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Research Article

Macroeconomic Currency Crisis Early Warning Indicators in Emerging Countries

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Abstract

This study investigates the relationships between exchange rate and the main macroeconomic variables as GDP, inflation and unemployment on one hand and the ability of these variables in alerting about coming exchange rate crisis in emerging countries. The three variables have significant coefficients with exchange rate in line with literature signs except unemployment rate. The study uses signal approach, dealing specifically with the main macroeconomic variables, selected by system GMM method in emerging markets. The study develops macroeconomic pressure indices from these selected macroeconomic variables using the market pressure index methodology from Early Warning System literature. Based on the macroeconomic variables, a combined macroeconomic pressure index has been built. The results of the non-parametric early warning system indicate that the individual macroeconomic pressure indexes created are good warning tools of a currency crisis. The macroeconomic pressure indexes are better early warning indicators than market pressure index built from international reserves, in emerging countries for four quarters warning period window. Production pressure index appears more accurate followed by inflation but unemployment pressure index is the most sensitive. However, the number of effective indicators and the accuracy of the indexes are not the same for all the countries, changing from a country to another.

Keywords

Exchange Rate, Crisis, Macroeconomics, Warning System

1. Introduction

The world is in an era of growing globalization of business activities and volatility in international financial markets. Globalization is in fact today what implicitly establishes bridges between countries made of rules that govern interactions and make sure that countries are protected from each other from domination and contagions. Established states have their own policies in line with the sovereignty principle. Monetary sovereignty allows each country to have its own currency. But not all countries have the same economic weight allowing different values of currencies and establishing exchange rates. Globally, the volatility in the activities is reflected in market prices. The exchange value risk is reoccurring and overwhelming with growing uncertainty and volatility.

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According to Bartram and Karolyi [4], the management of foreign exchange rate risk, in this globalization era, gains in importance in financial and nonfinancial sectors. The focus has been first made on the relationship between exchange rate and the volatility of firms' cash flow, managers concerns. The Basel Committee on Banking Supervision [6] defines market risk as 'the risk of losses in on and off-balance-sheet positions arising from movements in market prices' (BIS [5]). According to Swami et al. [54], market risk is the risk of losses to the bank arising from movements in market prices as a result of changes in interest rates, foreign exchange rates and equity and commodity prices. The focus source of market prices volatility here is Foreign exchange rate risk, which is the risk that the value of the bank's assets or liabilities changes comes from currency exchange rate fluctuations. Generally, banks are vulnerable to three types of foreign exchange risk: transaction (commitment), economic (operational, competitive or cash flow) and translation (accounting) (Abor [2]). Transaction risk arises when the value of existing obligations is deteriorated by movements in foreign exchange rates (Abor [2]). Economic risk occurs due to impact of high unexpected volatility in the exchange rate on equity/income for both domestic and foreign operations. Translation risk is associated with the assets or income derived from offshore activities (Abor [2]). Exchange rate risk appears large enough to destabilize an economy.

In fact, policy makers are interested today in understanding possible sources and capturing this kind of risk because in the long terms, sharp fluctuations of the exchange rate will result in a currency crisis which can be economically fatal.

Since the early 1980s, researchers have been working on approaches to analyze the vulnerability of exchange rates and predict currency crises. The first theoretical models of external shocks on asset valuation schemes had been developed a few years prior, pushing researchers to consider crises as rational processes. Important countries and regions faced serious currency crises soon after. For instance, the crises in Latin America (e.g., Mexico 1994–95, Brazil 1999, Argentina 2001), Asia (e.g., Thailand, South Korea, Indonesia 1997–98), and Russia 1998 raised new issues. These crises were actually followed by a banking and sovereign debt crisis. All of this intensified the need for tools to predict or at least better understand crises among policymakers and the financial industry. It is intuitive and meaningful to ask the question whether we can identify a distinct pre-crisis regime before these crises happened, so that these currency crises are not total surprises. The solution of this question may give policymakers of each country enough time to take preemptive actions to deal with the coming currency crisis and even prevent or avoid the undesired consequences thereof, (Du & Lai [17]).

The currency could stir volatility depending on the economic situation. Macroeconomic variables have direct or indirect impact on exchange rate movements and fluctuations in exchange rates may have an adverse effect on the economy, Abdoh [1]. This questions about the specification of the relationship between exchange rate and macroeconomic variables, is it a dynamic one?

This study focuses on selected main macroeconomic variables, GDP, inflation and unemployment, by determining first their relationship with exchange rate and second investigates on their ability to alert on the occurrence of currency crises regarding different time horizons in emerging economies.

The paper is organized as follows. The following section describes exchange rate systems. In the third section we review first the literature macroeconomic variables and exchange rate nexus and second, the currency crisis early warning system. The fourth section presents methodological aspects of the study. Empirical findings are given in the fifth section and section six concludes and gives recommendations.

1.1. Exchange Rate Systems

According to Rose [47], the exchange rate is an unusual asset price and even the most heavily traded asset price in that it has official regimes of volatility. There are different exchange rate regimes that governments choose from and that are managed by their central bank. A country should choose the regime best suited to meet its particular economic challenges, taking into account in its decision the implications of this choice for overall systemic stability, from Ghosh et al. [26]. In theory, if the right regime is adopted, it could facilitate better business climate (Mohammed et al. 2017). There are two polar extreme, either freely floating currency or hard peg such as a currency union or currency board, Ilzetzki et al. [32]. However, intermediate regimes are some popular options for many countries in line with political-economy considerations according to Ilzetzki et al. [32]. The paper borrows Abdoh et al. [1] exchange rate systems.

1.2. Fixed Exchange Rate System

In a fixed exchange rate system, the exchange rate was being allowed to volatility only within very narrow boundaries. If the exchange rate begins to move extreme, the governments will intervene in order to maintain it within the boundaries. It is to ensure that the exchange rates movement is drifted no more than one percent above.

1.3. Freely Floating Exchange Rate System

Under freely floating exchange rate system, the exchange rate values would be determined by the market forces. The freely floating exchange rate systems are not intervention by various governments in the country. Under this system also, a central bank is not forced to implement an intervention policy that may have an unfavorable effect on the economy just control exchange rates.

1.4. Managed Float Exchange Rate System

Managed float exchange rate system is similar to the fixed system. The managed float exchange rate system is allowed the governments to intervene for preventing their currencies from moving too much. This system shown that the currencies have no explicit boundaries. But this will tie in with supply and demand factors.

1.5. Pegged Exchange Rate System

Some countries may use pegged exchange rate system when their bone currency's value is pegged to a foreign currency. One of the best-known pegged exchange rate arrangements was been established by the European Economic Community knows as EEC in April 1977, when the EEC members decided to maintain their currencies to be established with the limits of each other. The market pressure will cause some of the currencies to fluctuate at outside their established limits.

2. Literature Review

Since the early 1980s, researchers have been working on approaches to analyze the vulnerability of exchange rates and to predict currency crises. Global, regional and local financial crises follow one another, and they attracted considerable attention in literature where two main views regarding them emerged according to Budsayaplakorn et al. [8]. The first view supported by some researchers as [35, 42, 11, 34, 19, 17] and others, argues that the sources of financial crises are regional contagion, investors panic, market behavior and changings in market expectations. [13, 16, 14] are among those holding the second point of view, which makes weak economic performances and the poor quality of institutions, the determinants of crises. Many authors stress the role of deteriorating economic fundamentals prior to currency crises according to Budsayaplakorn et al. [8]. That, from this paper point of view, makes macroeconomic determinants potential warning signs of currency crises for an economy, provided they are statistically consistent.

2.1. Exchange Rate and Macroeconomic Variables Nexus

Economists mentioned that currency crisis is a phenomenon where more than 20 percent of the value of domestic currency suddenly drops against the foreign currency (Yazdani & Nikzad [56]. In literature, at least three theoretical sources for currency crises are developed. These underlying theories include, in the following order of ranking, weak macroeconomic fundamentals, economic actors' bad expectations and ineffective banking intermediary. These sources of currency crises seem to be linked, being able to cascade one after the other until the crisis. Macroeconomic results could impact actors' expectations expressed in speculative attacks that could affect in turn, through financial panic, banking intermediation. That puts macroeconomic variables at the heart of the topic and puzzle out their relationship with exchange rate when studying countries currency crises. The theoretical relationships between the exchange rate and macroeconomic variables are known, but there is no empirical consensus on their significance, direction and sign. Under these conditions, before using a variable as a warning tool, it is necessary to determine the relevance of its link with the exchange rate.

For Simon [52], exchange rate badly affects mainly small economies and it has direct and positive relationship with inflation. Roubini [48] stated that changes in macroeconomic phenomenon could cause changes in exchange rate movements. Specifically, he shows that the positive change in nominal interest at domestic level will cause the currency to be appreciated and can be vice versa. Kasif [35] shows for Pakistan that, when exchange rate increased and the inflation rate decreased, that does not occur simultaneously. Harberger [30] investigated the impact of GDP growth on real exchange rate. He found that there is no systematic relationship between economic growth and real exchange rate. Kamin [34] empirically found that the relationships between inflation and the real exchange rates in most countries of Asia and Latin America shown a negative relationship. Husain et al. [31] experienced no robust relationship between economic fundamentals and exchange rate in developing countries. In developed economies higher economic growth is associated with lower inflation and lower exchange rate, determining negative connexion between GDP and exchange rate. Moccero [41] have done an investigation to find out the link between the real exchange rate volatility and the export in Argentina and found that there are significantly negative relationships between those variables. In the study of Achsani [3], inflation gives the theoretical correct sign in its relationship with exchange rate, which is negative. Mirchandani [40] investigated various macroeconomic variables leading to exchange rate in India. Results show that exchange rate has a negative correlation with interest rate and inflation rate. The connexion of exchange rate with GDP and foreign direct investment is positive. But there is no correlation between current account and exchange rate. Ramasamy & Abar [46] show that interest rate, Balance of Payment and inflation rates should influence the exchange rate positively as per theory, but the results show the opposite.

2.2. Currency Crisis Prediction

According to Yazdani & Kikzad [56], the theoretical literature has usually focused on the pre-crisis periods to investigate the reasons of currency crises. Mainly two major approaches are expressed in the empirical literature on currency crises. The first group of studies focus on crisis prediction [9, 25, 39], and the second group of studies consider the outcome of currency crises and particularly output effects [29, 12]. We are interested in the first group dealing with currency crises prediction. Many

authors stress the role of deteriorating some indicators prior to currency crises. They are various statistical and econometric methods in literature that have been used to predict crisis. The definition of crisis, models utilized, and explanatory variables have varied from one study to another, (Sevim et al. [50]). To deal with currency crises prediction, three types of research are known in literature. The earliest category refers to the regression models such as Logit–Probit models estimating crises ahead of time via leading indicators. This category is hold by researchers as [19, 23, 27, 10, 49, 15, 44]. The second category uses potential early warning indicators and is associated with the Kaminsky et al. [33] (KLR) Model, which is also known as the signaling approach. The third category focuses on machine learning applications, which are relatively new in forecasting financial crises. It is a popular predictive tool used by [57, 36, 21, 24].

3. Methodological Aspects

Efforts to anticipate currency crises systemically have created a monitoring instrument known as the Early Warning System, Sutrisno et al. [53], among others. According to Shi and Gao [51], in the mainstream models for the financial crisis early warning, the KLR has better performance. A large mass of research constructed early warning system for currency crises. In this line Kaminsky et al. [33] (KLR) introduced the signal approach. They have proposed watching the evolution of some macroeconomic variables that experience unusual behaviors prior to a currency crisis and estimate the probability of crisis event within 24 months before. Kaminsky [33] built a foreign exchange market pressure index (MPI) to quantify the financial crisis, which is the weighted average of percentage change of exchange rate and international reserves. In this study we choose to use signal approach, dealing specifically with the main macroeconomic variables GDP, inflation and unemployment in emerging markets. In this study, we develop macroeconomic pressure indices by selecting relevant macroeconomic variables using the market pressure index methodology. Instead of basing on literature nexus we choose to calculate the indices from the empirical nexus between exchange rate and macroeconomic variables. This is based on the non-consensus phenomenon in literature about these relationships (no relationship, bidirectional and unidirectional from one to other and vice versa). So, the first step is the estimation of empirical relationships between exchange rate and GDP, inflation rate and unemployment rate. The second step is macroeconomic pressure indices determination and the third is the estimation of their ability to alert or to give crisis event signal.

3.1. Macroeconomic Determinants

This study focuses on three main macroeconomic variables, GDP, inflation and unemployment. Literature review shows that there is possible bidirectional relationship between exchange rate and the study's macroeconomic variables. There may be simultaneity in terms of influence that is one of the sources of endogeneity among unobserved heterogeneity, measurement errors, endogenous sample and serial autocorrelation. To deal with endogeneity (reverse causality), we use a dynamic framework, performing the Blundell and Bond [7] system GMM model and compare it to pooled and fixed effect models to ensure its robustness. This model is designed for situation with few time periods and many individual units, linear functional relationship, endogenous variable depending on its own past realizations, independent variables that are not strictly exogenous (correlated with errors), unobserved heterogeneity and heteroskedasticity and autocorrelation within individual units' errors but not accross them. The model is specified as:

$$Exchge_{i,t} = \alpha + \beta_1 Exchge_{i,t-1} + \beta_2 Exchge_{i,t-2} + \beta_3 GDP_{i,t} + \beta_4 Inf_{i,t} + \beta_5 Uemp_{i,t} + \beta_6 Reserv_{i,t} + \beta_7 Money_{i,t} + \beta_8 LInterest_{i,t} + \beta_9 DInterest_{i,t} + \beta_{10} Trade_{i,t} + \varepsilon_{i,t} \quad (1)$$

Where the variable Exchge is exchange rate, the endogenous variable. There are two groups of independent variables. The first one represents the focuses macroeconomic variables chosen for signal ability analysis, GDP growth (GDP), inflation rate (Inf) and unemployment (Uemp). The second are control variables, international reserves (Reserv), broad money (Money), lending interest rate (LInterest), deposit interest rate (DInterest) and terms of trade (Trade).

3.2. Currency Crisis

This study uses the Frankel-Rose definition of a currency crisis. It is based on two main conditions. The first condition identifies crisis when a country's nominal bilateral dollar exchange rate depreciates by 25 % or more in a given quarter compared to the previous year's value. The second condition sets that the depreciation has to be at least 10 % greater than the depreciation in the preceding quarter. The two inclusive two conditions lead to a binary variable computed as follow:

$$Crisis = \begin{cases} 1 \; if \; \frac{\Delta \text{Exchge}_{i,t}}{Exchge_{i,(t-4)}} > 0.25 \; and \; \frac{\Delta \text{Exchge}_{i,t}}{Exchge_{i,(t-4)}} - \frac{\Delta \text{Exchge}_{i,(t-1)}}{Exchge_{i,(t-5)}} > 0.1 \\ 0 \; Otherwise. \end{cases} \quad (2)$$

The double condition was set so that reoccurring currency crashes due to the first condition could be avoided. We need to make sure that the crisis variable captures only sudden crashes of currency. Furthermore, we will be using a crisis window of four quarters which is called a combined crisis period. This simplifies the model by avoiding repeated crises by treating clusters of recurring crises as a particular event.

3.3. Early Warning System

In general, the features of the currency crisis include exchange rate depreciation due to the decrease in international reserves mainly. The signal approach commonly uses Market Pressure Index (MPI) built by Kaminsky et al. [33] (KLR) from the two variables, exchange rate and international reserves. This study follows KLR method by building Financial Pressure Indexes (FPI). The first FPI is the MPI, second the macroeconomic pressure indexes specifically Production Pressure Index (PPI), Inflation Pressure Index (IPI) and Unemployment Pressure Index (UPI) and the combine Macroeconomic Pressure Index (MePI).

$$MPI = \frac{\Delta \text{Exchge}_{i,t}}{Exchge_{i,t}} - \frac{\sigma_{Exchge}}{\sigma_{reserv}} \times \frac{\Delta \text{reserv}_{i,t}}{reserv_{i,t}} \quad (3)$$

$$PPI = \frac{\Delta \text{Exchge}_{i,t}}{Exchge_{i,t}} \pm \frac{\sigma_{Exchge}}{\sigma_{GDP}} \times \frac{\Delta \text{GDP}_{i,t}}{GDP_{i,t}} \quad (4)$$

$$IPI = \frac{\Delta \text{Exchge}_{i,t}}{Exchge_{i,t}} \mp \frac{\sigma_{Exchge}}{\sigma_{Inf}} \times \frac{\Delta \text{Inf}_{i,t}}{Inf_{i,t}} \quad (5)$$

$$UPI = \frac{\Delta \text{Exchge}_{i,t}}{Exchge_{i,t}} \mp \frac{\sigma_{Exchge}}{\sigma_{Uemp}} \times \frac{\Delta \text{Uemp}_{i,t}}{Uemp_{i,t}} \quad (6)$$

$$MePI = \frac{\Delta \text{Exchge}_{i,t}}{Exchge_{i,t}} \mp \frac{\sigma_{Exchge}}{\sigma_{GDP}} \times \frac{\Delta \text{GDP}_{i,t}}{GDP_{i,t}} \mp \frac{\sigma_{Exchge}}{\sigma_{Inf}} \times \frac{\Delta \text{Inf}_{i,t}}{Inf_{i,t}} \mp \frac{\sigma_{Exchge}}{\sigma_{Uemp}} \times \frac{\Delta \text{Uemp}_{i,t}}{Uemp_{i,t}} \quad (7)$$

The σ are standard deviations and $\frac{\Delta x_{i,t}}{x_{i,t}}$ denote percentage changes in study's variables (x). The $\mp$ symbol in equations (4) to (7) indicate that this study doesn't consider the a priori theoretical relationship's direction between exchange rate and the leading macroeconomic indicators. Instead, the study based on the empirical relationship from model (1). According to Sevim et al [50], financial crisis arises when a threshold of financial pressure index, the macroeconomic and market pressure indexes in this study, is exceeded. We called this threshold, the pressure index value at risk (PIVaR) beyond which the corresponding indicator gives a crisis warning as follows:

$$Wraning = \begin{cases} 1 \; if \; FPI > PIVaR = \mu_{FPI} + \kappa \times \sigma_{FPI} \\ 0 \; Otherwise \end{cases} \quad (8)$$

Where, κ is a factor that takes values between 1 and 3 in financial crisis literature. According to Sevim et al. [50], it is a It is a country-specific and heuristic value that seeks to improve the signal performance. The κ factor is usually an arbitrary coefficient. In this study we estimate the optimal factor that minimizes forecast errors following Kaminsky et al. [33]. They determine the value ok κ that is the minimum and the best threshold (Shi and Gao, [51]) for individual indicators through noise-to-signal ratio (NSR) from the summarized matrix of their performances as follows:

Table 1. *Indicator signal matrix.*

	Crisis in signaling window	No crisis in signaling window
Signal issued	A	B
No signal issued	C	D

In this matrix, A is the number of quarters where the indicator issued a good signal, B is the number of quarters where the indicator issued a bad signal (type II error), C is the number of quarters where the indicator failed to issue a good signal (type I error), and D is the number of quarters where the indicator refrained from issuing a bad signal. The NSR of each indicator is calculated following Goldstein et al. [28]. According to Phadan and Prabheesh [43], they determine the NSR from the unconditional probability of a crisis P(crisis) = (A+C) / (A+B+C+D) and the conditional probability of a crisis P(crisis | Signal) = A / (A+B) as follows:

$$NSR = P(crisis|signal) - P(crisis) = \frac{B/(B+D)}{A/(A+C)} \quad (9)$$

From Shi and Gao [51], an effective early warning indicator has a NSR > 0 and the indicator that NSR is larger than 1 cannot act as leading indicators.

3.4. Warning Period Window

When talking about forecasting or prediction, the time window has a significant effect on the quality of the prediction and in our case the quality of the signal. There is therefore also interest in the study to assess the quality of the indicators over four quarters. From equation (8) the perfect signal takes a value of 1 if a crisis is expected to occur within the upcoming window period and a value of 0 if otherwise.

For instance, if a crisis is assumed in January of 2022, the perfect signal indicator always takes a value of 1 before 12-months period of January 2022 for the chosen warning period window.

3.5. Data Description

The data collection in this research study is derived from secondary sources, the International Monetary Fund (IMF) and World Bank open online database from 1990 to 2020. In fact, two types of data sets have been used during this work. Yearly data are used to estimate model (1) and quarterly data in all other models. The variables collected are Exchange Rate (Dollar per Local Currency), Gross Domestic Product (Per Capita), Consumer Price Index, Unemployment (Measured in percentages), Real lending rate, Real deposit rate, Terms of trade, Broad Money, International reserves (in US dollars). The study's countries are emerging ones specifically Brazil, Chile, China, Colombia, Czech Republic, Hungary, Republic of Korea, Mexico, Poland, South Africa, Thailand.

4. Findings and Interpretations

4.1. Stationarity

To ensure models stability the study performs stationarity tests and results table shows that only GDP growth and unemployment rate are stationary at first difference I(1). The other variables are I(0).

Table 2. *Stationarity.*

Variables	First level			First difference			Conclusion
	LLC	*IPS*		*LLC*	*IPS*		
Exchge	-6,599***	-1,684**	S	-9,438***	-6,128***	S	*I(0)*
	(0.00)	*(0.04)*		*(0.00)*	*(0.00)*		
GDP	1,213	-3,604***	NS	-1,488*	-6,859***	S	*I(1)*
	(0.88)	*(0.00)*		*(0.06)*	*(0.00)*		
Inf	-6,777***	-6?277***	S	-9,726***	-9,009***	S	*I(0)*
	(0.00)	*(0.00)*		*(0.00)*	*(0.00)*		
Uemp	-1,924**	0,915	NS	-3,049***	-4,347***	S	*I(1)*
	(0.02)	*(0.81)*		*(0.00)*	*(0.00)*		
Reserv	-3,777***	-5,885***	S	-17,467***	-9,224***	S	*I(0)*
	(0.00)	*(0.00)*		*(0.00)*	*(0.00)*		
Money	-3,495***	-5,671***	S	-8,610***	-8,581***	S	*I(0)*
	(0.00)	*(0.00)*		*(0.00)*	*(0.00)*		
Trade	-6,488***	-3,856***	S	-8,919***	-7,084***	S	*I(0)*
	(0.00)	*(0.00)*		*(0.00)*	*(0.00)*		
Linterest	-6,191***	-3,491***	S	-5,209***	-5,853***	S	*I(0)*
	(0.00)	*(0.00)*		*(0.00)*	*(0.00)*		
Dinterest	-6,103***	-4,186***	S	-5,350***	-6,247***	S	*I(0)*
	(0.00)	(0.00)		(0.00)	(0.00)		

Notes: S determines Stationarity and NS is non stationarity

4.2. Granger Causality

In the study, this step is important so that one could have a preliminary point of view of where the data set is standing compared to what history or literature says. Thus, the study will conduct a Granger Non-Causality test on the macroeconomic variables and the exchange rate one by one respectively. Granger Non-Causality is an econometric test used to verify the usefulness of one variable to forecast another. Granger causality is not an absolute one. It is based on 2 principles; the cause happens prior to its effect and the cause has unique information about the future values of its effect.

Table 3. *Granger causality test of exchange rate on macroeconomic variables.*

Variables	p-values	Conclusions
GDP	0.09615	Exchange rate does not Granger cause GDP
Inflation	0.2999	Exchange rate does not Granger cause Inflation
Unemployment	2.351e-09	Exchange rate Granger cause Unemployment

Table 4. *Granger causality test of macroeconomic variables on exchange rate.*

Variables	p-values	Conclusions
GDP	0.2601	GDP Granger cause Exchange rate
Inflation	0.2999	Inflation does not Granger cause Exchange rate
Unemployment	1.531e-14	Unemployment Granger cause Exchange rate

From tables 3 and 4, it appears that there is bidirectional causality between exchange rate and unemployment, a unidirectional causality from GDP to exchange and no causality relationship between exchange rate and inflation in emerging countries. The analysis needed deeper techniques and bidirectional case involves taking into account endogeneity bias.

4.3. Exchange Rate Macroeconomic Determinants

Model (1) is estimated three times with different methods (pooled OLS, fixed effect and system GMM) to deal with endogeneity and to ensure results robustness. Table 5 gives results divided in two parts where the upper gives coefficients and the lower shows diagnostic statistics. Starting by models' diagnostic, it appears that the determination coefficients of pooled-OLS and fixed effect models are low. The models barely explain a quarter of variations in exchange rate. GMM regression is two-step and the Windmeijer [55] finite sample correction for standard errors is employed. Instrument matrix is collapsed in SYS-GMM regression. For first and second order autocorrelation, the null hypothesis of over-identifying restrictions validity and instruments validity necessary for system GMM robustness, respectively the study reports the p-values of AR(1), AR(2), Sargan and Hansen tests. The results of the Arellano-Bond tests indicate that there is no second-order serial correlation. The null hypotheses of Sargan's test and Hansen's J test cannot be rejected. It therefore appears that the test statistics show an appropriate specification. SYS-GMM gives robust results and determines the exchange rate and macroeconomic variables relationships in emerging markets. In the robust estimations (i.e. the system GMM) the lags (1 & 2) of exchange rate and the focuses macroeconomic variables are significant. Lags 1 & 2 exchange rate variable have opposite effects on its current value, respectively significantly positive at 1% level and significantly negative at 10% level. The differential effect from the two lags remains significantly positive. The exchange rate tends to potentially follows its recent momentum in emerging economies.

Table 5. *Exchange rate and macroeconomic variables relationships.*

	POOLED-OLS	FIXED EFFECTS	SYS-GMM
Exchge(-1)			0,353***
			(0.00)
Exchge(-2)			-0,266*
			(0.06)
GDP	-0,003**	-0,004**	-0,018**
	(0.01)	(0.01)	(0.02)

	POOLED-OLS	FIXED EFFECTS	SYS-GMM
Inf	0,006***	0,006***	0,053**
	(0.00)	(0.00)	(0.05)
Uemp	0,010*	0,010*	-0,074*
	(0.06)	(0.07)	(0.08)
Reserv	-0,099***	-0,09***	-0,098
	(0.00)	(0.00)	(0.13)
Money	-0,0002	-0,0002	-0,0009
	(0.50)	(0.52)	(0.11)
Trade	-0,0004	-0,0004	-0,001
	(0.15)	(0.36)	(0.49)
Linterest	0,0002	0,001	0,00001
	(0.73)	(0.59)	(0.99)
Dinterest	0,005***	0,0009	-0,003
	(0.00)	(0.79)	(0.66)
Year dummy	0,005***	0,004***	0,007***
	(0.00)	(0.00)	(0.00)
Constant	10,607***	-9,732***	-14,349***
	(0.00)	(0.00)	(0.00)
R^2	0.25	0.23	
AR (1)			-1,87*
AR (2)			-0,84
Sargan			2,94
Hansen			3,22

Notes: (*), (**) and (***) indicate significant level at 10%, 5% and 1% respectively.

However, some country structural forces could enhance or inhibit this trend. It appears that GDP and unemployment are inhibition forces as they have negative relationship with exchange rate respectively (-0.018) and (-0.074) at 5% and 10%. GDP has the expected literature negative sign, but unemployment has the unexpected negative sign. It implies that with growth or growing unemployment rate, study's emerging countries' currency grows in value. If GDP or unemployment increases by 100%, exchange rate drops by 2% and 7% respectively. Inflation has the expected sign, which if increases by one the exchange rate will go up by 0.053, defining a positive relationship. GDP, inflation and unemployment are exchange rate determinants with the expected sign for GDP and inflation but not for unemployment. A decrease in GDP growth or in unemployment rate and an increase in inflation demonstrate the depreciation of exchange rate of national currency. As seen in financial pressure indexes equations (3) to (7), increased index will raise pressure of national currency to be sold.

4.4. Early Warning System

Table 5 gives empirical relationship between exchange rate and macroeconomic variables in emerging markets that allows determining the financial pressure indexes and their ability to alert on currency crises through the signal-to-noise ratio (lower than 1) and the optimal κ factor ($1 < \kappa < 3$). From table 5 the $\mp$ symbol in the financial pressure indexes formulas is determine negative for PPI and UPI, positive for IPI. The study started building the EWS model looking for the optimal threshold for each indicator given in table 6.

Table 6. *Optimal threshold factor.*

Indicators	Financial pressure indexes	Optimal threshold
International reserves	MPI	1.7
GDP	PPI	1.7
Inflation	IPI	1.2
Unemployment	UPI	2.6
GDP-Inflation-Unemployment	MePI	1.3

In literature, the critical value of FMP index that leads to the crisis has been mainly calculated by 1-3 standard deviations. In this study the factor is in line with literature as $1.2 \leq \kappa \leq 2.6$. From equation (2) and (8) the study determines effective currency crises on one hand and the financial and macroeconomic indexes crisis warnings on the other hand. This allows determining confusion matrices for each country and indexes performances, given in table 7. It gives information on indicators for each country. The column FPI shows the indicators and that with asterisk (*) are the helpful ones in predicting currency crises. It appears that none of the macroeconomic and market indicators is significant for Chile, Colombia, Cezch Republic and Hungary. For the other countries, on average three indicators out of five are useful in signaling currency crises.

Table 7. *Performances of indicators under signal approach.*

BRAZIL											
FPI	A	B	C	D	$Correct^a$	$Good^b$	Bad^c	NSR^d	$P(crisis\|signal)^e$	$P(crisis)^f$	$(e-f)^g$
MPI	3	9	21	49	63.41	0.125	0.155	1.24	0.25	0.29	-0.04
PPI	1	4	23	54	67.07	0.041	0.068	1.65	0.2	0.29	-0.09
IPI	3	9	21	49	63.41	0.125	0.155	1.24	0.25	0.29	-0.04
UPI*	3	4	21	54	69.51	0.125	0.068	0.55	0.43	0.29	0.14
MePI	3	9	21	54	65.52	0.125	0.155	1.14	0.25	0.29	-0.04
CHILE											
FPI	A	B	C	D	$Correct^a$	$Good^b$	Bad^c	NSR^d	$P(crisis\|signal)^e$	$P(crisis)^f$	$(e-f)^g$
MPI	3	10	35	34	45.12	0.07	0.22	2.87	0.23	0.46	-0.23
PPI	0	1	38	43	52.44	0	0.02	-	0	0.46	-0.46
IPI	0	0	38	44	53.66	0	0	-	-	0.46	-0.46
UPI	3	4	35	40	52.44	0.07	0.09	1.15	0.42	0.46	-0.04
MePI	2	5	36	39	50.00	0.05	0.11	2.15	0.28	0.46	-0.18
CHINA											
FPI	A	B	C	D	$Correct^a$	$Good^b$	Bad^c	NSR^d	$P(crisis\|signal)^e$	$P(crisis)^f$	$(e-f)^g$
MPI*	7	8	22	45	63.41	0.24	0.15	0.62	0.46	0.35	0.11
PPI*	4	4	25	49	64.63	0.13	0.07	0.54	0.5	0.35	0.15
IPI*	7	8	22	45	63.41	0.24	0.15	0.62	0.46	0.35	0.11
UPI*	4	6	25	47	62.20	0.13	0.11	0.82	0.4	0.35	0.05
MePI*	4	6	25	47	62.20	0.13	0.11	0.82	0.4	0.35	0.05
COLOMBIA											

FPI	A	B	C	D	$Correct^a$	$Good^b$	Bad^c	NSR^d	$P(crisis\|signal)^e$	$P(crisis)^f$	$(e-f)^g$
MPI	2	8	27	45	57.32	0.06	0.15	2.18	0.2	0.35	-0.15
PPI	0	3	29	50	60.98	0	0.05	-	0	0.35	-0.35
IPI	2	8	27	45	57.32	0.06	0.15	2.18	0.2	0.35	-0.15
UPI	3	12	26	41	53.66	0.10	0.22	2.18	0.2	0.35	-0.15
MePI	3	12	26	41	53.66	0.10	0.22	2.18	0.2	0.35	-0.15
CEZCH REPUBLIC											
FPI	A	B	C	D	$Correct^a$	$Good^b$	Bad^c	NSR^d	$P(crisis\|signal)^e$	$P(crisis)^f$	$(e-f)^g$
MPI	4	5	36	37	50.00	0.1	0.11	1.19	0.44	0.48	-0.04
PPI	0	1	40	41	50.00	0	0.02	-	0	0.48	-0.48
IPI	4	5	36	37	50.00	0.1	0.11	1.19	0.44	0.48	-0.04
UPI	3	7	37	35	46.34	0.07	0.16	2.22	0.33	0.48	-0.15
MePI	3	7	37	35	46.34	0.07	0.16	2.22	0.33	0.48	-0.15
HUNGARY											
FPI	A	B	C	D	$Correct^a$	$Good^b$	Bad^c	NSR^d	$P(crisis\|signal)^e$	$P(crisis)^f$	$(e-f)^g$
MPI	3	5	28	46	59.76	0.09	0.10	1.01	0.375	0.378	-0.003
PPI	0	1	31	50	60.98	0	0.02	-	0	0.378	-0.378
IPI	3	5	28	46	59.76	0.09	0.10	1.01	0.375	0.378	-0.003
UPI	2	12	29	39	50.00	0.06	0.23	3.64	0.14	0.378	-0.238
MePI	2	12	29	39	50.00	0.06	0.23	3.64	0.14	0.378	-0.238
KOREA REPUBLIC											
FPI	A	B	C	D	$Correct^a$	$Good^b$	Bad^c	NSR^d	$P(crisis\|signal)^e$	$P(crisis)^f$	$(e-f)^g$
MPI*	5	4	27	46	62.20	0.15	0.08	0.52	0.55	0.39	0.16
PPI	1	2	31	48	59.76	0.03	0.04	1.28	0.33	0.39	-0.06
IPI*	5	4	27	46	62.20	0.15	0.08	0.51	0.55	0.39	0.16
UPI*	7	7	25	43	60.98	0.21	0.14	0.64	0.5	0.39	0.11
MePI*	7	7	25	39	58.97	0.21	0.14	0.69	0.5	0.39	0.11
MEXICO											
FPI	A	B	C	D	$Correct^a$	$Good^b$	Bad^c	NSR^d	$P(crisis\|signal)^e$	$P(crisis)^f$	$(e-f)^g$
MPI	3	8	30	41	53.66	0.09	0.16	1.79	0.27	0.40	-0.13
PPI*	6	7	27	42	58.54	0.18	0.14	0.78	0.46	0.40	0.06
IPI	3	8	30	41	53.66	0.09	0.16	1.79	0.27	0.40	-0.13
UPI*	4	5	29	44	58.54	0.12	0.10	0.84	0.44	0.40	0.04
MePI*	4	5	29	44	58.54	0.12	0.10	0.84	0.44	0.40	0.04
POLAND											
FPI	A	B	C	D	$Correct^a$	$Good^b$	Bad^c	NSR^d	$P(crisis\|signal)^e$	$P(crisis)^f$	$(e-f)^g$
MPI*	5	4	23	50	67.07	0.17	0.07	0.41	0.55	0.34	0.21
PPI	2	7	26	47	59.76	0.07	0.12	1.81	0.22	0.34	-0.12
IPI*	5	4	23	50	67.07	0.17	0.07	0.41	0.55	0.34	0.21
UPI*	4	7	24	47	62.20	0.14	0.12	0.90	0.36	0.34	0.02

MePI*	4	7	24	47	62.20	0.14	0.12	0.90	0.36	0.34	0.02
SOUTH AFRICA											
FPI	A	B	C	D	$Correct^a$	$Good^b$	Bad^c	NSR^d	$P(crisis\|signal)^e$	$P(crisis)^f$	$(e-f)^g$
MPI*	5	6	28	43	58.54	0.15	0.12	0.80	0.45	0.40	0.05
PPI*	2	2	31	47	59.76	0.06	0.04	0.67	0.5	0.40	0.10
IPI*	5	6	28	43	58.54	0.15	0.12	0.80	0.45	0.40	0.05
UPI	3	8	30	41	53.66	0.09	0.16	1.79	0.27	0.40	-0.13
MePI	3	8	30	41	53.66	0.09	0.16	1.79	0.27	0.40	-0.13
THAILAND											
FPI	A	B	C	D	$Correct^a$	$Good^b$	Bad^c	NSR^d	$P(crisis\|signal)^e$	$P(crisis)^f$	$(e-f)^g$
MPI	4	10	28	40	53.66	0.12	0.20	1.6	0.28	0.39	-0.11
PPI*	1	1	31	49	60.98	0.03	0.02	0.64	0.50	0.39	0.11
IPI	4	10	28	40	53.66	0.12	0.20	1.6	0.28	0.39	-0.11
UPI*	4	4	28	46	60.98	0.12	0.08	0.64	0.50	0.39	0.11
MePI*	4	4	28	46	60.98	0.12	0.08	0.64	0.50	0.39	0.11

Notes: * indicates valid financial pressure index a Percentage of observations correctly called under signal approach [(A+D)/(A+B+C+D). b Good signals as percentage of possible good signals; A/(A + C). c Bad signals as percentage of possible bad signals; B/(B + D). d Adjusted noise signal ratio; [B/(B + D)]/[A/(A + C)]. e Percentage of signals that were followed by at least one crisis within the subsequent window (4 quarters) = A/ (A + B). f The unconditional probability of a crisis—that is, (A + C)/(A + B + C + D).

The column "correct" indicates the percentage of observations correctly called under the signal approach. The percentages seem relatively acceptable. However, it appears that for each country there is a threshold percentage between 58% and 60% from which the indicator becomes efficient. The good signals as the percentage of possible good signals are ranging from 0 percent to 24 percent. This is another measure of the propensity of the indicators to issue good signals unlike the bad signals percentage one would like to be small. NSR is the adjusted noise-to-signal ratio, which measures the noisiness of indicators. The lower the NSR, the better the signal. It is the main criterion in crises prediction probability. A financial pressure index with a NSR equal or greater than 1 introduces too much noise and therefore cannot be an effective indicator. The last three columns show the probability of a crisis conditional on a signal from the indicator, the unconditional probability of a crisis and their difference, respectively. The difference between the probability of a crisis conditional on a signal and the unconditional probability measures the noisiness of indicators. If the indicator is useful, the conditional probability should be higher than the unconditional one. The variables with a positive sign in the last column are the effective indicators that are classified in table 8. All the indicators are effective for China and production pressure index is better than literature market pressure index that is as better as inflation pressure index. In Korea Republic and Poland, only PPI is not effective and the best indicator is IPI. South Africa, Thailand and Mexico experienced three effective indicators where IPI seems to be the best.

It appears that, when effective the macroeconomic indicators mainly inflation and GDP are as better as or better than market pressure index based on international reserves. This is opposed to Budsayaplakorn et al. [8] study's results which instead used twice the warning period window of this study. Unemployment based indicator is the one that appears effective more times than the others, followed by the combined macroeconomic index, MePI. The GDP indicator is the most accurate one but unemployment indicator is the most sensitive. GDP is the main macroeconomic variable with the most accurate data available. Unemployment variable is that experiencing in model (1) results, unexpected or opposite theoretical sign, indicating greatest unusual behavior before currency crisis in emerging countries.

Table 8. *Effective indicators by country.*

	MPI	PPI	IPI	UPI	MePI
China	2nd	1st	2nd	3rd	3rd
Korea Rep.	2nd	Not effective	1st	3rd	4th
Poland	1st	Not effective	1st	3rd	3rd
South Africa	2nd	1st	2nd	Not effective	Not effective
Thailand	Not effective	1st	Not effective	1st	1st
Mexico	Not effective	1st	Not effective	2nd	2nd
Brazil	Not effective	Not effective	Not effective	1st	Not effective
Chile	Not effective	Not effective	Not effective	Not effective	Not effective
Colombia	Not effective	Not effective	Not effective	Not effective	Not effective
Czech Rep.	Not effective	Not effective	Not effective	Not effective	Not effective
Hungary	Not effective	Not effective	Not effective	Not effective	Not effective

5. Conclusion

This study has examined the probability of currency crisis based on macroeconomic variables, GDP, inflation and unemployment from the KLR signal approach method in emerging countries. The study compared its created macroeconomic pressure indexes with the literature's market pressure index based on international reserves. Instead of using theoretical relationships to determine financial pressure indexes, the study based on macroeconomic variables' empirical signs with exchange rate.

The results indicated from system GMM method that GDP, inflation and unemployment have significant relationships with exchange rate. GDP and inflation coefficients have the expected negative and positive signs respectively contrary to unemployment having the unexpected negative sign in emerging countries. The study has determined market pressure index, production pressure index, inflation pressure index, unemployment pressure index and a combine macroeconomic index. It appears that they are effective early warning indicators if they correctly called at least 60 percent of observations providing them low noise-to-signal ratio (lower than 1). The macroeconomic pressure indexes are better early warning indicators than market pressure index in emerging countries for one-year warning period window. Production pressure index appears more accurate followed by inflation but unemployment pressure index is the most sensitive.

However, the number of effective indicators and the accuracy of the indexes are not the same from a country to others. The study can be improve estimating indicators relationships with exchange rate by country and considering different warning period window from 3 months to 24 months.

Abbreviations

AR: Auto Regressive
BCBS: Basel Committee on Banking Supervision
BIS: Bank for International Settlement
EEC: European Economic Community
EWS: Early Warning System
FMP: Financial Market Index
FPI: Financial Pressure Index
GDP: Gross Domestic Product
GMM: Generalized Methods of Moments
IMF: International Monetary Fund
IPI: Inflation Pressure Index
IPS: Im-Pesaran-Shin
KLR: Kaminsky Lizondo Reinhart
LLC: Levin-Lin-Chu
MPI: Market Pressure Index
MePI: Macroeconomic Pressure Index
NSR: Noise-to-Signal Ratio
OLS: Ordinary Least Square
PIVAR: Pressure Index Value at Risqk
PPI: Production Pressure Index
SYS-GMM: System Generalized Methods of Moments
UPI: Unemployment Pressure Index

Author Contributions

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Aya Marouane: Data curation, Software, Writing - original draft, Methodology, Visualization

Conflicts of Interest

The authors declare no conflicts of interest.

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