Early Warning Indicators of Financial Crises: Original Sin and Currency Mismatches*

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Abstract

Emerging and developing economies are rapidly accumulating foreign currency-denominated debt in recent years. Such debt leads to currency mismatches and further result in external vulnerability. This study investigates the role of balance sheet vulnerabilities in financial crises such as currency, banking, and sovereign debt crisis. wE develop the broad original sin and new currency mismatch indices to measure the external vulnerabilities and constructs the early warning indicators. The empirical results show that the higher value of original sin and currency mismatches are associated with a greater likelihood of currency, banking, and debt crisis. The original sin and currency mismatches play a crucial role in early warning signals; hence these indicators need to be monitored and part of the calibrated policy framework. The results suggest that the accumulation of forex reserves can safeguard the economy from external vulnerabilities and support financial stability during tumultuous periods.

JEL Classification: G01, G20, F31, F32, F34.

***Keywords*:** Financial crises, foreign currency debt, original sin, currency mismatches, early warning indicator.

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1 Introduction

The emerging and developing economies (EDEs) weathered the global financial crisis (GFC) relatively well. However, the recent financial crises[1] in EDEs such as Argentina, Turkey, and Venezuela dwarfing the impact suffered during the GFC. The rapid accumulation of foreign currency-denominated debt (FCD) and currency mismatches are seen as the primary indicators of crises. Therefore, we aim to investigate the role of FCD and currency mismatches in financial crises. The first and second-generation crisis models fall short of explaining the causes of the crisis in EDEs during the 1990s. Of late, third-generation crisis models recognize often neglected causes of financial crises such as FCD. The liabilities in foreign currencies are widely believed as the protagonist of financial crises in Asia and Latin American economies.

The EDEs are pursuing financial liberalization and raising the capital from international markets in foreign currency, primarily due to original sin (Eichengreen and Hausmann, 1999). Thus, foreign currency liabilities on the balance sheet create currency mismatches — a mismatch between assets and liabilities where assets are denominated in domestic currency but liabilities in foreign currency (Goldstein and Turner, 2004). The currency mismatch creates a systemic risk in the economy that leads to severe insolvencies and macroeconomic volatility. Thus, the mismatch between assets and liabilities is the leading indicator of financial crises (Goldstein and Turner, 2004; Eichengreen et al., 2005b). The present investigation of the role of original sin and currency mismatches in predicting crises against this backdrop assumes importance.

The third-generation crisis models show how liability dollarization exacerbates financial crises, decreases output, and hurts economic growth (Krugman, 1999; Chang and Velasco, 2000). A sharp rise in FCD is more problematic for the banks after the currency depreciation. The mismatches between banks' assets and liabilities increase financial vulnerability and cause the banking system to collapse. The corporate and banking sector panics and runs as happened during the Asian financial crisis (1997) were primarily due to balance

1 The financial crises refer to currency crisis, banking, and sovereign debt crises.

sheet vulnerabilities.

In a theoretical model, Bocola and Lorenzoni (2020) consider FCD as a source of financial instability in emerging markets, since currency depreciation increases the real burden of FCD and amplifies the effects of financial crises. The central banks in EDEs, which often enjoy little credibility, resort to interest rate hikes to fight inflation and retain foreign investment. Such action increases borrowing costs to inflate the existing liabilities, and causes corporate and sovereign defaults. The wide swathe of default triggers a debt crisis, resulting in substantial losses for banks and firms. Hence, the currency composition of debt matters for debt crisis (Jeanne, 2005; Schneider and Tornell, 2004; Dell'Erba et al., 2013).

A growing body of literature highlights that FCD and currency mismatches are the potential indicators of financial crises (Allen et al., 2002; Calvo et al., 2004; Eichengreen et al., 2005a,b; Goldstein and Turner, 2004; Bordo and Meissner, 2006; Goldstein and Xie, 2009; Bordo et al., 2010). However, there is no concrete empirical validation on the role of original sin and currency mismatches in financial crises. Bordo et al. (2010) examines this relationship for the sample of 45 countries and find a positive association. Nevertheless, Bordo and Meissner (2006) show that FCD does not necessarily increase the probability of financial crises, and a few countries avoided the financial vulnerability despite having original sin.

The extant empirical work on the role of original sin and currency mismatches in financial crises, still in its infancy, focuses on narrow indicators, which do not fully capture the currency exposure. The extant research also does not assess the role of the currency composition of debt in financial crises. The literature identifies the potential predictors of financial crises such as forex reserves, exchange rate overvaluation, and short-term external debt (Frankel and Rose, 1996; Eichengreen et al., 1996; Kamin and Klau, 1998; Schularick and Taylor, 2012; Frankel and Saravelos, 2012; Babecky et al., 2014; Frost and Saiki, 2014; Erler et al., 2015; Hung, 2017). Nevertheless, researchers shy away from looking beyond these predictors, although original sin and currency mismatches are potential

indicators of financial crises. In this context, this study is the first of its kind to analyze the extent to which original sin and currency mismatches influence the probability of financial crises. We depart from pertinent literature in many dimensions that underpin the main contribution of the present study.

We contribute to the literature by developing a broad version of original sin, including the currency composition of international debt securities and cross-border banking loans. We also develop the new currency mismatch index using the broad original sin index. These indices are more comprehensive than the existing measures in terms of coverage of economies, time, and inclusion of bank debt. These indicators allow us to test whether countries with high currency mismatches are more vulnerable to financial crises than economies with only original sin problems. This is the first study to analyze the most comprehensive and recent dataset for original sin and currency mismatch indicators to the best of our knowledge. Further, investigating whether the foreign currency liabilities beyond certain limits appear to be a financial risk is an important policy question for many EDEs. To address this policy issue, we estimate the nonlinear effect of original sin and identify the threshold value of original sin.

Further, we use the novel dataset on financial crises, which enables us to analyze the impact of external vulnerabilities on the financial crises for the most extended panel. The present sample consists of both advanced economies (AEs) and EDEs for a longer period, which ensures the robustness and precision of the estimates. Such a sample helps avoid overfitting the model and biases. A predictive analysis of a large, long-term, cross-country dataset supports the idea that external vulnerable indicators increase the likelihood of financial crises in AEs and EDEs. To the best of our knowledge, this study is the first to analyze the role of original sin and currency mismatches in financial crises.

The present investigation shows that several economies suffer from a greater level of original sin problem that have potential to increase the probability of financial crises. We empirically show that the likelihood of a financial crisis rises as the balance sheet composition tilts towards the liability position in foreign currency. The rest of the paper is

organized as follows. In Section 2, we develop the broad original sin and new currency mismatches indicators to measure the external vulnerability. We discuss the definitions and trends of the financial crises in Section 3. The theoretical and empirical studies on early warning indicators (EWIs) of financial crises and the empirical strategy of the present study are discussed in Section 4. We discuss the results in Section 5, while Section 6 concludes the paper with policy implications.

2 External vulnerability indicators

2.1 Broad original sin

Eichengreen and Hausmann (1999) define original sin as "the inability of a country to borrow abroad in its own currency". Eichengreen et al. (2005a,b) construct the narrow version of the original sin (OSIN) index as follows:

$$OSIN_{i,t} = max\left(1 - \frac{Securities\ in\ currency\ i\ in\ year\ t}{Securities\ issued\ by\ country\ i\ in\ year\ t}, 0\right) \tag{1}$$

where the securities include only international debt securities. We extend the OSIN by including the currency composition of cross-border bank loans and international debt securities and develop a broader version of the OSIN (BOSIN) index:

$$BOSIN_{i,t} = max\left(\frac{LBS^{f}_{i,t} + IDS^{f}_{i,t}}{LBS_{i,t} + IDS_{i,t}}, OSIN_{i,t}\right) \tag{2}$$

where i indicates the country and t is the time indicator. OSIN and BOSIN indices range between zero (secure position in foreign currency) and one (severe original sin problem and exposure to external shocks). The $LBS^{f}_{i,t}$ and $IDS^{f}_{i,t}$ in Eq. 2 are defined as follows:

$$LBS^{f}_{i,t} = \sum_{t=1}^{n}(USD_t + EUR_t + GBP_t + JPY_t + CHF_t)^f \tag{3}$$

$$IDS^{f}_{i,t} = \sum_{t=1}^{n}(USD_t + EUR_t + GBP_t + JPY_t + CHF_t)^f \tag{4}$$

The five major foreign currencies are the US dollar (USD), Euro (EUR), Pound (GBP),

Japanese Yen (JPY), and Swiss Franc (CHF). Further, $LBS_{i,t}$ and $IDS_{i,t}$ refer to the total loans and securities denominated in all currencies from the locational banking statistics and international debt securities of BIS database, respectively. We follow the framework of Amstad et al. (2020) to develop the BOSIN index. The proposed approach (BOSIN) has several advantages. BOSIN includes cross-border bank flows and international debt securities, and thus better captures the currency exposure than OSIN.

We exclude the loans and securities of five countries (the US dollar, Euro, Pound, Japanese Yen, and Swiss Franc) that denominate debt in their own currency. The exclusion is because of the dominance of these five currencies in the international financial structure. This exclusion captures the external risk accurately. Further, we set the index limits that exclude the economies with total debt securities higher than their nationals' issuance. This limit is because of the nonresidents' debt issuance in the domestic market. For example, the index takes negative values for the US and the UK since the debt is issued in their own currency higher than the debt issued by their nationals. Overall, the BOSIN index covers 165 countries for the period from 1970 to 2018, whereas the OSIN is limited to a group of 44 EDEs and available only up to 2003.

2.2 New currency mismatch

Goldstein and Turner (2004) criticize the original sin index as a measure of currency mismatches on several grounds. *First*, OSIN addresses the liability side of the balance sheet effect, i.e., debt securities. In the real world, both assets and liabilities are used to hedge the foreign exchange positions. *Second*, the original sin framework ignores the essential inputs such as the differences in export openness and reserve holdings to assess currency risks. *Finally*, it does not consider cross-border bank loans and international bonds. Goldstein and Turner (2004) construct the aggregate effective currency mismatch (AECM) index to address these drawbacks. However, this index is confined to 22 emerging economies and available for a shorter period due to data unavailability.

We develop the new currency mismatch index (NCM) by including the forex reserves, currency composition of cross-border bank debt, international debt securities, and export

openness to address these critics and overcome the shortcomings of the narrow version of original sin. The NCM is more comprehensive and better captures the currency exposure than original sin indicators. The NCM index is as follows:

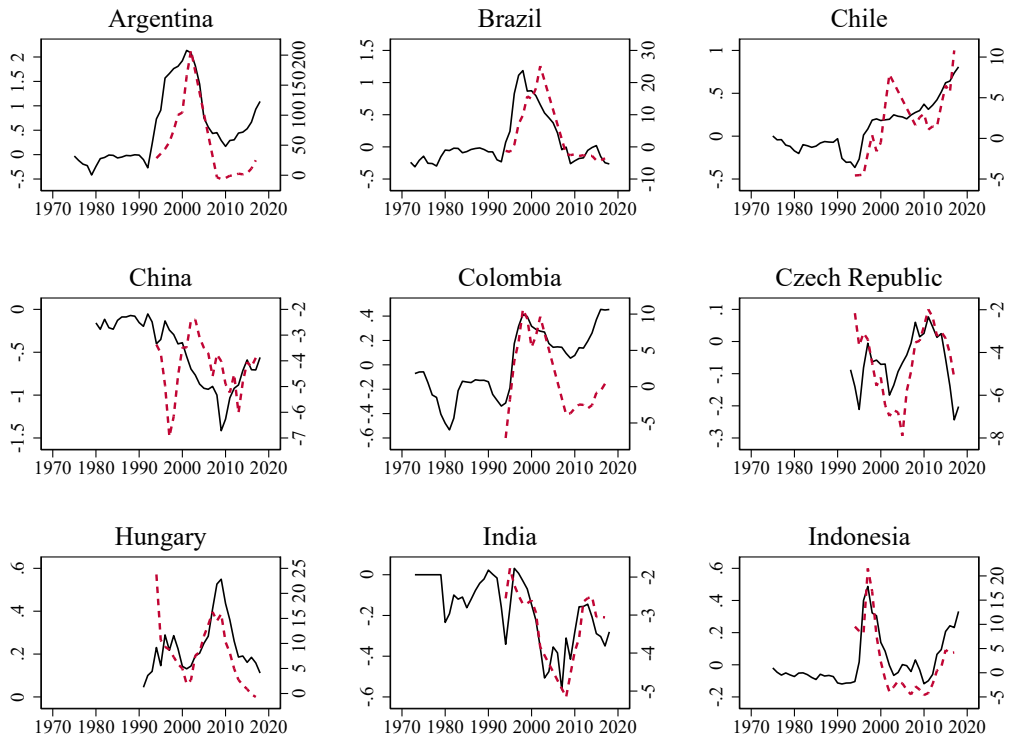
$$NCM_{i,t} = \left(\frac{FR_{i,t} - ID_{i,t}}{Exports_{i,t}} \right) \times BOSIN_{i,t} \tag{5}$$

where $NCM_{i,t}$ indicates new currency mismatch index for country i in year t. $FR_{i,t}$ and $ID_{i,t}$ denotes the total foreign exchange reserves and international debt securities held in a country i at year t, respectively. NCM > 0 indicates net reserve position in foreign currency of a country, high forex reserves, and lesser dependence on FCD and global liquidity (lower original sin). Whereas the NCM < 0 suggests the net liability position in foreign currency. The lower forex reserves and higher FCD tend to increase the mismatches and foreign currency risk. When NCM $= 0$, the forex reserves equal international debt securities, implying no currency mismatch. An exchange rate depreciation causes adverse balance sheet effects when there is a net liability position in foreign currency (debt securities higher than forex reserves). On the other hand, the net reserves position can have a positive balance sheet and competitive effect. NCM index can reflect the degree to which a country is exposed to currency risk. The new index does not contain the asset hedging instruments to capture the complete foreign currency due to non-availability data on hedging. This can be considered as one of the limitations of the present study.

The NCM and AECM indicators are not identical, but share certain similarities. The higher correlation between NCM and AECM implies that NCM captures most of the foreign currency exposure. Figure 1 further indicates that the proposed method captures most of the foreign currency exposure and covers a longer period than AECM index. The region-wise balance sheet vulnerabilities presented in Table 1 shows that Sub-Saharan Africa, Latin America, and the Caribbean regions suffer from the greater level of original sin. As expected, the developed countries have the lowest average original sin (0.64), thanks to their well-developed financial markets. In case of currency mismatches, Latin America and the Caribbean (0.19), emerging and developing Europe (0.016) suffer from

the liability position in foreign currency that tends to increase currency and systemic risk in these economies.

Figure 1. New currency mismatch vis-à-vis AECM index



Data sources: Authors' own calculations based on data drawn from the Bank for International Settlements, International Monetary Fund, and World Bank.
Notes: The y-axis denotes the new currency mismatch index (LHS) and AECM index (RHS). We develop the new currency mismatch indicator with a broad original sin index.

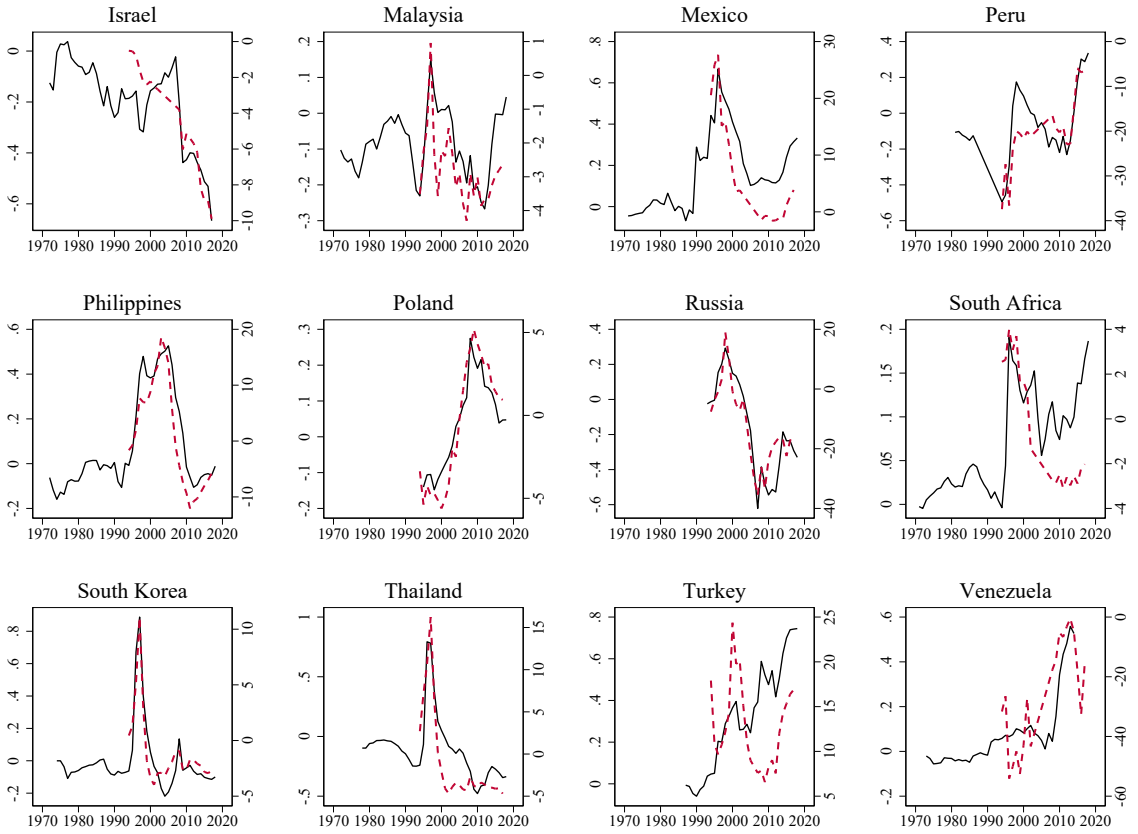
3 Financial crises: Definitions and trends

The growing body of research primarily identifies three types of crises: currency, banking, and sovereign debt (Kaminsky and Reinhart, 1999; Reinhart and Rogoff, 2011). The crises measures are broadly classified as quantitative and qualitative (Reinhart and Rogoff, 2011). The currency and balance of payment crisis are quantitative, whereas the banking and debt crisis are based on qualitative analysis.

The currency crisis is defined as the speculative attack on currency through exchange rate depreciation or devaluation that prompts the monetary authority to hike interest rates and control capital flows.[2] Therefore, the exchange rate shock is the sole cause of the

2 There is no specific and unanimous definition of the currency crisis. For instance, Frankel and Rose (1996) define crisis as "a currency crisis is nominal depreciation of a currency of at least 25 percent or at least 10 percent increase in the rate of depreciation". Kaminsky et al. (1998) define this crisis as "when a weighted average of monthly percentage depreciation in the exchange rate and monthly

Figure 1. New currency mismatch vis-à-vis AECM index (Other sample)



Data sources: Authors' own calculations based on data drawn from the Bank for International Settlements, International Monetary Fund, and World Bank.
Notes: The y-axis denotes the new currency mismatch index (LHS) and AECM index (RHS). We develop the new currency mismatch indicator with a broad original sin index.

currency crisis. The sudden stop crisis, also known as the balance of payment or capital account crisis is often due to a sharp cut in capital flows (Calvo, 1998; Calvo et al., 2004). The banking crisis occurs when significant financial distress, losses, and liquidation in the banking sector. Lastly, sovereign debt crises involve outright default on government debt obligations, including nonpayment, repudiation, or restructuring debt into less favorable to the lender than the original contract (Reinhart and Rogoff, 2011).

The discrete and continuous methods are employed in the pertinent literature to describe the crisis (see Frankel and Saravelos, 2012). The discrete measure is a binary variable — when a threshold value of financial or economic variables is breached, it takes the value of one and zero otherwise. For example, Eichengreen et al. (1995) define a crisis when the 'exchange rate market crisis index' moves at least two standard deviations above

percentage declines in reserves exceeds its mean by more than three standard deviations". In some cases, currency crisis due to current account deficits are known as balance of payments crisis.

Table 1. Broad original sin and new currency mismatch indicators

Group	*Broad original sin*	*New currency mismatch*
Sub-Saharan Africa	0.908	-0.052
Latin America and the Caribbean	0.883	0.193
The Middle East and Central Asia	0.866	-0.204
Emerging and Developing Europe	0.865	0.016
Emerging and Developing Asia	0.812	-0.444
Advanced economies	0.647	-0.479

Notes: The table presents the average values of broad original sin and new currency mismatches for each group of countries. We classify the sample countries into several groups following the IMF-WEO method. The value of broad original sin lies between zero and one; the value closer to one is severe original sin problem implying greater currency risk. Similarly, the positive value of currency mismatch indicates liability position in foreign currency (international debt is more than the foreign reserves). In contrast, a negative sign suggests a net asset position in foreign currency (reserves greater than debt).

the mean. On the other hand, continuous measures of crisis such as speculative pressure index and nominal/real exchange rate index do not differentiate the type of crisis during a particular time.

To overcome the limitations in existing measures, Laeven and Valencia (2013, 2018, 2020) developed new methods to measure the three types of crises such as currency, banking, and sovereign debt and prepared a database. *First*, the authors measure currency crisis as a "nominal depreciation of the currency vis-à-vis the US dollar of at least 30 percent that is also at least ten percentage points higher than the rate of depreciation in the year before".[3] *Second*, they define the banking crisis as an event that meets the following two conditions:

1. "Significant signs of financial distress in the banking system (as indicated by significant bank runs, losses in the banking system, and/or bank liquidations)."

2. "Significant banking policy intervention measures in response to significant losses in the banking system."

The sovereign debt crisis is based on debt default and restructuring data collected from the reports of rating agencies, reserve accumulations, IMF staff reports, and bond market development.

3 This definition extends the approach of Frankel and Rose (1996) on currency crisis.

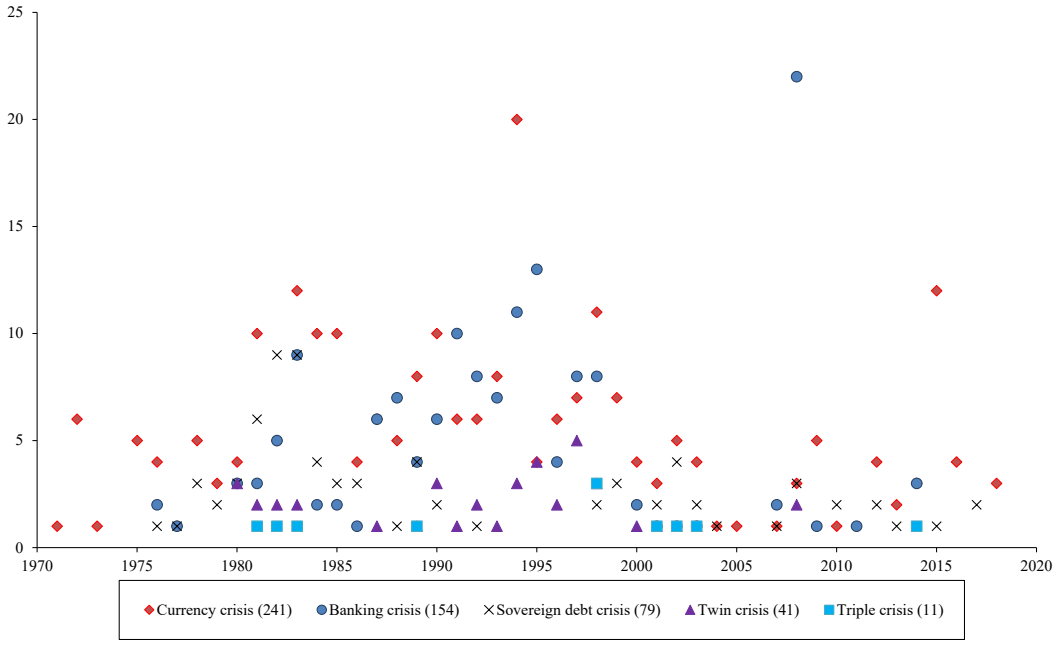
We collect the novel dataset on three types of crises (currency, banking, and debt crisis) covering 162 countries from 1970 to 2018. The sample includes 34 AEs and 128 EDEs (country coverage presented in Appendix Table 8). We use the annual frequency because quarterly data of many predictors are unavailable for many EDEs. This study enjoys the data on the longest cross-country financial crises from the well-known database of Laeven and Valencia (2020), Reinhart and Rogoff (2011), and Koh et al. (2020).[4] This dataset is standard and reliable. Moreover, the country experts also confirmed the crisis periods in this dataset (Bluwstein et al., 2020). To make the current results comparable to the past studies, we employ these standard crisis definitions (Section 3).

Figure 2 presents the annual frequency between 1970 and 2018. The trend shows that 241 currencies, 154 banking, and 79 sovereign debt crises occurred during the study period. The data indicates an unusual pickup of crises episodes in the early 1980s in Latin America, the dissolution of the Soviet Union (1988–1991). During the 1990s, the largest number of currency crises occurred (20) in the transition economies, Latin America (Tequila crisis in 1994), and East Asia (Asian crisis in 1997). The GFC is relatively the worst crisis since 1970, ending with the highest number of banking crises (22).

The currency, banking, and sovereign debt crisis often occur during the same period and often interact with each other. In the sample, there are 54 twin crises (currency-banking, 31; currency-debt, 20; banking-debt, 3) and 11 triplet crises (currency-banking-sovereign debt) (Figure 3). The crisis mechanism reveals that currency, banking, and debt crisis are inter-link, and the banking crisis precedes the currency and debt crises. In turn, the currency crisis also precedes a banking crisis at times (Kaminsky and Reinhart, 1999). We estimate the causal relationship among these crises using the panel vector autoregression function. Figure 4 reports the impulse response functions (IRFs) of currency, banking, and sovereign debt crisis. The findings suggest these three crises are interrelated at times. The present results support the findings of Babecky et al. (2014), Bordo and Meissner (2006),

4 Laeven and Valencia (2020) provide dataset on currency crisis, banking crisis and sovereign debt crisis from 1970 to 2017 in cross-country setting. From Reinhart and Rogoff (2011) database, we collect the Chinese Taipei's financial crises information and add data from Koh et al. (2020) on crisis for 2018.

Figure 2. Frequency of financial crises

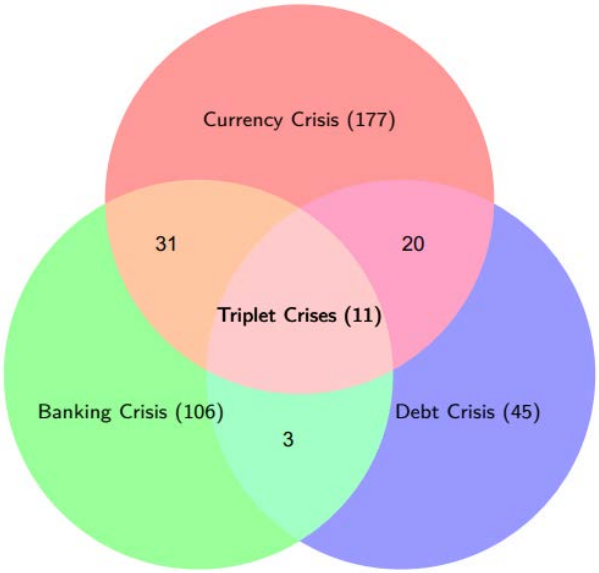


Data sources: Laeven and Valencia (2020); Reinhart and Rogoff (2011); Koh et al. (2020).
Notes: This figure shows the number of financial crises from 1970 to 2018. The vertical axis indicates the number of crises in a given year, and the horizontal axis represents the time in years.

and Bordo et al. (2010). Babecky et al. (2014) estimate the interaction between the crises and find that the debt crisis contemporaneously affects the likelihood of a currency crisis.

Further, Figure 5 shows that the balance sheet vulnerable indicators such as BOSIN and NCM are unusually high in the run-up to the financial crises. Therefore, we argue that these indices are better EWIs on a standalone basis. Argentina and Brazil experienced more number of financial crises due to the larger amount of FCD. These countries suffer from severe original sin and currency mismatch problems than others. The current estimates suggest that economies suffered from relatively severe original sin and currency mismatches before the Asian crisis. In Indonesia, currency mismatches increased before the financial crisis (1997-1999) (Figure 5). Similar is the case with Argentina, Brazil, Colombia, and Turkey. The high currency mismatches in Poland and Hungary during 2008-09 led them into financial crises. After the crisis periods, the NCM and BOSIN were drastically reduced to safer levels.

Figure 3. Simultaneous occurrence of financial crises



Data sources: Laeven and Valencia (2020).
Notes: The twin crises (54) are calculated as the currency crisis during the year *(t-1, t+1)* and banking (sovereign debt) crisis in year *t*. The triplet crises (11) denote the currency crisis during the year *(t-1, t+1)*, the banking crisis in year *t*, and the sovereign debt crisis during the year *(t-1, t+1)*.

4 Theoretical underpinnings and empirical strategy

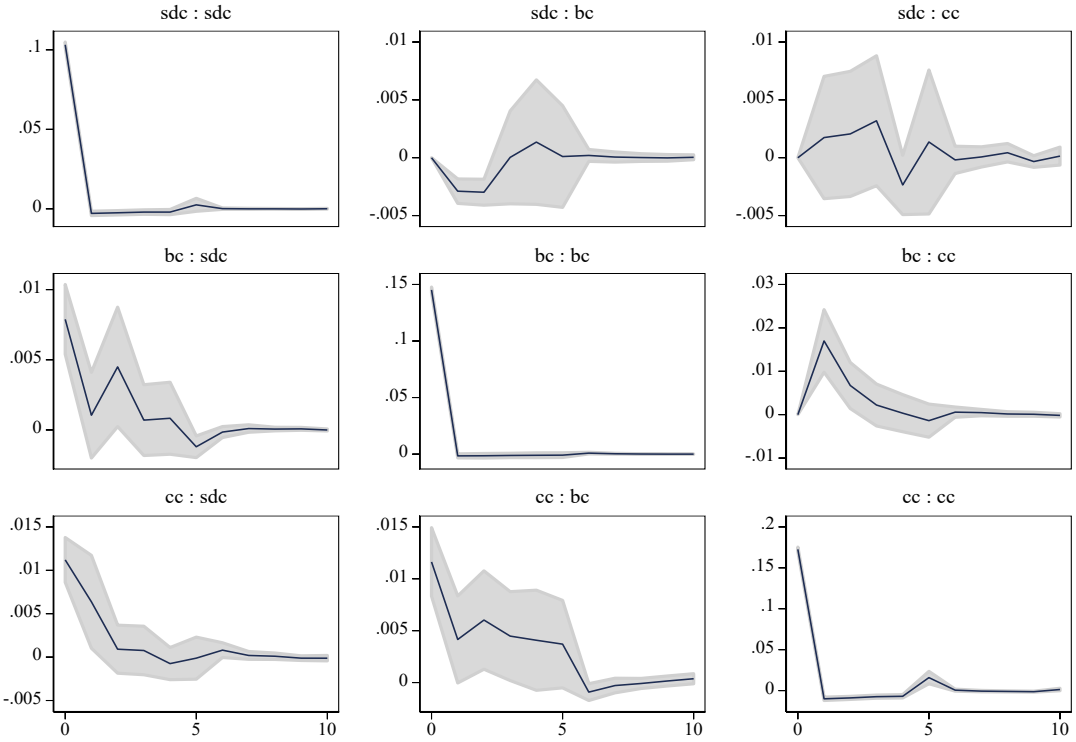
The primary objective of this study is to examine whether original sin and currency mismatches are potential EWIs of financial crises. To construct EWIs, we estimate logistic regression with a limited dependent variable. The dependent variable takes the value of one in the year during which the crisis occurred and zero otherwise. This regression model is most appropriate for crisis prediction studies (Eichengreen et al., 1995; Demirgüç-Kunt and Detragiache, 1998; Frankel and Rose, 1996). We use the maximum likelihood method of estimation, as suggested by Gourinchas and Obstfeld (2012). This approach allows testing the significance of the different leading indicators of the crisis (Cerovic et al., 2018). The logistic cumulative distribution function is determined to examine the role of BOSIN and NCM in predicting the financial crises:

$$Pr(Y_{i,t} = 1|x_{i,t-1}) = \frac{e^{\beta_i + \gamma_i X'_{i,t-1}}}{1 + e^{\beta_i + \gamma_i X'_{i,t-1}}} \tag{6}$$

$$Y_{i,t} = \alpha_i + \beta_1 BOSIN_{i,t} + \epsilon_{i,t} \tag{7}$$

$$Y_{i,t} = \alpha_i + \beta_1 NCM_{i,t} + \gamma_i X_{i,t-1} + \epsilon_{i,t} \tag{8}$$

Figure 4. Impulse responses of currency, banking, and sovereign debt crises

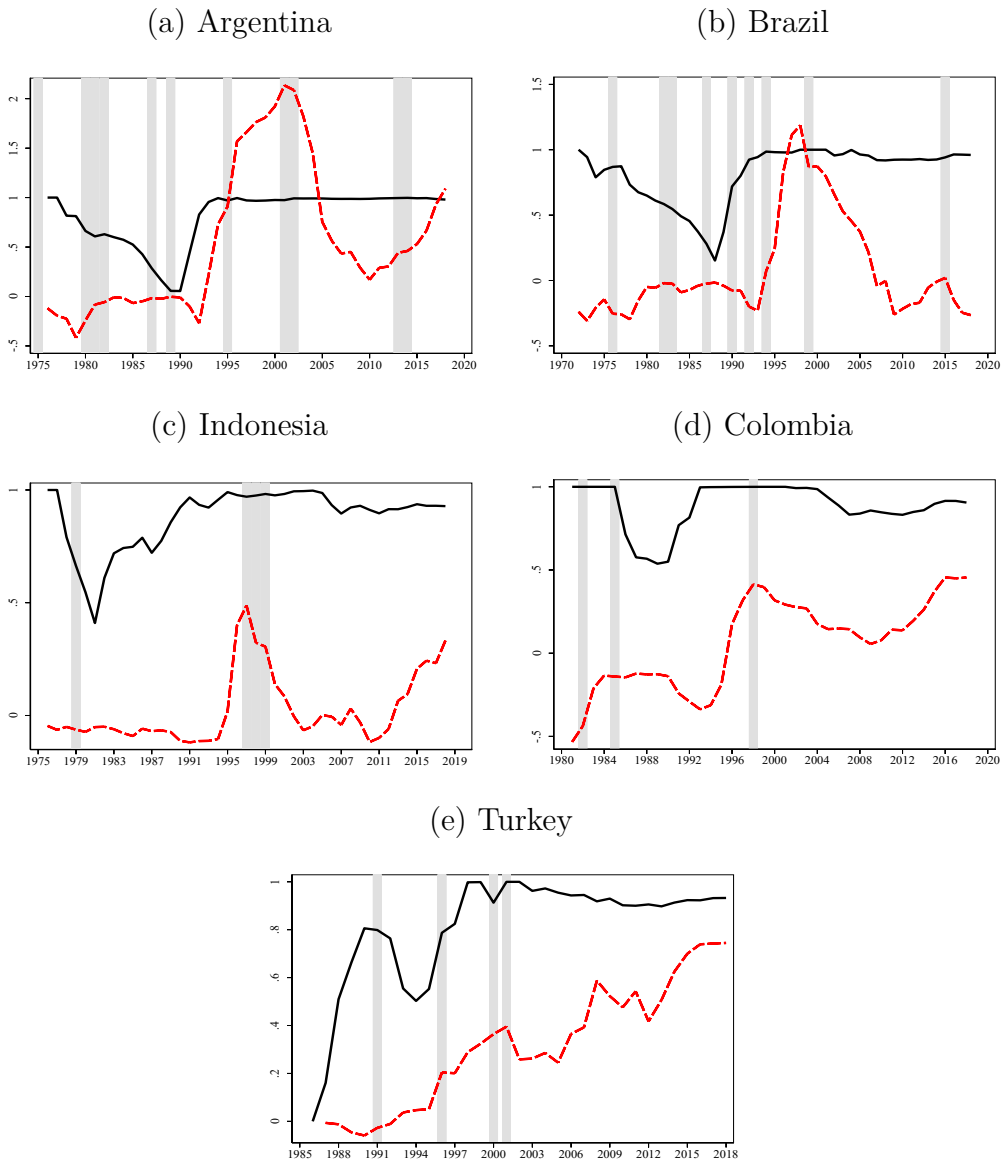


Notes: The figure shows the impulse response functions (IRFs) of currency, banking, and sovereign debt crisis. We use GMM on the system of equations cc, bc, and sdc denote currency, banking, and sovereign debt crisis, respectively. We cluster standard errors at the country level. and use the orthogonal IRFs of panel VAR according to Cholesky decomposition. The confidence intervals at 5% and 95% (grey lines) are calculated using Monte-Carlo simulations with 200 replications. The IRFs suggest that currency, banking, and sovereign debt crisis are interrelated.

where $Y_{i,t}$ is a dummy variable that takes value one when a crisis occurred during time t, for country i. We estimate Eq. 7 and Eq. 8 for each type of crisis, such as currency, banking, and sovereign debt crisis, separately. The BOSIN and NCM denote the broad original sin (Eq. 2) and the new currency mismatch index (Eq. 5). $X_{i,t-1}$ indicates a set of predictors of financial crises. α_i captures the country-specific unobserved characteristic of country i. $\epsilon_{i,t}$ is the error term. We estimate robust standard errors to control the heteroscedasticity and autocorrelation by clustering the panels. Similarly, we perform the estimations with one-year lagged explanatory variables to control the possible simultaneous bias and endogeneity issues (see Demirgüç-Kunt and Detragiache, 1998).

We extensively review the theoretical and empirical literature to identify the significant predictors of financial crises employed in the past (see Frankel and Rose, 1996; Kamin and Klau, 1998; Reinhart and Rogoff, 2011; Frankel and Saravelos, 2012; Babecky et al., 2014; Frost and Saiki, 2014; Erler et al., 2015; Hung, 2017). As a result, we selected 18

Figure 5. Broad original sin and new currency mismatches with financial crises



Notes: The y-axis denotes the broad original sin (black line) and new currency mismatch indices (dashed-red line). The shadow lines (shown as a grey line) denote the occurrence of a crisis (currency, banking, and sovereign debt crisis).

potential EWIs for three types of crisis.[5] Appendix Table 9 provides a detailed description of the definitions, measurement, and data sources. In this study, we analyze the following predictors in the baseline regression models.

a) Exchange rate regime: Exchange rate policy determines the currency risk and therefore a crucial predictor of financial crises. The choice of exchange rate regime remains one of the vital factors in the open-economy macroeconomic policy. A flexible exchange rate

5 A predictor is included in the sample if the observations are more than 70 percent, as suggested by Badia et al. (2020).

regime often reflects an excessive currency risk and fluctuates freely to respond to external shocks, leading to a higher likelihood of currency crisis (Frankel and Saravelos, 2012; Nakatani, 2018). Thus, a country often experiences a currency crisis under a flexible exchange rate regime than in a fixed regime. Therefore, Calvo and Reinhart (2002) argue that a free-floating exchange rate regime is less viable for small EDEs. Similarly, Domaç and Peria (2003) find that adopting a pegged regime reduces the likelihood of banking crises in developing countries.

In the case of a sovereign debt crisis, a flexible exchange rate regime increases the exchange rate volatility that mounts the debt burden. Further, the debt burden demands a fiscal adjustment, which can be risky to the private sector who borrows foreign currency (Allen et al., 2002; Arteta, 2005). However, adopting a fixed exchange rate regime implicitly guarantees debt obligations that lead to currency mismatches. Therefore, Bordo and Meissner (2006) recommend an intermediate peg exchange rate regime and monetary union to reduce the risk of FCD and currency mismatches.

b) Economic openness: Finance and trade openness are essential indicators of a country's openness. Financial openness stimulates development and growth in the domestic financial markets (Mishkin, 2007). Frost and Saiki (2014) show that financial openness is associated with a lower probability of currency crises in advanced and emerging economies. However, a higher degree of financial liberalization makes EDEs vulnerable to external shocks that have severe adverse effects on the economy (Stiglitz, 2002; Bhagwati and MacMillan, 2004; Frost and Saiki, 2014).

In addition, financial liberalization can create credit booms and bubbles in the banking sector (Demirgüç-Kunt and Detragiache, 1998; Kaminsky and Reinhart, 1999; Ranciere et al., 2008). For example, the rapid liberalization of capital markets in the late 1970s caused an increase in the severity and frequency of banking crises in EDEs. Dell'Ariccia et al. (2012) find crisis is preceded by the one third of booms. They argue that liberalization of capital account with weak regulation and poor banking supervision leads to the crisis. Trade openness is another proxy of the economic integration of a country with the

rest of the world. Trade openness increases creditor confidence, earns more forex reserves through exports, and reduces the currency crisis risk (Rohn et al., 2015).

c) Current account balance: The current account balance reflects the country's capacity to meet its trade and financial obligations. Catão and Milesi-Ferretti (2014) argue that current account imbalance has a higher predictive power of currency crisis than any other factor. The negative value of the current account refers to the deficit and measures the illiquidity risk of a country. The current account deficit increases the differences in net foreign currency positions that lead to speculative attacks on the domestic currency and rise in incidence of currency crisis (Catão and Milesi-Ferretti, 2014).

d) Inflation rate: The extant literature often identifies inflation rate, forex reserves, and exchange rate as the potential predictors of financial crises (see Frankel and Saravelos, 2012). A higher inflation rate detects a financial vulnerability in a country. The greater inflation indicates the macroeconomic mismanagement that adversely affects the whole economy, including the banking sector (Demirgüç-Kunt and Detragiache, 1998). Indeed, the banking crisis often follows higher inflation or lower interest rates. Several studies find a strong association between higher inflation and the occurrence of financial crises (see Reinhart and Rogoff, 2011; Jeanneret and Souissi, 2016).

e) Forex reserves: The foreign exchange reserve is a crucial predictor of crisis in the first and third-generation crisis models. Several studies show that depletion of forex reserves creates currency risk and increases the probability of currency crisis, and forex reserves act as a crisis prevention device (Obstfeld et al., 2010; Bordo et al., 2010; Frankel and Saravelos, 2012; Babecky et al., 2014; Frost and Saiki, 2014; Catão and Milesi-Ferretti, 2014). Similarly, the recent literature suggests reserve accumulation as a viable strategy to avoid troubling currency and limit the sovereign debt default (Dawood et al., 2017; Badia et al., 2020; Koh et al., 2020). On this count, Bordo et al. (2010) confirm that reserves lowered the incidence of currency and debt crisis. However, Bordo and Meissner (2006) find no such evidence.

f) Real effect exchange rate (REER): The real effective exchange rate is identified as a

good predictor of currency and sovereign debt crisis in the literature (Frankel and Saravelos, 2012; Frost and Saiki, 2014; Bocola and Lorenzoni, 2020). For example, exchange rate depreciation is associated with capital outflows, and ineffective monetary policy raises the probability of a currency crisis. Frankel and Saravelos (2012) show that a real effective exchange rate was the significant predictor for the currency crisis during GFC. The exchange rate depreciation leads to an increase in the cost of debt service and raises default risk, which increases the likelihood of a sovereign debt crisis (Dawood et al., 2017).

g) Government debt: we capture the characteristics of both public and private debt. These two forms are identified as the key indicators of financial crises in the literature (Babecky et al., 2014; Mbaye et al., 2018; Koh et al., 2020). Reinhart and Rogoff (2011) argue that the government debt burden often amplifies during the crisis, exposing sovereign entities to insolvency risk. Nevertheless, Bordo and Meissner (2006) find that sovereign debt is always associated with higher financial instability, but it alone does not enhance the likelihood of a crisis.

h) Private credit: The domestic credit to the private sector as a percent of GDP measures the non-financial sector indebtedness. The credit growth rate is a crucial predictor of financial crises (Reinhart and Rogoff, 2009; Schularick and Taylor, 2012; Babecky et al., 2014). Therefore, these crises are described as "credit booms gone wrong" (Aliber and Kindleberger, 2015).[6] The excess credit growth leads to net worth loss defaults. Credit shocks further the probability of a banking crisis.

An excessive credit growth rate in the corporate sector increases the incidence of a currency crisis (Rohn et al., 2015). In the event of the debt crisis, the excess credit growth in the corporate sector steadily turns into more considerable public debt. For example, government bailout on bank runs and contingent liabilities may weaken the sustainability of government finance. Such a situation further aggravates the feedback loop from the banking to the public sector (Acharya et al., 2014; Mbaye et al., 2018). The credit boom in the private sector is thus associated with the sovereign debt crisis.

6 A credit boom is a period during which the private credit increases more than in a normal business cycle expansion.

i) Bank-specific factors: we also include the bank-specific variables, namely broad money and bank credit to deposits as EWI. These factors have the potential role in predicting banking crises, but unrelated to sovereign debt and currency crises (Koh et al., 2020). Broad money measures the money multiplier of the economy. The sharp rise in the broad money is associated with a lower incidence of banking crisis because it reduces credit growth in the private sector, lowering the probability of banking crisis (Cobham and Kang, 2012). Similarly, the ratio of bank credit to deposit measures the banking sector's liquid liability (Jordà et al., 2021; Casabianca et al., 2019; Koh et al., 2020). An increase in bank credit is associated with a larger probability of a banking crisis. Casabianca et al. (2019) document that higher bank credit growth overheats the economy.

j) External debt indicators: we analyze the role of external debt-related factors in the sovereign debt crisis in EDEs.[7] The debt service ratio (the principal and interest payments relative to the exports income) is a potential EWI (Drehmann and Juselius, 2014). The rising debt service ratio increases the interest rate further, and borrowers may default on their debt. As a result, the rate of debt defaults increases, and consumption and investment fall in the economy. Likewise, debt intolerance is the "extreme duress" for many EDEs, but AEs would easily manage such debt (Claessens et al., 2014). This indicator is only related and often linked to the sovereign debt crisis. The safe debt thresholds largely depend on country-specific factors such as inflation and default history (Reinhart et al., 2003a,b; Reinhart and Rogoff, 2009). The likelihood of an external debt crisis substantially rises when the external debt of EDEs is higher than 35 percent of GDP (Bordo and Meissner, 2006).

k) Global factors: Besides the country-specific factors, global shocks could trigger financial crises (Rey, 2015). The cross-country spillover effects also drive crises and not mere domestic macroeconomic instability. For instance, the tight monetary conditions in the US caused a reversal in capital flows from EDEs, which increased the debt servicing cost of the latter (Manasse and Roubini, 2009; Hung, 2017). Thus, the US real interest rate is considered as the key indicator of a currency crisis.

7 Due to data unavailability, these two indicators are included only for EDEs sub-sample analysis.

Recently, Durdu et al. (2020) show that the countries with direct linkages to the US, either in the form of trade or dollar-denominated debt, had a higher probability of banking crisis when the US monetary policy tightened. Similarly, Jeanneret and Souissi (2016) argue that sovereign defaults are often identified when the US interest rate is higher. The increase in the 10-year US Treasury rate increases the value of debt-denominated in dollars, raising the default risk (Eichler and Maltritz, 2013).

Similarly, the rising world GDP growth rate brings financial stability to the global economy. Recently, Casabianca et al. (2019) show that a higher global GDP growth rate either increases the financial stability or buoyant global economic environment and thus lowers the probability of a systemic banking crisis. Indeed, Cerovic et al. (2018) show that such growth reduces the likelihood of debt default. Increasing energy prices are often associated with financial crises. For instance, a sustained increase in oil prices creates a supply shock in the economy. The negative shock prompts the probability of a balance of payment crisis and weakens economic growth (Hung, 2017).

5 Results and discussion

The average value of BOSIN (0.81) statistics in Table 2 shows that several economies suffer from original sin problems. Such severe problem shows that these economies are exposed to currency risk. Notably, 25 percent of the sample countries suffer from the severe original sin problem (value closer to one). In contrast, a fifth-percentile of countries have low levels of original sin (0.16). Similarly, economies are having a liability position in foreign currency as NCM stood 0.25. The sample countries have diversified positions in foreign currency as suggested by the percentile distribution of currency mismatches (a fifth percentile holds net asset position in foreign currency, 0.63, whereas the 75^{th} percentile shows net liability position, 0.26). The pairwise correlation analysis confirms no significant correlations among the predictors (Table 3).

5.1 Currency crisis

The estimates of baseline regressions (Eq. 7 and Eq. 8), including marginal effects, are presented in Table 4. The outcome variable is a dummy that takes the value one when

there is a currency crisis and zero otherwise. The currency crisis is defined as "nominal depreciation of currency vis-à-vis the US dollar of at least 30 percent that is also at least ten percentage points higher than the rate of depreciation in the year before." First, we test the role of original sin in predicting currency crises. The larger amount of FCD raises the costs of currency depreciation that leads to higher inflation and create a moral hazard problem, which increases the likelihood of currency crisis (Ce´spedes et al., 2004; Eichengreen et al., 2007; Bordo et al., 2010; Eijffinger and Karataş, 2012). The theoretical literature suggests a positive association. As per the theoretical expectation, we find the BOSIN positive and significant, implying that a larger value of original sin leads to a higher probability of a currency crisis because countries with high original sin suffer from severe macroeconomic volatility and currency risk. This finding validates the view of Eichengreen et al. (2005b).

Table 2. Descriptive statistics

Variable	N	Mean	Median	SD	Min	Max	Skewness	Kurtosis	p5	p75
BOSIN	5030	0.81	0.94	0.27	0.00	1.00	-1.59	4.55	0.16	0.99
New currency mismatch	3918	0.25	0.00	1.00	-1.58	5.83	3.06	15.30	-0.63	0.26
Exchange rate regime	7641	2.23	2.00	1.42	1.00	6.00	1.17	3.53	1.00	3.00
Financial openness	6270	0.43	0.28	0.35	0.00	1.00	0.55	1.80	0.00	0.72
Trade openness	6404	4.17	4.18	0.57	2.59	5.76	-0.16	3.40	3.16	4.55
Current account	6405	-5.31	-3.44	13.28	-53.26	33.09	-0.65	5.62	-28.47	1.35
Inflation	5760	-0.02	-0.01	0.92	-2.97	2.75	-0.09	4.75	-1.55	0.41
Forex reserves	6167	0.10	0.08	0.40	-1.22	1.55	0.18	6.09	-0.51	0.27
REER	7060	0.80	0.59	11.51	-42.97	51.67	0.42	9.54	-15.26	4.57
Government debt	5822	0.02	0.01	0.23	-2.38	2.96	0.57	23.71	-0.26	0.10
Private credit	6460	0.02	0.02	0.16	-0.60	0.54	-0.42	6.38	-0.25	0.09
Broad money	5576	0.02	0.02	0.15	-2.39	1.90	-2.10	47.84	-0.17	0.08
Bank credit to deposits	6595	4.44	4.46	0.54	1.87	7.96	-0.29	5.40	3.49	4.77
Debt service	3330	0.12	0.08	0.15	0.00	1.51	3.84	24.95	0.01	0.16
Debt intolerance	4515	6.07	0.56	12.05	0.00	46.46	2.42	7.83	0.00	4.94
US treasury rate	7938	6.41	6.35	2.98	1.80	13.92	0.49	2.78	2.14	7.99
World GDP growth	7938	3.11	3.11	1.39	-1.68	6.51	-0.58	4.77	0.60	3.93
Energy price index	7938	5.76	0.31	22.14	-48.33	60.66	0.36	3.93	-34.17	19.51

Notes: This table summarizes the descriptive statistics of crises indicators and selected predictors employed in this empirical analysis. The sample consists of 34 advanced economies (AEs) and 128 emerging and developing countries (EDEs) from 1970-2018 (annual frequency). The sample country details are reported in Appendix Table 8. Variables and data sources are as defined in Appendix Table 9. The data is winsorized at 1% and 99% percentile to remove the extreme outliers in selected observations, N: The acronym of descriptive statistics: N - total number of observations; S.D. - standard deviation, Min & Max -minimum and maximum (Min and Max); and p5, p75 - 5^{th} & 5^{th} percentiles.

Table 3. Correlation analysis

Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*	*(14)*	*(15)*	*(16)*	*(17)*	*(18)*	*(19)*	*(20)*	*(21)*
(1) Currency crisis	1.00																				
(2) Banking crisis	0.07*	1.00																			
(3) Sovereign debt crisis	0.11*	0.09*	1.00																		
(4) BOSIN	0.03*	0.01	-0.02*	1.00																	
(5) New currency mismatch	-0.01*	0.08*	0.02*	0.03*	1.00																
(6) Exchange rate regime	0.17*	0.06*	0.06*	-0.05*	-0.07*	1.00															
(7) Financial openness	-0.11*	-0.01	-0.04*	-0.09*	0.35*	-0.18*	1.00														
(8) Trade openness	-0.08*	-0.03*	-0.02*	0.09*	0.18*	-0.27*	0.30*	1.00													
(9) Current account	0.01*	0.00	0.00	-0.14*	0.10*	0.07*	0.13*	0.01*	1.00												
(10) Inflation	0.10*	-0.01	0.03*	-0.03*	0.01	0.03*	-0.02*	0.00	0.03*	1.00											
(11) Forex reserves	-0.02*	-0.01*	-0.02*	0.04*	-0.04*	0.01*	-0.02*	0.00	0.05*	0.03*	1.00										
(12) REER	-0.25*	-0.01*	-0.04*	0.05*	-0.05*	-0.00	0.02*	-0.01*	-0.03*	-0.13*	0.00	1.00									
(13) Government debt	0.14*	0.06*	0.07*	-0.07*	0.04*	0.03*	-0.01*	-0.03*	-0.07*	-0.01	-0.16*	-0.18*	1.00								
(14) Private credit	-0.04*	-0.02*	-0.01	0.05*	-0.04*	-0.08*	0.02*	0.02*	-0.09*	-0.14*	-0.13*	0.03*	0.10*	1.00							
(15) Broad money	-0.00	-0.03*	-0.00	0.01*	0.00	-0.08*	0.02*	0.01*	-0.02*	-0.14*	-0.01*	-0.02*	0.15*	0.45*	1.00						
(16) Bank credit to deposits	-0.03*	0.04*	0.03*	-0.08*	0.13*	-0.12*	0.14*	-0.00	0.10*	-0.01*	-0.03*	-0.04*	0.05*	0.00	0.04*	1.00					
(17) Debt service	0.04*	0.03*	0.04*	0.03*	0.14*	0.10*	0.02*	-0.09*	-0.11*	-0.01	-0.06*	-0.05*	0.03*	-0.06*	-0.03*	-0.10*	1.00				
(18) Debt intolerance	0.03*	-0.01	0.03*	-0.02*	0.28*	0.06*	0.16*	0.14*	-0.08*	-0.02*	-0.03*	0.02*	-0.01	-0.01*	0.00	0.04*	0.09*	1.00			
(19) US treasury rate	0.05*	0.04*	0.07*	-0.33*	-0.16*	0.15*	-0.22*	-0.22*	-0.03*	0.01*	-0.01*	-0.00	0.08*	-0.03*	-0.03*	0.05*	0.02*	-0.15*	1.00		
(20) World GDP growth	-0.03*	-0.05*	-0.03*	-0.03*	-0.02*	-0.02*	-0.04*	-0.06*	0.05*	0.14*	0.07*	-0.02*	-0.12*	0.00	-0.02*	0.00	-0.05*	-0.04*	0.01*	1.00	
(21) Energy price index	-0.05*	-0.02*	-0.02*	0.06*	0.01*	-0.05*	0.01*	0.02*	0.03*	0.15*	0.04*	0.02*	-0.13*	-0.00	-0.05*	-0.00	-0.09*	-0.02*	-0.00	0.33*	1.00

Notes: This table presents pairwise correlation coefficients. The variables are as defined in Appendix Table 9. * denotes significance at the 5 % level.

Furthermore, the currency risk arising from the original sin can be hedged by accumulating forex reserves (Goldstein and Turner, 2004). For example, Asian countries, particularly China and Chinese Taipei, hedge their foreign currency risk by accruing enormous assets in foreign currency.[8] Therefore, the net asset position in foreign currency hedges the currency risk and lowers the probability of currency crisis. Against this backdrop, we analyze the effects of mismatches between assets and liabilities that may further reveal the currency risk and likelihood of financial crises. We include the NCM indicator in the second model of Table 4. The estimates show that the NCM index is positive and significant in all currency crisis models. The results imply that the greater degree of currency mismatches (liability position in foreign currency) creates the systemic risk and severe insolvencies that raise the probability of currency crisis.

Moreover, currency mismatches can hinder the implementation of monetary policy and impede the working of the exchange rate mechanism. Thus, currency mismatches can make monetary policy ineffective during crisis periods (Goldstein and Turner, 2004). The empirical results are in line with the evidence of Bordo and Meissner (2006) and Bordo et al. (2010) who find that the extent of currency mismatches increases the likelihood of currency crisis. Overall, the findings suggest that both original sin and currency mismatches are the leading indicators of the currency crisis.

In models (2) and (3), we show the impact of NCM along with macroeconomic and debt-related control variables. Exchange rate policy plays a major role in limiting external shocks. We use the exchange rate regime index developed by Ilzetzki et al. (2019). This index is based on coarse classification codes, including six exchange rate regimes starting from rigid (1) to a more flexible exchange rate regime (6). The result shows that the coefficient of the regime is positive and significant, indicating a higher probability of currency crisis when the exchange rate policy changes from pegged to floating regimes. This finding is in line with pertinent literature (Eichengreen and Hausmann, 1999; Frankel and Saravelos, 2012; Koh et al., 2020). For example, during the 1980s to 1990s, switching from

8 China and Chinese Taipei holds the net foreign currency assets to the tune of $3,676.70 billion and $683.20 billion as of 2017, respectively.

pegged to a more flexible exchange rate and contractionary monetary policy triggered the crisis in Latin America and Asia. In addition, Calvo and Reinhart (2002) argue that the floating exchange rate regime can be more dangerous when the debt is denominated in foreign currency, which leads economies to adopt pegged exchange rate regimes, i.e., *fear of floating*.

Further, we use Chinn and Ito (2006) index to measure the country's degree of financial openness and find that a higher degree of financial openness lowers the probability of currency crises. The present finding highlights the importance of financial openness with a transparent banking sector to withstand a currency crisis. Financial openness increases the country's credit ratings and FDI investment. It induces the investors to issue debt in the local currency, which lowers foreign currency exposure and reduces the crisis.

We also include the trade openness and current account balance to measure the economic integration of a country and its capacity to meet trade obligations. We measure trade openness as the sum of exports and imports as a percentage of GDP. Similarly, the current account balance is the sum of net exports of goods and services, net secondary income, and net primary income as in the World Bank definition. The inclusion of these factors increases the marginal effect of original sin. The result shows that the coefficient on trade openness is negatively associated with the probability of currency crisis — a rise in trade openness increases investors confidence and earn more forex reserves through exports that reduce the likelihood of currency crisis. The present results are in line with Rohn et al. (2015). Similarly, the current account balance lowers the probability of currency crisis, whereas the deficit is associated with the speculative attack on the currency.

The inflation rate, forex reserves, and exchange rate are considered standard predictors of financial crises (Frankel and Saravelos, 2012). In an influential paper, Reinhart and Rogoff (2011) argue the strong association between the inflation rate and the probability of financial crises. The present result shows that the inflation rate is positively associated with the likelihood of currency crises. Further, we find high forex reserves lowering the currency risk and reducing the probability of currency crisis. This finding suggests that

a larger amount of reserves helps maintain financial stability. The experience of the East Asian financial crisis reinforces this inference. The results are consistent with the findings of Bordo and Meissner (2006), Frankel and Saravelos (2012), and Hung (2017).

Similarly, the present estimates show that the role of the real effective exchange rate (REER) is negative and significant in the currency crisis models (models 3 and 4 of Table 6). The rise in the REER index suggests a stronger local currency against a group of 66 trading partners. The finding implies that a stronger local currency lowers the financial vulnerabilities and reduces the risk of a currency crisis. Hence, we argue that reducing currency mismatches may not be sufficient to ensure financial stability without stabilizing the local currency. Therefore, economies should issue debt in local currency and lower the macroeconomic volatility to stabilize the domestic currency.

In the case of the debt-related factors, we find that government debt (as a percent of GDP) is positive and significantly associated with the likelihood of a currency crisis. This finding suggests that the rising government debt burden tends to increase the solvency risk. Another potential predictor of currency crisis is the private credit (domestic credit to the private sector as a percentage of GDP), which measures the non-financial sector indebtedness. An excessive credit growth rate increases the financial sector vulnerability, leading to firms' net worth loss. The Eurozone debt crisis is a testimony to the linkage between the public and financial sector indebtedness (Rohn et al., 2015). We find a positive link between private credit and currency crisis, implying the likelihood of a currency crisis fueled by a credit boom.

We analyze the role of global shocks such as the US Treasury rate, world GDP growth, and energy price index in the currency crisis. We use the 10-year US Treasury rate as the proxy monetary policy decision of the US. The estimates confirm that a higher Treasury rate is associated with a larger likelihood of currency crisis in EDEs. Recent studies also consider the rise in the US real interest rate as the key indicator of the currency crisis in EDEs (Hung, 2017; Casabianca et al., 2019). Further, rising world GDP growth either increases the financial stability of the global economy or buoyant economic environment.

The current estimations show that world GDP growth lowers the probability of currency crisis in the model (1) and (2) but positively links with the crisis in the model (3) and (4). The increasing energy prices deteriorate the balance of payments and have supply shocks to the economy (Hung, 2017). We use the energy price index, which is the composite of energy raw materials. We find the higher oil prices increasing the probability of a currency crisis.

We include a dummy variable to test whether AEs have a lower likelihood of currency crisis than EDEs. Because the former have stronger fundamentals and less original sin. Bordo and Meissner (2006) and Hung (2017) show that EDEs suffer from more number of crises than AEs because the latter economies are financially mature and issue bonds in their own currency and manage FCD carefully. The dummy variable takes the value of 1 for AEs, and 0 for EDEs.[9] The coefficient on the AEs dummy is negative and significant, implying that the AEs have less likelihood of currency crisis than EDEs. Because the former countries have lower levels of original sin and less exposed to currency risk than the latter.

Further, we estimate the sub-sample analysis of EDEs to check the effect of EDEs financial instability on crises.[10] The results of sub-sample presented in Table 4 (see model 4) show that the impact of balance sheet vulnerabilities on currency crisis is similar to that in full-sample estimations. However, the marginal effects of currency mismatches are larger for the EDEs than for the full sample. This difference is due to severe currency mismatch problem in EDEs (Table 1).

9 The sample is classified as advanced economies (AEs) and emerging and developing economies (EDEs) based on the IMF-World Economic Outlook methodology.

10 In case of AEs, the number of observations are less, and a few crises constrain the sub-sample analysis for these economies.

Table 4. Baseline regression: Currency crisis

Currency crisis	*(1)*	*(2)*	*(3)*	*(4)‡*
BOSIN	0.026***			
	(0.010)			
New currency mismatch		0.008**	0.006*	0.012**
		(0.003)	(0.003)	(0.005)
Exchange rate regime		0.006***	0.005**	0.006*
		(0.002)	(0.002)	(0.003)
Financial openness		-0.036***	-0.033***	-0.029**
		(0.011)	(0.010)	(0.013)
Trade openness		-0.007	-0.002	-0.006
		(0.006)	(0.004)	(0.006)
Current account		-0.0001	-0.0001	-0.0001
		(0.0002)	(0.0001)	(0.0002)
Inflation		0.015***	0.006*	0.007*
		(0.004)	(0.003)	(0.004)
Forex reserves		-0.019***	-0.010	-0.010
		(0.007)	(0.007)	(0.010)
REER			-0.002***	-0.002***
			(0.0001)	(0.0002)
Government debt			0.041***	0.049***
			(0.009)	(0.011)
Private credit			0.003	0.006
			(0.018)	(0.025)
US Treasury rate	0.004***	0.003***	0.003***	0.002
	(0.001)	(0.001)	(0.001)	(0.001)
World GDP	-0.002	-0.004**	0.000	0.001
	(0.001)	(0.002)	(0.002)	(0.003)
Energy price index	-0.0001***	-0.0001**	-0.001***	-0.001***
	(0.0002)	(0.0002)	(0.0004)	(0.0002)
Advanced economies	-0.030***	-0.010	-0.004	-
	(0.010)	(0.007)	(0.005)	-
Observations	5,018	3,105	2,639	1,777
Pseudo R^2	0.100	0.265	0.408	0.396
Pseudolikelihood	-568.6	-301.9	-197.6	-162.6
χ^2 (Test for AEs effects = 0)	10.530	1.921	0.497	-
p-value	0.001	0.166	0.481	-
χ^2 (Overall test statistic)	206.8***	381.5***	221.2***	214.2***
AUROC (Predictive ability)	0.743***	0.892***	0.948***	0.944***
Standard error (ROC)	0.019	0.016	0.012	0.013

Notes: The dependent variable is a binary indicator for a currency crisis; one indicates the positive class of crisis year and otherwise zero. The reported results are the marginal effect of selected indicators on the probability of a currency crisis. ‡ denotes estimations for emerging and developing countries (EDEs). The total number of observations may vary in each model due to the non-availability of data on predictors. The pseudo R^2 values range between 0.100 and 0.408, showing that adding the predictors in the benchmark model is a better fit. The area measures the predictive ability of the model under the receiver operating characteristic (AUROC), which increases from 74% to 95% from the benchmark model to the full-sample model (3). The AUROC test against the null hypothesis of 0.5 tests whether the model's signals are significantly different between crisis and normal periods. The results suggest that the predictive power of the currency crisis is impressive at this stage of in-sample prediction. The variables are as defined in Appendix Table 9. The control variables are lagged one year to address endogeneity biases. Robust standard errors are given in parentheses. ***, **, and * denote statistical significance at 1%, 5% and 10% level, respectively.

5.2 Banking crisis

We re-estimate Eq. 7 and Eq. 8 to investigate the EWIs of the banking crisis and report the estimates in Table 5. The banking crisis episode is defined as the significant signs of financial distress in the banking system (bank runs, losses, and liquidation) and policy intervention measures in response to significant losses in the banking system (Laeven and Valencia, 2018). We include the financial vulnerability indicators (original sin and currency mismatches), bank-specific factors, and other potential predictors in the empirical model.

The result shows that the rising original sin value increases the probability of banking crises. The sharp rise in original sin exposes currency risk and poses a policy dilemma for exchange rate management. For example, the government raises interest rates to defend the currency depreciation that drains the liquidity from the financial system. This hike tends to bank runs and liquidations, which often increase the probability of a banking crisis. Eichengreen and Hausmann (1999) also show how a larger amount of FCD leads to the banking crisis in EDEs. Similarly, the liability dollarization of banks, firms, and the government is often exposed to episodes of financial instability and increases the real burden of FCD. This instability is associated with financial crises (Bocola and Lorenzoni, 2020).

Third-generation crisis models stress that balance sheet vulnerabilities in banks and corporates tend to bank panics and credit frictions (Krugman, 1999; Chang and Velasco, 2000). Hence, the banking and corporate sectors often face liquidity shocks when currency composition of balance sheets are mismatched (Burnside et al., 2004). The mismatches between assets and liabilities of banks escalate the currency exposure and result in a crisis. Furthermore, currency exposure increases the interest rate and exchange rate risk of firms and households, leading to net worth loss. We find positive association between NCM and risk of a systemic banking crisis, and significant in all models. The result indicates that currency mismatches tend to exacerbate the non-financial and banking sector vulnerabilities, as they happened during the Asian financial crisis. This finding is in line

with the view of Goldstein and Turner (2004) — a greater degree of currency mismatches leads to a higher incidence of the banking crisis.

Table 5. Baseline regression: Banking crisis

Banking crisis	*(1)*	*(2)*	*(3)*	*(4)‡*
BOSIN	0.017*			
	(0.010)			
New currency mismatch		0.026***	0.022***	0.019***
		(0.005)	(0.005)	(0.006)
Exchange rate regime		0.002	0.002	0.001
		(0.002)	(0.002)	(0.003)
Financial openness		-0.017*	-0.017*	-0.020*
		(0.009)	(0.009)	(0.011)
Inflation		0.001	0.003	0.003
		(0.002)	(0.003)	(0.003)
Private credit			0.042	0.058**
			(0.026)	(0.027)
Broad money			-0.040*	-0.052**
			(0.024)	(0.022)
Bank credit to deposits			0.011**	0.009*
			(0.005)	(0.005)
US Treasury rate	0.003***	0.004***	0.004***	0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
World GDP	-0.005***	-0.006***	-0.004**	-0.002
	(0.001)	(0.002)	(0.002)	(0.002)
Energy price index	0.0001	0.0001**	0.0001	-0.0001
	(0.0001)	(0.0002)	(0.0002)	(0.0001)
Advanced economies	0.003	-0.014**	-0.023***	-
	(0.004)	(0.007)	(0.008)	-
Observations	5,018	3,144	2,407	2,004
Pseudo R^2	0.043	0.125	0.134	0.132
Pseudolikelihood	-480.6	-303.4	-227.5	-199.7
χ^2 (Test for AEs effects = 0)	0.704	4.259	9.871	-
p-value	0.401	0.039	0.002	-
χ^2 (Overall test statistic)	117.1***	169.4***	197.9***	173.7***
AUROC (Predictive ability)	0.722***	0.803***	0.816***	0.799***
Standard error (ROC)	0.024	0.023	0.026	0.029

Notes: The dependent variable is a binary indicator of a banking crisis; one indicates the positive class of crisis year and otherwise zero. The reported results are the marginal effect of indicators on the probability of a banking crisis. ‡ denotes estimations for emerging and developing countries (EDEs). The AUROC is the area under receiving operating characteristics. The variables are as defined in Appendix Table 9. The positive value signifies a crisis year. All control variables are lagged one year to address the endogeneity biases. Robust standard errors are in parentheses. ***, **, and * denote statistical significance at 1%, 5% and 10% level, respectively.

The estimates further suggest that before the banking crisis, pressure in the banking sector materializes first due to a larger amount of FCD, then increases the probability of bank runs and liquidation. Overall, the results provide strong evidence that both original sin and currency mismatches are the potential EWIs of the banking crisis. The crisis incidence is greater when a larger amount of FCD is accumulated, and forex reserves are lower. This situation further leads to banks being prone to crisis. In line with this finding,

Mulder et al. (2002) suggest that crises are severe when the banks and corporations are exposed to currency mismatches.

The fixed exchange rate regime is associated with credibility and may help promote financial stability (Domaç and Peria, 2003). We find that the coefficient on the exchange rate regime is positive and significant. The fixed exchange rate regime reduces domestic shocks and stabilizes the exchange rate, lowering the probability of banking crises. In addition, the banking sector vulnerabilities stem from the vast amount of cross-border banking loans and stressed banks. Therefore, adopting a fixed exchange rate regime stabilizes the financial system and lowers the probability of a banking crisis. Further, we find that financial liberalization is significant and negatively associated with the likelihood of a banking crisis. The estimates show that a one-unit increase in financial openness lowers the 1.7 percent likelihood of a banking crisis.

The banking crisis often follows higher inflation or lower interest rates. Demirgüç-Kunt and Detragiache (1998) suggest that higher inflation indicates the macroeconomic mismanagement that adversely affects the whole economy, including the banking sector. The present results show that the probability of a banking crisis is positively associated with higher inflation. Further, credit to the private sector is a robust predictor of currency and banking crisis as it reflects the banking system's vulnerability (Frankel and Saravelos, 2012; Babecky et al., 2014). We find that the coefficient on private credit is positive.

Further, we examine the role of bank-specific factors, namely broad money, and bank credit to total deposits. We use broad money as a share of GDP to capture the bank's ability to meet the demand deposits. The estimates show that a rise in broad money lowers the occurrence of the banking crisis. The increase in broad money reduces credit growth in the private sector, lowering the probability of a banking crisis. We also include the ratio of bank credit to deposits, which measures the liquid liability of a bank. We find that the bank credit to deposits ratio is significant and positively associated with the banking crisis. This finding is consistent with Jordà et al. (2021) and Casabianca et al. (2019), who document the banking crisis due to bank credit.

Finally, we investigate the role of global shocks in predicting banking crises. Recently, Durdu et al. (2020) suggest that countries with direct linkages with the US (either in the form of trade or debt) are prone to a banking crisis when the US monetary policy is tightened. The current results also show that the probability of a banking crisis increases when the US Treasury rate rises. Similarly, we find that increasing world GDP growth lowers the likelihood of a banking crisis. Further, the crisis incidence increases as a result of increasing energy prices.

5.3 Sovereign debt crisis

The sovereign debt default and restructuring are defined as the sovereign debt crisis. We examine the role of original sin and currency mismatches in predicting sovereign debt crisis using Eq. 7 and Eq. 8. The estimates of the regression models are presented in Table 6. Countries with high original sin suffer from severe insolvency risk and macroeconomic volatility, which increases the debt burden. Hence, original sin is the leading indicator of crises and often raises the probability of sovereign debt default (Flandreau, 2003; Eichengreen et al., 2005a,b; Bordo and Meissner, 2006). In addition, FCD is often used for domestic activities in EDEs; however, FCD raises the currency risk that erodes the net worth of the firms and households. Such erosion constrains the ability of sovereign entities to meet the debt obligations, leading to the debt crisis. Further, higher dependency on dollar debt of the private sector increases the sovereign debt risk (Du and Schreger, 2016).

We find that BOSIN is negatively associated with the probability of a debt crisis (Table 6). This result is possibly due to the nonlinear relationship between the original sin and debt crisis, as documented by Bordo and Meissner (2006). The marginal effects of BOSIN on the probability of debt crisis presented in Figure 6 show the nonlinear relationship between BOSIN and debt crisis. We find that the marginal effect of BOSIN is negative until its value is 0.60 but later turn positive, suggesting the S-shape effects on the debt crisis. The result implies that the lower value of original sin does not lead to the debt crisis. We also test the nonlinear effects of original sin by including the squared term of BOSIN in the sovereign debt crisis model (Table 7). The estimates show that the squared

term of BOSIN is positive and significant, indicating the severe original problem tends to increase the currency and insolvency risk. This increased risk resulted in the sovereign debt crisis. The present results support the findings of Bordo and Meissner (2006).

We find that NCM is positive and significantly associated with sovereign debt crisis (Table 6). The mismatch between assets and liabilities increases systemic risk and macroeconomic volatility. Further, currency mismatches create waves of insolvencies and increase the debt burden, raising the probability of a debt crisis when there is a liability position in foreign currency. This result suggests that currency mismatch is the leading predictor of the sovereign debt crisis. The finding is in line with the proposition of Goldstein and Turner (2004).

Sovereign debt defaults occur when a country exhibits higher inflation because higher inflation increases an economy's currency risk and debt burden. Similarly, Jeanneret and Souissi (2016) find that inflation was higher in debt defaulted countries (21.9%) than non-defaulted countries (6.1%). Thus, we show that the level of inflation is the key driver for a debt default. Further, the accumulation of forex reserves is a viable strategy to avoid the currency risk and avert a sovereign debt crisis. The estimates suggest that debt default is lower when the forex reserves grow at a higher rate. This finding is consistent with previous studies (Bordo and Meissner, 2006; Dawood et al., 2017; Badia et al., 2020; Koh et al., 2020).

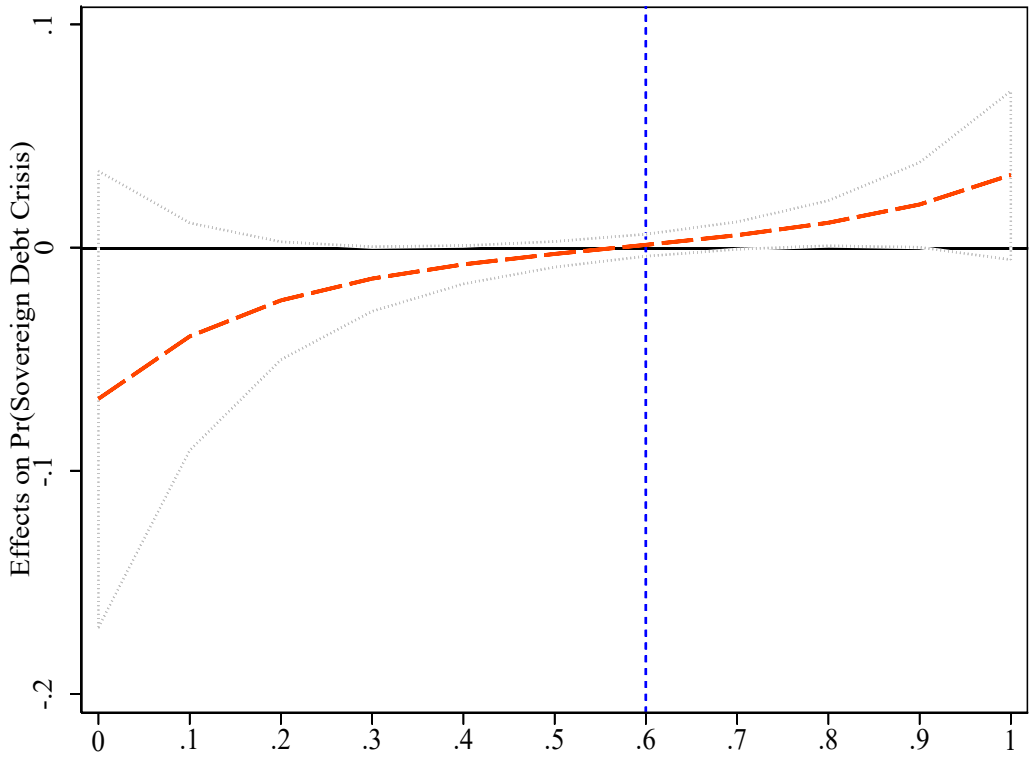
Another significant result is an increased probability of a debt crisis due to the greater amount of government debt. Government debt accumulation is an appropriate decision in the short–run and can be a counter-cyclical fiscal policy to boost the economy during the recession. Nonetheless, the rapid growth in debt leads to the crisis, as experienced by China (Jiang and Xu, 2014) and many EDEs (Koh et al., 2020). The present finding contrasts the evidence of Bordo and Meissner (2006) on the sovereign debt crisis.

Table 6. Baseline regression: Sovereign debt crisis

Debt crisis	*(1)*	*(2)*	*(3)*	*(4)‡*
BOSIN	-0.007			
	(0.004)			
New currency mismatch		0.012***	0.013***	0.021***
		(0.004)	(0.005)	(0.006)
Exchange rate regime		0.0001	0.0001	0.001
		(0.001)	(0.002)	(0.002)
Financial openness		-0.001	0.002	0.006
		(0.007)	(0.008)	(0.012)
GDP growth rate			-0.163***	-0.166***
			(0.046)	(0.052)
Inflation			0.0001	-0.001
			(0.002)	(0.003)
Forex reserves			-0.010***	-0.011**
			(0.004)	(0.006)
REER			-0.0001	-0.0001
			(0.0002)	(0.0001)
Government debt			0.004**	0.004
			(0.002)	(0.002)
Private credit			0.002	0.004
			(0.010)	(0.018)
Debt service				0.018**
				(0.008)
Debt intolerance				0.0001
				(0.0001)
US Treasury rate	0.001***	0.002**	0.001	0.003***
	(0.000)	(0.001)	(0.001)	(0.001)
World GDP	-0.001	-0.001	-0.001	-0.003
	(0.001)	(0.001)	(0.001)	(0.003)
Energy price index	0.0001	-0.0002	0.0001	0.0001
	(0.0002)	(0.0001)	(0.0002)	(0.0002)
Advanced economies	-0.019***	-0.026***	-0.027***	-
	(0.007)	(0.008)	(0.009)	-
Observations	5,018	3,495	2,673	1,465
Pseudo R^2	0.178	0.255	0.387	0.312
Pseudolikelihood	-215.1	-142.6	-86.86	-66.83
χ^2 (Test for AEs effects = 0)	9.902	16.23	14.64	-
p-value	0.002	0.000	0.000	-
χ^2 (Overall test statistic)	96.31***	106.8***	168.8***	108.6***
AUROC (Predictive ability)	0.803***	0.928***	0.934***	0.910***
Standard error (ROC)	0.039	0.009	0.026	0.026

Notes: The dependent variable is a binary indicator of a sovereign debt crisis. The reported results are the marginal effect of indicators on the probability of sovereign debt crisis. ‡ denotes estimations for emerging and developing countries (EDEs). The AUROC is the area under receiving operating characteristics. The variables are as defined in Appendix Table 9. The positive value signifies a crisis year. All control variables are lagged one year to address endogeneity biases. Robust standard errors are in parentheses. ***, **, and * denote statistical significance at 1%, 5% and 10% level, respectively.

Figure 6. Nonlinear effect of original sin on the sovereign debt crisis



Notes: The figure presents the marginal effects of broad original sin on the probability of debt crisis with 95% confidence intervals. The figure shows the nonlinear effect of broad original sin on the sovereign debt crisis. The marginal effect of broad original sin index (BOSIN) is negative until 0.60 but turns positive, suggesting the S-shape effect. The result implies that a lower level of a foreign currency or original sin does not lead to a debt crisis.

The growth of private credit signals overheating of the economy, resulting in financial instability and external risk. Thus, excess credit growth further aggravates the feedback loop from the banking sector to the public sector (Acharya et al., 2014; Mbaye et al., 2018). In addition, private sector bailouts are more common than bank bailouts. Therefore, we assess the association between private credit and the incidence of the sovereign debt crisis. The results show that private credit growth is positively associated with the sovereign debt crisis as expected. The findings suggest that policymakers and market agents should pay attention to the total debt stock in all sectors, rather than a single sector.

The debt service on external debt includes the principal and interest payments on external debt. A lower debt service ratio to the exports indicates a safer position, whereas a higher ratio makes the external sector vulnerable. Thus, a positive association between debt service costs and sovereign debt default is expected. The debt service ratio and debt intolerance indicators are available only for EDEs, which we include in model 4 of Table 6.

Table 7. Nonlinear effect of original sin on the sovereign debt crisis

Sovereign debt crisis	Model
BOSIN	-4.163**
	(1.774)
$BOSIN^2$	3.657 **
	(1.559)
Controls Included	Yes
Observations	5,030
Pseudo R^2	0.120

Notes: This table shows the nonlinear effect of broad original sin on the sovereign debt crisis. We assess the nonlinear effects by including the squared term of BOSIN in the first model of the sovereign debt crisis (Table 6). ** denotes significance at 5% level.

The estimates of sovereign debt crisis indicate that larger debt service is associated with a higher likelihood of a debt crisis in EDEs.

Another debt exposure indicator is debt intolerance, which is essential to assess debt service problems and restructure. Debt intolerant countries tend to have weak fiscal structures and financial systems. We measure debt intolerance as the ratio of external debt to GDP, as suggested by Reinhart et al. (2003a). These authors argued that debt intolerance might lead to slower growth and high macroeconomic volatility. The rise in external debt creates a financial vulnerability that shuts the doors for international capital markets, causing the debt crisis (Obstfeld et al., 1996; Rodrik, 2008). Reinhart et al. (2003a) argue that debt intolerant economies have difficulty in sustaining access to the international capital market unless they lower their debt ratios to a safer level. The empirical result shows that debt intolerance tends to increase the probability of sovereign debt crisis in EDEs. A tight monetary condition in the US may cause a reversal of capital flows from EDEs, which increases their debt servicing cost (Manasse and Roubini, 2009). The result shows that the 10-year US Treasury rate hike increases debt value and furthers the default risk. The result supports the assertion of Eichler and Maltritz (2013), and Jeanneret and Souissi (2016).

In a nutshell, the regression estimates show BOSIN and NCM increase the probability of financial crises. The original sin is related to the sovereign debt crisis in a nonlinear form.

6 Conclusion and policy implications

The emerging and developing economies survived well from the global financial crisis compared with developed countries. However, the recent rapid accumulation of foreign currency-denominated debt and resurgence of currency mismatches in these economies may raise the probability of financial crises. Thus, the present study examines the role of foreign currency-denominated debt and currency mismatches in financial crises. We contribute to the literature by developing a broader version of original sin and new currency mismatch indices using the currency composition of international debt securities and cross-border bank loans. To estimate the effects of these indicators on financial crises, this study also constructs the early warning models.

The empirical findings show that higher value of original sin and currency mismatches are associated with a greater incidence of financial crises, and also support the third-generation crisis models. In addition, we find the original sin has a nonlinear effect on the sovereign debt crisis. The results suggest that the accumulation of forex reserves can safeguard the economy from external vulnerabilities and support financial stability during tumultuous periods. Overall, measuring external vulnerability can guide policymakers in their efforts to address financial crises at the right time. Therefore, these indicators need to be monitored and part of the calibrated policy framework. Further, these indicators can flag risks of excessive vulnerability that could call for the implementation of macro-prudential policies. The possible extension of this study is to account the nonlinear effects of early warning indicators through advanced machine learning applications.

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7 Appendix

Table 8. Country coverage

Advanced economies (34)
Australia, Austria, Belgium, Canada, China P.R.: Hong Kong, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovak Republic, Slovenia, South Korea, Spain, Sweden, Switzerland, United Kingdom, and United States.
Emerging and developing economies (128)
Albania, Algeria, Angola, Argentina, Armenia, Azerbaijan, Bangladesh, Barbados, Belarus, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Cape Verde, Central African Republic, Chad, Chile, China, Chinese Taipei, Colombia, Comoros, Congo Democratic Republic, Congo Republic, Costa Rica, Croatia, Côte d'Ivoire, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Ethiopia, Fiji, Gabon, Gambia, Georgia, Ghana, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, India, Indonesia, Iran, Jamaica, Jordan, Kazakhstan, Kenya, Kuwait, Kyrgyz Republic, Lao People's Dem. Rep., Lebanon, Lesotho, Liberia, Libya, Macedonia, Madagascar, Malawi, Malaysia, Maldives, Mali, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nepal, Nicaragua, Niger, Nigeria, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Romania, Russia, Rwanda, Sao Tome and Principe, Senegal, Serbia, Seychelles, Sierra Leone, South Africa, Sri Lanka, St. Kitts and Nevis, Sudan, Suriname, Syria, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, Uruguay, Uzbekistan, Venezuela, Vietnam, Yemen, Zambia, and Zimbabwe.

Notes: The selection of countries is based on the availability of data. The sample consist of 34 advanced countries and 128 emerging and developing countries from 1970 to 2018. The countries are classified as advanced countries and emerging and developing countries based on the IMF-WEO methodology.

Table 9. Variables definition and sources

Variable	Measure	Sources	Sign
Currency crisis	"Nominal depreciation of currency vis-à-vis the U.S. dollar of at least 30 percent that is also at least 10 percentage points higher than the rate of depreciation in the year before (0 and 1)". The total number of currency crises — 241.	Laeven and Valencia (2020)	NA
Banking crisis	(a) "significant signs of financial distress in the banking system (as indicated by significant bank runs, losses in the banking system, and/or bank liquidations)." (b) "significant banking policy intervention measures in response to significant losses in the banking system (0 and 1)" Total number of banking crisis — 154.	Laeven and Valencia (2020)	NA
Sovereign debt crisis	"Information related to debt default and restructuring collected rating agencies reports, reserve accumulations, IMF staff reports, and bond market development (0 and 1)". A total number of the sovereign debt crisis — 79.	Laeven and Valencia (2020)	NA
Broad original sin	Broader version of original sin defines in Eq. 2. The index value ranges between 0 and 1.	Authors' own calculations	(+)
New currency mismatch	The difference between forex reserves and international debt securities multiplied with broad original sin (Eq. 5).	Authors' own calculations	(+)
Exchange rate regime	The coarse classification includes 6 categories of the exchange rate. Regime starting from rigid (1) to a more flexible exchange rate regime (6).	Ilzetzki et al. (2019)	(+)
Financial openness	The index measures the country's degree of financial openness. The binary dummy variable codifies the tabulation of restrictions on cross-border financial transactions reported in IMF's annual report on exchange rate arrangements and exchange rate restrictions (0 to 1).	Chinn and Ito (2006)	(-)
Trade openness	Trade is the sum of exports and imports of goods and services measured as a share of GDP (%). In log form.	W.B.	(-)
Current account	The current account balance is the sum of net exports of goods and services, net primary income, and net secondary income (% of GDP).	W.B.	(-)
Inflation	Inflation, GDP deflator (annual %).	W.B.	(+)
Forex reserves	Change in total reserves minus gold reserves (current US$).	IMF IFS	(-)
REER	Change in the real effective exchange rate of 66 trading partners.	Bruegel	(-)
Government debt	Log of total stock of debt liabilities issued by the central government as % GDP.	GDD	
Private credit	Change in domestic credit to the private sector as a % of GDP.	IMF IFS	(±)
Broad money	Change in broad money as a % of GDP.	W.B.	(-)
Bank credit	Ratio of bank credit to bank deposits (%).	GFD	(+)
Debt service	Ratio of total external debt service to exports.	IMF IFS	(+)
Debt intolerance	Total external debt stock as a % of GDP.	W.B.	(+)
US treasury rate	10-year Treasury constant maturity rate (%).	FRB	(+)
World GDP growth	World GDP growth rate (%).	W.B.	(-)
Energy price index	Energy price index, growth rate† (%).	W.B.	(±)

Notes: This table provides a detailed description of the variables, measurements, and data sources. The Authors' calculations are based on data obtained from the Bank for International Settlements (BIS), International Financial Statistics (IFS) of the International Monetary Fund (IMF), and the World Bank database (W.B.). The official data of each country provided by the national databases is also the source of the data. GFD and FRB denotes Global Financial Debt and Federal Reserve Bank of St. Louis. † denote average weighted prices of energy raw materials (weight = 4.7), crude oil (weight= 84.6) and natural gas (weight = 10.8).