasters reduces the current private output. Sufficient FERs can serve as personal consumption and rescue expenditures during this period to reduce indirect losses caused by climate disasters. Reconstruction work after a disaster requires a large amount of FERs to supplement public capital and support reconstruction [12]. If public capital cannot be effectively replenished, private output can decrease during reconstruction, causing the expansion of indirect losses. Therefore, FERs can not only supplement consumption during disasters but can also supplement the capital damaged during disasters, indicating that FERs decrease CDLs. In conclusion, there is a mutual influence between FERs and CDLs.

However, has the effect of CDLs on FERs changed as FERs continue to accumulate? It is uncertain whether there are too many FERs in emerging Asian markets and whether FERs have played the biggest role in coping with shocks [13], which makes our previous analysis of the relationship between the two variables questionable. The anomaly shows that after Typhoon Haiyan, the FERs of the Philippines keep declining. To answer this question, this paper explores the dynamic causal relationships of FERs and CDLs to investigate whether countries are maintaining a balance between opportunity costs and the benefits of FERs from a climate risk perspective. If FERs are sufficient, more FERs should not reduce the impact of CDLs on economic operations, and higher CDLs should not bring significant changes to FERs.

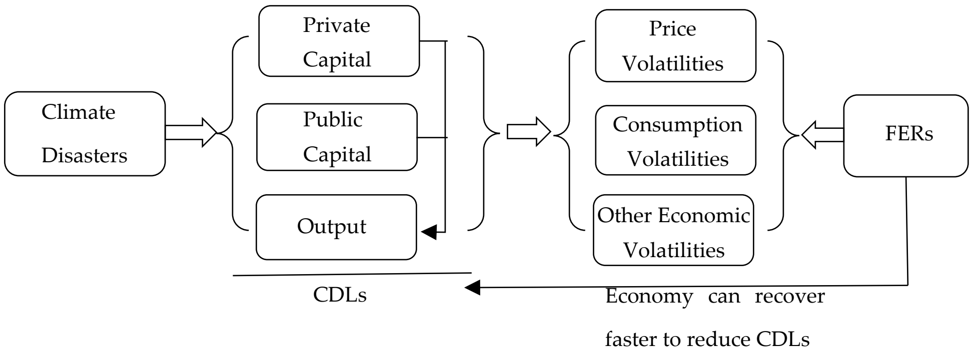

Figure 1. The relationship between FERs and CDLs.

This paper is ordered as follows: we briefly present the related studies in Section 2. Section 3 introduces the dataand methodology. Section 4 highlights the empirical results. In Section 5, we conclude the study and make some suggestions.

2. Literature Review

2.1. Motivation for the Accumulation of FERs

The existing literature on FERs is rich. We focus on the motivations for the accumulation of FERs according to the objectives of this research.

FERs, as a policy instrument for capital account management, can overcome fragile economic fundamentals. Dooley et al. [14] suggest that international reserves accumulation for Asian countries is driven by concerns about export competitiveness. They believe that the accumulation of FERs promotes export growth by preventing or slowing down currency appreciation in China. Aizenman and Lee [15] point out that the motivation of developing countries to hoard FERs is mainly preventive demand. As a kind of self-insurance, FERs can avoid the expensive output contraction caused by sudden stops and capital outflows. Jeanne and Ranciere [16] also believe that the accumulation of FERs in emerging economies is mainly motivated by the prevention demand. Pringle and Carver [17] find that the main reason for the increase of FERs since the Asian financial crisis is to "ensure protection from volatile capital flows", based on a survey of central bank governors of developing and emerging market countries. Stiglitz [18] points out that East Asian countries have learned the lesson of instability during the Asian financial crisis: they increase FERs to ensure that they no longer need to borrow from the IMF. Other countries witnessed the suffering of neighboring countries and came to the same conclusion: there must be sufficient FERs to deal with the serious effects of the world economic changes. Shin and Turner [19] indicate that financial integration in the past few decades and the great transformation of international financial intermediation after the global economic crisis make emerging economies more sensitive to financial shocks, which may require more FERs.

2.2. Climate Disasters and Climate Disaster Losses

Nordhaus [20] first introduces climate issues into economic research. With the increasingly serious climate problems, the economic results of climate disasters have drawn much attention. The current research mainly focuses on the following two aspects.

First, some researchers analyze the costs caused by climate disasters, the negative effects of economic development, as well as the negative macroeconomic phenomena caused by these effects. Kellenberg and Mobarak [10] show that the most obvious and direct impact of climate disasters is capital losses, including private capital and public capital. Auffret [12] argues that after natural disasters, it is difficult to guarantee the speed of post-disaster reconstruction, leading to a large reduction of private investment and large indirect losses. Bevan and Adam [21] discuss that the indirect losses may be much larger than direct losses because of the lack of money for reconstruction in low-income countries. In this case, pre-disaster public capital accumulation enhances disaster preparedness and response capacity, and financing instruments can assure governments of sufficient post-disaster capital for emergency response and repairing public infrastructure [22]. Hallegatte et al. [23] find that financing instruments like FERs are likely to reduce the indirect losses caused by disasters. Specifically, an appropriate size of FERs not only helps accelerate the economic recovery after the climate disaster but also helps smooth consumption by supplementing private output and public capital, which reduces the indirect losses of climate disasters.

Second, some researchers focus on the relationship between CDLs and risk premiums. Many researchers such as Aizenman and Lee [24] and Davis et al. [25] show that climate disasters are related to asset pricing in real estate markets, bond markets, stock markets, and foreign exchange markets. Bourdeau-Brien and Kryzanowski [26] demonstrate that extreme weather events cause a significant increase in financial risk aversion in U.S. municipal bond markets. Albala-Bertrand [27], a study of 28 natural disasters from 1960 to 1979, found that CDLs led to a significant deterioration of the current account as well as the capital and financial accounts. This has led to a sharp reduction in FERs, exchange rate fluctuations, and liquidity tightening. Therefore, the importance of FERs is emphasized again. So except for the role of supplementing public capital, FERs can be used to reduce price volatility after disasters. FERs, as a policy instrument for capital account management, can overcome fragile economic fundamentals. Although Kohlscheen [28] argues that the worldwide financial crisis is unpredictable using rational economic models, it is commonly accepted that FERs reduce risk premiums. Taguchi [29] shows the accumulation of FERs helps to maintain monetary autonomy, meaning that FERs act as an anchor for monetary autonomy in emerging market economies. Maintaining a certain amount held in FERs often supports the growth process but also provides confidence and security for the domestic economy. Therefore, in the short term, countries need to use a large amount of FERs after disasters to deal with the shock. At the same time, climate disasters have a significant impact on individual risk-taking behavior. Ahsan and Brandt [30], Cameron and Shah [31] find that individuals who suffer from natural disasters are more likely to believe that they will encounter natural disasters in the future, thus becoming more risk averse. Goebel et al. [32] hold that the Fukushima incident increased people's risk aversion. So, in the long run, the higher disaster frequency in the Asia Pacific region, coupled with cultural differences [33], can make people in this region more risk-averse. The motive of developing countries to hoard FERs is mainly precautionary demand, so East Asia Pacific countries may accumulate more FERs.

Compared with the existing literature, this study contributes to the literature on the association between CDLs and FERs in several ways. First, most of the existing studies regard FERs as a policy tool to resist financial shocks and seldom consider the impact of external shocks such as CDLs on FERs. Climate disasters have profoundly affected the development and policy formulation of many countries [34]. Thus, this issue should not be ignored. As a policy tool, it is particularly important to study FERs from the perspective of climate disasters. This paper pioneeringly studies the interaction of CDLs and the central bank's holdings of FERs. Second, the previous literature only studied the one-way relationship and ignored the mutual relationship and structural changes. This may be the reason for the conflicting and unstable research conclusions. And this seriously damages the reliability of the statistical results. Thus, the dynamic relationships between variables are explored in this research, and the empirical results are consistent with the small open economy model which highlights the relationships between FERs and CDLs. Finally, the causal relationship between these two variables provides implications for central banks. Countries with frequent climate disasters may need to accumulate more FERs. The implications for investors are that they should consider the ability of countries to resist climate disasters when investing internationally.

3. Methodologies and Data

3.1. Theoretical Model

We apply the small open economy model developed by Kim [7], which explored the relationship between sudden stops and FERs. In the later research of this paper, only China is a country with a large economic volume and no capital account open in the sample. So in this study, this small open economy model is applicable.

A small open endowment economy borrows from the international credit market by issuing one-period, noncontingent discount bonds (B), and the economy holds FERs assets (A), which are invested at a risk-free rate. Both B and A are measured by their ratio to GDP because the model explores their impact on the economy as a whole. The income of this country in each period is y, which follows a Markov process with transition function $f(y, y')$. In order to intuitively reflect the role of FERs, we assume that the economy may suffer from sudden stops. In sudden-stop periods, new bond issues are invalid. Foreign debt is not enforced so the country may default. As a result, this economy will not be able to borrow in the international credit market and suffer a loss of revenue due to possible retaliation by some investors, and the cost of issuing bonds will increase in the future. In each period, the country decides whether to default. The economy needs to maximize its benefits according to Equation (1), which is a utility maximization problem.

$$W(B, A, y, s, k) = \max_{d \in \{0,1\}} \left\{ (1-d)W^R(B, A, y, s, k) + dW^D(A, y, s, k) \right\}, \tag{1}$$

where W^R and W^D mean the value of payment and the value of default, respectively. The other variables in the model are defined as follows: s is the sudden stop shock ($s \in \{0, 1\}$, $s = 1$ denotes a sudden stop), d is the default choice ($d = 1$ denotes default, and $d = 0$ means that the country pays all debt in this period), and k is the fraction of income loss caused by climate disasters, which is exogenous.

If the country does not default, it maximizes the value of W^R by choosing its debt (B') and FER assets (A') in the next period. In the case of a sudden stop, the repayment value is calculated as follows:

$$W^R(B, A, y, s, k) = \max_{B', A'} u(c) + \beta E_{y', s' | y, s} \left[W\left(B', A', y', s', k\right) \right], \tag{2}$$

$$c = (1 - s\lambda^s)(y - k) - B + A + (1 - s)q\left(B', A', y - k, 0\right)B' - \frac{A'}{1 + r}. \tag{3}$$

where $u(c)$ is a concave utility function, λ^s indicates the fraction of income loss in a sudden stop, $q(\cdot)$ refers the discount bond price, and r is the risk-free rate.

W^R is calculated using the following equations:

$$\begin{aligned} s = 0 : \int_{y'} [1 - {p'}_s(A'/B')W(B', A', y', 0, k) + {p'}_s(A'/B')W(B', A', y', 1, k)] f(y', y) dy' \\ s = 1 : \int_{y'} [\theta^s W(0, A', y', 0, k) + (1 - \theta^s)W(0, A', y', 1, k)] f(y', y) dy'. \end{aligned} \tag{4}$$

where $p'(A'/B')$ is the sudden stop probability in the next period and θ^s is the probability that a country regains access to the international debt markets in the period next to a sudden stop.

If the country avoids the sudden stop by default, debt becomes zero, and the probability of regaining access to the international debt markets increases. W^D is calculated using the following equation:

$$\begin{aligned} W^D(A, y, s, k) = \max_{A'} u\left((1 - \lambda^d)(1 - s\lambda^s)u + A - \tfrac{A'}{1+r} \right) + \\ \beta E_{y', s' | y, s} [\theta W(0, A', y', s', k) + (1 - \theta)W^D(A', y', s')], \end{aligned} \tag{5}$$

where λ^d is the default penalty factor.

The expectation of W^D is as follows:

$$\begin{array}{c} s = 0 : \int_{y'} \left[\theta W(0, A', y', 0, k) + (1-\theta) W^D(A', y', 0, k)\right] f(y', y) dy' \\ s = 1 : \int_{y'} \{\theta[\theta^s W(0, A', y', 0, k) + (1-\theta^s) W(0, A', y', 1, k) \\ +(1-\theta)\left[\theta^s W^D(A', y', 0, k) + (1-\theta^s) W^D(A', y', 1, k)\right]\} f(y', y) dy' \end{array} \quad (6)$$

Therefore, regardless of whether the country chooses default, A or A' increases its expected W^D or W^R. Because the utility function is concave, when k is larger, it is more efficient to use A or A' to smooth consumption. Therefore, FERs benefit the country when the country has no access to the international financial market. FERs lower the probability of a sudden stop, especially in countries whose k is larger. When the country is facing a huge disaster shock, FERs can serve to smooth consumption and a country with high FERs has a lower risk of a sudden stop. However, it is not clear how many FER assets each country should hold.

In a word, higher CDLs of a country make the central bank need to reserve more FERs. More FERs play a role as stabilizers in the event of climate disasters, so that the economy can recover faster and reduce the sustained impact of CDLs. The interaction between FERs and CDLs is shown in the figure below. The general regression model can not identify the relationship between FERs and CDLs because of endogeneity. To investigate the dynamics of the interaction between FERs and CDLs, we quantitatively apply bootstrap full-sample and sub-sample Granger rolling window estimation respectively in support of our analysis in the following sections.

3.2. Data Description

We collect FERs and GDP monthly data for 13 East Asia Pacific countries, Cambodia, China, Indonesia, South Korea, Lao PDR, Malaysia, Mongolia, Myanmar, Papua New Guinea, the Philippines, Singapore, Thailand, and Vietnam, to calculate total FERs excluding gold (percent of GDP). The data are sourced from the IMF International Financial Statistics.

For CDLs, we use data from the International Disaster Database (EM-DAT), which collects data on major disasters that occurred from 1900 to 2020 worldwide. We divide the disaster loss by the duration to approximate monthly CDLs. CDLs include direct economic losses, which are quite exogenous, plus losses indirectly related to the disaster and reconstruction cost, which are endogenous. Thus, CDLs from this source may interact with FERs. Then, we count the CDLs in US dollars in the East Asia Pacific countries and calculate the total CDLs as an input variable in our model. We run for the longest period for which data are available, with the earliest starting point being 1994 and the latest end point being 2019.

Figure 2 shows the trends of FERs and CDLs. We can observe that since the Asian financial crisis, the FERs of the sample countries have begun to rise rapidly. This trend stops until approximately 2013–2014, and FERs start to decrease. The CDLs show a clear downward trend in recent years. Both FERs and CDLs show seasonal trends, and the seasonal trend of CDLs is more obvious. Figure 2 seems to indicate a positive relationship between FERs and CDLs. However, CDLs are only one factor that may affect FERs. It is worth noting that the turning point of FERs basically coincides with the occurrence of Typhoon Haiyan. If this positive correlation was always significant, then FERs should not have started to decrease in 2014. Therefore, we can initially guess that the relationship between FERs and CDLs is unstable and that a temporally varying model can be applied.

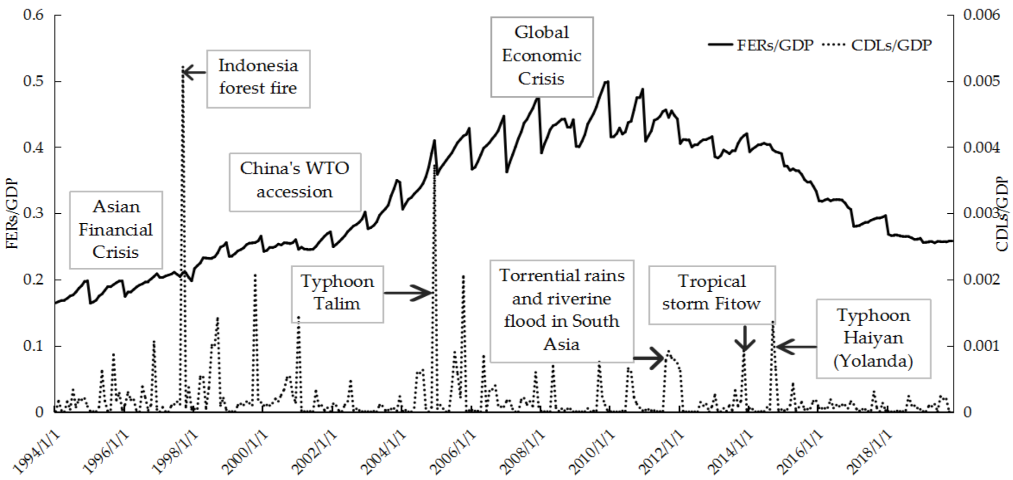

Figure 2. The trend of FERs and CDLs in East Asia Pacific.

Table 2 presents descriptive statistics. It is indicated that the series of FERs and CDLs are concentrated at 0.000305 and 0.000819, respectively, and FERs are left-skewed and CDLs are right-skewed. The kurtosis of FERs and CDLs is more than 18 so leptokurtic distributions are suggested. In addition, the Jarque-Bera test shows that the variables be significantly non-normally distributed. Therefore, we employ the RB method to prevent the non-normal distribution of FERs and CDLs.

Table 2. Descriptive statistics for FERs and CDLs.

	FERs	CDLs
Observations	312	312
Mean	0.000305	0.000819
Median	0.00239	5.53×10^{-5}
Maximum	0.0230	0.00520
Minimum	−0.0868	0
Standard Deviation	0.0137	0.000452
Skewness	−3.841	6.780
Kurtosis	18.957	61.774
Jarque-Bera	21.413 ***	5037.481 ***

Note: *** denotes significance at the 1% level.

3.3. Stationary Test and Granger Causality Test

One of the prerequisites for VAR and Granger causality tests is stationarity or cointegration, with the aim of avoiding "pseudo-regression" results [35]. Therefore, a unit root test should be carried out for the stability of each time series before the Granger causality test [36]. The extended Dickey fuller test (ADF) is used to test the stability of each index sequence by the unit root test. To obtain robust results, we employ the Phillips–Perron (PP) test and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test as well.

The Granger causality test was developed to analyze the causal relationship between economic variables. However, the traditional Granger causality test only shows the average spillover effect and ignores the dynamics of Granger causality. The time-varying causality tests show better suitability for market integration and financial contagion where structural changes may happen [37].

3.4. Bootstrap Full-Sample Causality Test

Note that the LRT, LM, and Wald tests require asymptotic distributions, while Granger causality test statistics in the VAR model do not follow any asymptotic distributions. Thus, a residual-based bootstrap (RB) technique is employed to solve this problem. Moreover, Shukur and Mantalos [38] highlighted that the RB modified-LR method has a higher test power than both the standard and the modified Wald tests. Therefore, we use this method to examine the causalities between FERs and CDLs. First, we construct a VAR(p) process:

$$Y_t = \alpha_0 + \alpha_1 Y_{t-1} + \ldots + \alpha_p Y_{t-p} + v_t \; t = 1, 2, \ldots T \tag{7}$$

where p is the optimal lag order, and we select it based on the Schwarz information criterion (AIC), Schwarz information criterion (SC), and Hannan–Quinn information criterion (HQ). In our model, we can get $Y_t = (FR_t, CL_t)'$. Then, we can rewrite Equation (7) as Equation (8):

$$\begin{bmatrix} FR_t \\ CL_t \end{bmatrix} = \begin{bmatrix} \alpha_{10} \\ \alpha_{20} \end{bmatrix} + \begin{bmatrix} \alpha_{11}(L)\, \alpha_{12}(L)\, \alpha_{13}(L)\, \alpha_{14}(L) \\ \alpha_{21}(L)\, \alpha_{22}(L)\, \alpha_{23}(L)\, \alpha_{24}(L) \end{bmatrix} \begin{bmatrix} FR_t \\ CL_t \\ GPC_t \\ AUSI_t \end{bmatrix} + \begin{bmatrix} v_{1t} \\ v_{2t} \end{bmatrix} \tag{8}$$

where $\begin{bmatrix} v_{1t} \\ v_{2t} \end{bmatrix}$ is a white-noise process, L is a lag operator and $\alpha_{ij}(L) = \sum_{k=1}^{p} \alpha_{ij,k} L^k$, $i = 1, 2$; $j = 1, 2, 3$. We include GDP per capita (GPC_t) and the Bloomberg–JP Morgan Asia Dollar index ($AUSI_t$) as control variables. Then, we have $L^k Y_t = Y_{t-k}$.

Based on Equation (8), we can examine the null hypothesis that CDLs do not Granger cause FERs. It can be rejected if CDLs have an impact on FERs. We use the same method to examine whether FERs Granger causes CDLs.

3.5. Bootstrap Sub-Sample Rolling-Window Estimation

The full-sample causality test assumes that estimated coefficients are constant, but they are not in most cases if there are structural changes [39]. In the post-Asian financial crisis period, the elasticity of FERs of developing countries seems to be higher than that of some indicators of crisis vulnerability (such as foreign debt repayment rate and total foreign debt), which indicates that the preventive response of policy-makers through holding more FERs has been enhanced. Moreover, resident investors switch from negative feedback traders to positive feedback traders during the crisis. These temporally varying characteristics may lead to changes in the relationship between variables and FERs at different times. Therefore, we use a bootstrap sub-sample rolling-window estimation and investigate the association between causal links and significant economic or natural changes.

We employ the method developed by Balcilar et al. [40] to solve this problem. Specifically, the detailed steps are as follows: first, we set up a fixed-size rolling window with a width of $I = 36$ months (We use widths of 20-, 30- and 40- months as well, and the results are consistent with the 36-months rolling-window.), so the full sample is divided into $T - I = 276$ subsamples. Then, for each sub-sample, we apply RB-based modified LR tests. Finally, we calculate the p-values and LR statistics and summarize the sub-sample regression results.

4. Results

4.1. Full-Sample Estimation Results

To test the stationarity of FERs and CDLs, we use the ADF test, PP test and KPSS test. The results are shown in Table 3. We can conclude that CDLs are I(1). There is no consistent result regarding the stationarity of FERs, and the first difference of FERs is stationary. Thus, we conduct our following quantitative analysis with CDLs and the first difference in FERs.

We conduct the VAR process to examine the full-sample Granger causal relationship between FERs and CDLs. According to the LR, FPE, AIC, and HQ criteria, we choose 1 as the optimal lag order. The full-sample results are shown in Table 4. It is obvious that CDLs do not Granger-cause FERs and vice versa, which is not supportive of the results of the small open economy model.

Table 3. The results of unit root tests.

		ADF	PP	KPSS
Levels	FERs	−1.735 (1)	−1.656 [18]	1.0134 *** [15]
	CDLs	−12.31 *** (1)	−12.300 *** [2]	0.996 [5]
First differences	FERs	−2.903 ** (1)	−19.847 *** [20]	0.666 [21]
	CDLs	−16.34 *** (1)	−16.368 *** [3]	0.562 [4]

Notes: The number in parentheses is the lag order based on the SIC criteria. The number in the brackets indicates the bandwidth based on the Bartlett Kernel. *** and ** refer to significance at the 1% and 5% levels, respectively.

Table 4. Full-sample Granger causality tests.

Tests	H0: CDLs Do Not Granger-Cause FERs		H0: FERs Do Not Granger-Cause CDLs	
	Statistics	*p*-Value	Statistics	*p*-Value
Bootstrap LR test	1.279	0.206	1.715	0.174

Notes: To calculate *p*-values using 10,000 bootstrap repetitions.

The full-sample estimation result reveals constant parameters and constant relationships. The *p*-values indicate that the relationship between FERs and CDLs is not significant, which means FERs do not Granger-cause CDLs and vice versa. The results are inconsistent with the conclusion of the small open economy model.

4.2. Parameter Stability Tests Results

As national policies and climate change, structural change may occur over time. Therefore, we employ Sup-F, Ave-F, and Exp-F parameter stability tests. Besides, we use the Lc statistics to test the applicability of the Granger causality test. The results are shown in Table 5.

Table 5. The results of parameter stability tests.

Tests	FERs		CDLs		VAR System	
	Statistics	*p*-Values	Statistics	*p*-Values	Statistics	*p*-Values
Sup-F	14.96 **	0.03	33.57 ***	0.00	30.39 ***	0.000
Ave-F	6.93 **	0.03	19.71 ***	0.00	14.88 ***	0.000
Exp-F	5.13 **	0.02	13.62 ***	0.00	12.17 ***	0.000
Lc					3.18 ***	0.000

Notes: To calculate *p*-values using 10,000 bootstrap repetitions. *** and ** refer significance at the 1% and 5%, respectively.

It is obvious that all statistics suggest rejections of the null hypothesis at the 5% level. FERs and CDLs have structural changes, and the estimated parameters are time-varying. The VAR system does not follow a random walk process. Thus, the traditional Granger causality method is not applicable to our full sample, and a time-varying causal relationship exists between FERs and CDLs.

4.3. Bootstrap Rolling-Window Tests Results

We employ the bootstrap sub-sample rolling-window estimation because of the time-varying characteristic of the estimated parameters. The results are shown in Figures 3 and 4.

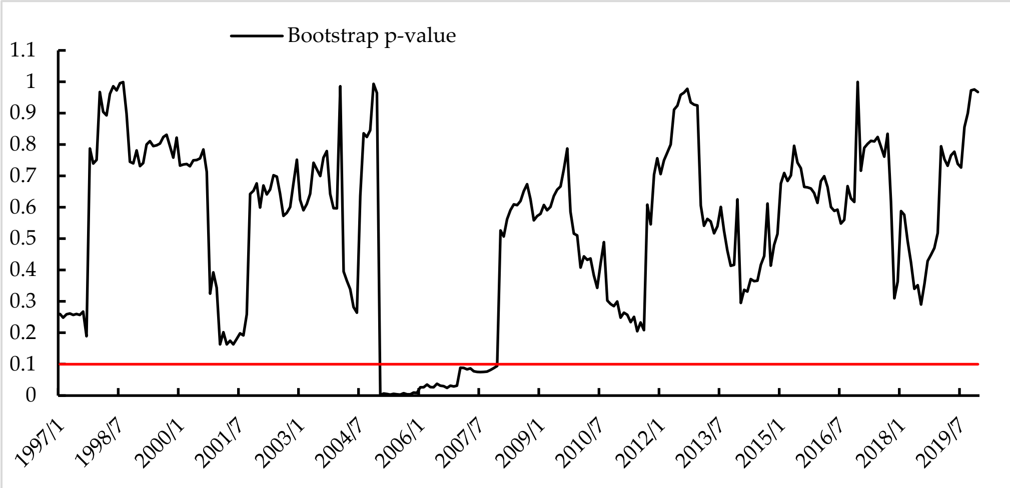

Figure 3. Bootstrap p-values of rolling test statistic testing the null hypothesis that FERs do not Granger cause CDLs.

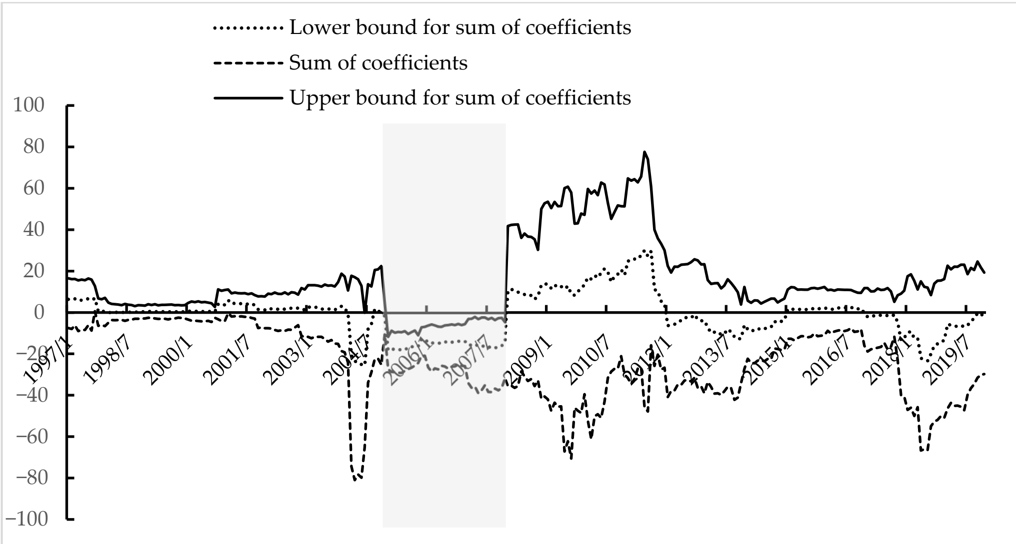

Figure 4. Bootstrap estimates of the sum of the rolling window coefficients for the impact of FERs on CDLs (The shadow indicates that the regression coefficient is significant during these time periods).

Figures 3 and 4 show the p-value and influence of FERs on CDLs, respectively. The null hypothesis is that FERs do not Granger-cause CDLs, except 2005 M1 to 2007 M12 at the 10% significance level. During this period, FERs negatively affected CDLs. This confirms our conclusions in the small open economy model. FERs act as a buffer to stabilize the economy and reduce CDLs. But we need to discuss why this significant relationship is only significant in the range from 2005 M1 to 2007 M12. We believe that the continuous and even excessive accumulation of FERs and the changes in the financial environment caused by the financial crisis are the factors that affect this time-varying relationship.

Before the beginning of the 21st century, the FERs of East Asia Pacific countries were at low levels that were inadequate to address the rapid flow of international capital and the volatility of the exchange rate in the foreign exchange markets. At the same time, however, we can observe that CDLs began to fluctuate sharply since 2004, which is caused by many serious natural disasters. In December 2004, a tsunami hit Indonesia, causing economic losses of more than 4451 million US dollars. In 2005, the storm hit Shanghai and Anhui of China, causing economic losses of at least 3650 million US dollars. In May 2006, an earthquake occurred in Indonesia, causing economic losses of at least

\$3100 million. The negative impact of climate disasters on economic activities is increasing. During this period, the countries in the region held sufficient FERs, which stabilized the exchange rate and reduced the occurrence of sudden stops. Countries with more FERs can devote more resources to disaster relief and post-disaster reconstruction after climate disasters [12]. Moreover, the financial environments of these countries are more stable, and their international liquidity is more abundant, so sudden stops are not prone to occur. Therefore, after suffering from climate disasters, these countries have fewer indirect economic losses. In this period, FERs act as a strong buffer.

Next, we explain why this relationship disappears over time (after 2008 M1, the relationship is no longer significant). We can observe that FERs experienced a rapid rise after 1997, and especially since 2001, and peaked from 2005 to 2012. Since then, many Asian Pacific countries have found that their FERs are excessive, which has led to an increase in the high cost of FERs, increased investment risks, and pressures for the appreciation of their currencies. The excessive FERs are sufficient to cope with many shocks, and with the increasing international aid, the need to use FERs to reduce CDLs has gradually decreased. The ability of foreign exchange reserves to intervene in financial markets declined because of the turbulence in financial markets in Autumn 2008. Therefore, we can observe that after 2008 M1, FERs did not reduce CDLs. And many Asian Pacific countries have begun to reduce their FERs. In a word, the total amount of FERs is a factor that affects its relationship with CDLs. And a stable global financial market is a prerequisite for the full play of FERs.

The empirical results of CDLs on FERs further prove this conclusion. Figures 5 and 6 show the *p*-value and coefficients for the impact of CDLs on FERs, respectively. The null hypothesis that CDLs do not Granger-cause FERs, except 2005 M1, 2007 M1, and 2013 M8 to 2014 M10 is rejected at the 10% significance level. During this period, CDLs increase FERs. Coincidentally, according to Figures 5 and 6, the *p*-value and influence of CDLs on FERs indicate a significant positive influence in almost the same period as in Figures 3 and 4, from 2005 M1 to 2007 M1, with the exception of the second half of 2005 and 2006. This indicates that countries pay more attention to climate risk. In 2014, the relationship reappeared, when the annual loss reached \$28314 million after Typhoon Haiyan hit South-eastern Asia in 2013. Therefore, we can demonstrate that if the central bank considers FERs insufficient, after every disaster, countries become more precautious, leading to FERs accumulation; however, if FERs are already sufficient, high CDLs will not make the central bank "overcautious". These results are supported by the small open economy model.

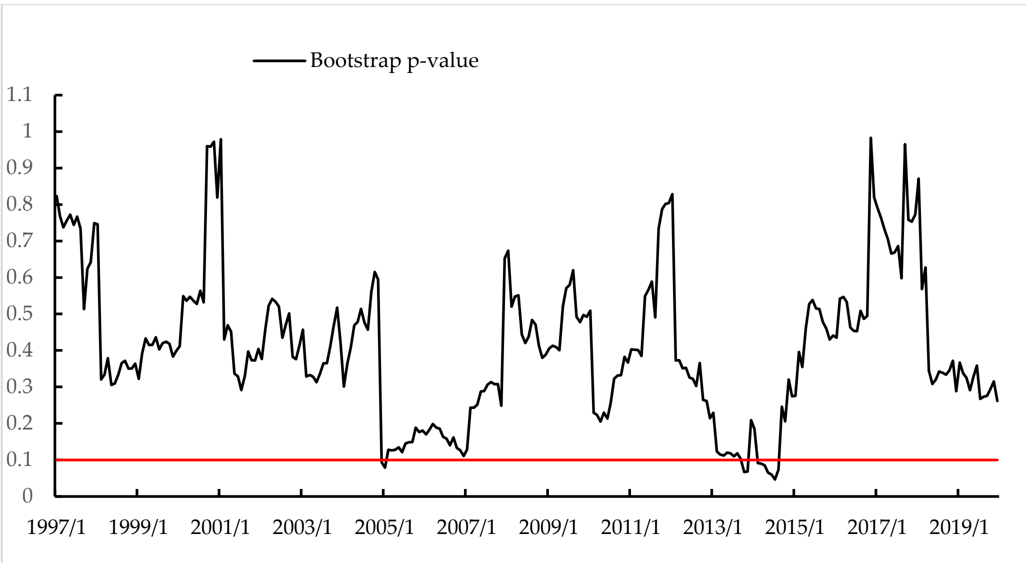

Figure 5. Bootstrap *p*-values of rolling test statistic testing the null that CDLs do not Granger-cause FERs.

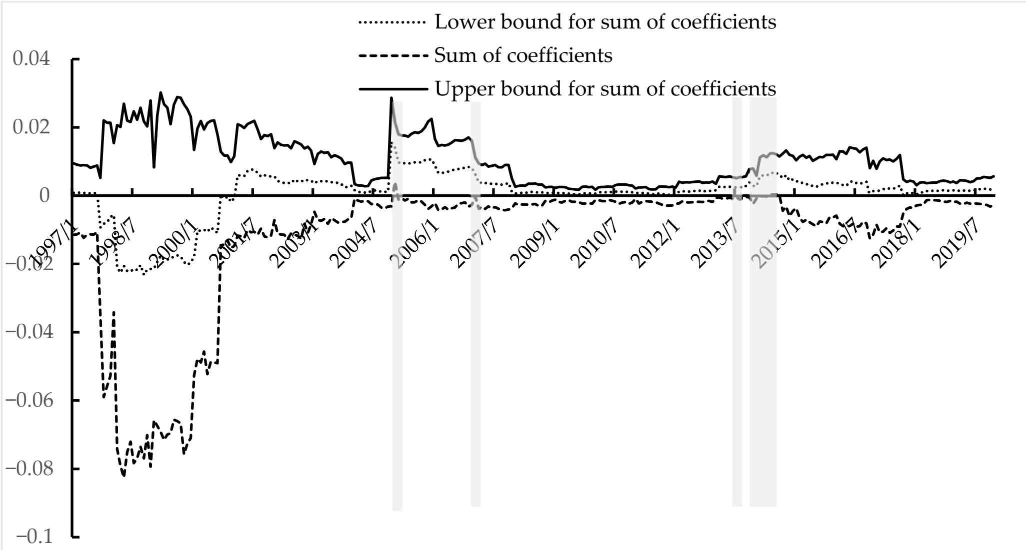

Figure 6. Bootstrap estimates of the sum of the rolling window coefficients for the impact of CDLs on FERs (The shadow indicates that the regression coefficient is significant during these time periods).

However, it is not always the case. It is worth noting that the results are different between the two time periods (2005 M1 to 2007 M12 and 2014). No evidence proves that FERs in 2014 reduce CDLs. This further confirmed the viewpoint of excess FERs in Asia [41]. FERs have fully played the functions of stabilizing the exchange rate and smoothing consumption, and the value of the excess is quite limited with low long-run investment returns [13].

China is a typical representative country of East Asia Pacific emerging economies. We find that the empirical results are consistent with the changes in both FERs and monetary policies in China from the 1990s. Specifically, since the reform of the exchange rate system in 1994, FERs began to grow rapidly. In 2003, China's FERs entered a period of rapid growth. In 2006, they surpassed Japan for the first time, and China became the country with the most FERs in the world. In the second quarter of 2014, the size of FERs peaked. The FERs accumulated by emerging market countries play an important role in financial stability and economic growth. The global financial crisis in 2008 did not lead to a large-scale foreign exchange crisis like the Asian financial crisis. During the crisis, Bulgaria, South Korea, Russia, and other countries prevented the sharp devaluation of their currencies by consuming FERs, thus alleviating the impact of the crisis on domestic financial markets. However, since 2017, the amount of FERs has fluctuated at approximately US $3 trillion. As of the fourth quarter of 2020, the amount held in FERs is US $3.22 trillion. In recent years, the trend of FERs also shows the new direction of FERs management, which is no longer "more is better", but how to better manage and use FERs. The step-by-step free fluctuation of the exchange rate is more important to China than the stability of the exchange rate (Bo, 2015). This is in line with the notion that many emerging markets may have noticed the negative effect of excessive FERs.

In summary, we conclude that the relationship between FERs and CDLs is unstable. The results of full-sample Granger causality tests do not support a significant causal relationship, while it is indicated by parameter stability tests that full-sample tests are not reliable. Therefore, a bootstrap sub-sample rolling-window estimation is applied to explore the time-varying relationship between FERs and CDLs. It is indicated that in some periods, FERs significantly reduce CDLs and CDLs increase FERs. In other sample periods, this relationship is not significant. Severe climate disasters put forward higher requirements for FERs. Insufficient FERs may further lead to problems such as deterioration of the balance of payments and exchange rate fluctuations. The rise in FERs is conducive to reducing CDLs, increasing the corresponding country's resistance to unexpected external shocks. This confirms the result of the small open economy model. However, this significant relationship weakens after 2015. From the perspective of climate risk, this shows that countries have better measures to deal with climate change and that FERs may have been excessive in playing the role of preventing climate shocks. With the continuous accumulation of FERs in East Asia Pacific, the defense ability of FERs against the impact of climate disasters has weakened. And after the Global Economic Crisis, the adjustment role of FERs has been significantly weakened. This is an important factor affecting the role of FERs.

5. Conclusions and Recommendations

5.1. Conclusions

We use the bootstrap subsample rolling window estimation to identify the temporally varying interaction between FERs and CDLs, providing a new perspective for FERs management in East Asian Pacific countries. The empirical results show that CDLs have had a positive effect on FERs in certain periods. After these periods, the positive effect of CDLs on FERs disappeared, indicating that countries have established more complete disaster resistance mechanisms and higher economic stability. In turn, FERs had a negative effect on CDLs in a certain period. This shows that FERs significantly improve the resistance of the economy to climate disasters, which is consistent with the analysis of the small open economy model in this paper. However, the negative effects have disappeared rapidly in the last decade, which proves that Asia has excessive FERs in terms of climate risk and that FERs have overplayed their role in controlling the impact of conventional climate disasters. This paper contributes to the success of the Sustainable Development Goals-UN 2030 agenda and meets the needs of Goal 13 (take urgent action to combat climate change and its impacts) and Goal 17 (strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development). We emphasized the positive role of FERs in reducing CDLs, and also discussed the prerequisites for FERs to play a role. This is helpful for the central banks to formulate policies. It is necessary to study this kind interaction between human society and natural processes regarding the global environmental variability and better achieve the targets of Sustainable Development Goals-UN 2030 agenda [42].

5.2. Recommendations

Understanding the relationship between FERs and CDLs can provide inspiration for investors and governments. For investors, the climate disasters and FERs of the country should be taken into account when they make foreign investments. The impact of serious climate disasters may lead to the country facing great loss during the sudden stops. As a result, investors may suffer losses or even be affected by the default of the state. An appropriate amount of FERs, sound economic systems, solid infrastructure and good national reputation can strengthen investments by exposing them to less climate risk. Investors should consider and disperse this risk when building their portfolios.

For the government, it is necessary to resist the impact of climate risk from four aspects. First, upgrade the industrial structure. If a country is affected by climate risk year-round and its industries are vulnerable to climate disasters, it is a better choice to upgrade industries such as agriculture to industry or service. Second, considering the vicious circle between low FERs and sudden stops, the state should fully realize the important role of FERs as a response to the impact. An appropriate amount of FERs should be required to ensure smooth consumption and exchange rate stability in the event of disasters. This attracts more foreign investors and obtains lower financing costs in the international debt markets. Third, better infrastructure construction is required. We can see that the global climate is worsening, and we cannot predict when this trend may stop. The damage of various climate disasters to national infrastructure is lasting and devastating, and it takes a long time to recover. The better the infrastructure, the less a country's overall climate exposure. Fourth, global climate issues need to be solved with the cooperation of all countries. Economic globalization leads to a higher correlation of return on global assets and a closer relationship between global industrial chains. The fundamental way to solve climate problems is to develop new forms of sustainable energy, set emission reduction targets, and effectively implement environmental protection policies.

5.3. Limitations and Future Research

This study has some aspects that need to be further improved. First, due to the limitation of research data, we cannot distinguish between direct loss and indirect loss in CDLs. More detailed data can make the research conclusion more convincing. We believe that one way to solve this problem is to analyze the impact of a single climate disaster event on the economy. Second, this paper uses the time series data of East Asia Pacific for research, which has lost the information of panel data to a certain extent. However, panel regression cannot recognize the time-varying characteristics of regression. A regression method that can identify the time-varying characteristics of the panel regression model is worth discussing.

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