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EFFECTIVENESS OF EARLY WARNING MODELS: A CRITICAL REVIEW AND NEW AGENDA FOR FUTURE DIRECTIONS

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ABSTRACT

This paper suggests a new agenda for constructing early warning models (EWMs) to enhance their effectiveness in predicting financial crises. The central argument of the new agenda aims to eradicate the weaknesses of existing EWMs, since their failure to predict the global financial crisis of 2007–2008 demonstrates the need to improve their efficiency. We document the history of EWMs and propose a new agenda as follows: 1) the accurate measurement of a financial crisis, 2) implementation of a fourth-generation crisis model to capture the dynamic nature of the financial crisis, and 3) the inclusion of interconnectedness/contagion variables as explanatory variables for the financial crisis.

Keywords: Early warning models; Financial crisis; Contagion; Global financial crisis; Crisis generation models.
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I. INTRODUCTION

Predicting financial crises[1] has become the central motive and a huge challenging task for policymakers in the face of the enormous costs associated with frequent financial crises. The nature of financial crises generates great costs in terms of economic slowdown, output losses, widespread bankruptcies, unemployment, financial instability, a vicious circle of low credit and insolvency, and so on (e.g.Krugman, 1999; IMF, 2002; Hutchison and Noy, 2006; Claessens et al., 2012; Laeven and Valencia, 2012; Claessens and Kose, 2013; Pritsker, 2013). These forms of economic consequences further lead to loss of confidence among investors, which is a major cause of low investment and capital outflows. The consequences become even more dire with the joint occurrence of different crises. The latest example of a triple crisis[2] is the global financial crisis in 2007–2008 (GFC), which provided light during the darkest phase of the economic downturn throughout the world. The consequences of financial crises are not limited to output loss and employment loss, but also include socio political-psychological imbalances that can destroy economic and social stability (Hutchison and Noy, 2006). Due to these multidimensional consequences, predicting the leading factors of a financial crisis is a major challenge for policymakers, and the difficulties are amplified by the dynamic nature of the financial crisis.

Financial crises are costly in terms of depth and duration.[3] Table 1 shows that, in terms of duration and cumulative gross domestic product (GDP) loss, the GFC, as a percentage, was more costly than all the financial events from 1880 to 2007. Apart from GDP loss, Blanchard and Kremer (1997) emphasize the problems with creditworthiness and bankruptcy spillover during a financial crisis. Claessens and Kose (2013) explain that the low ability to service debt can act as the seed for future crises, due to the collapse in output caused by the loss in creditworthiness. Similarly, Kaminsky et al. (1998) consider decreased credit ratings, loss of reserves, and increases in the cost of borrowing as crucial consequences of a financial crisis. Further, financial crises lead to sharp drops in real wages and employment and the deterioration of social and economic infrastructure (Gupta et al., 2003).

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[1] Financial crises can be regarded as efficiency losses in the financial market and imbalances in the financial sector. These can take the form of sudden and stronger changes in the pricing and quantities of financial instruments, such as foreign exchanges, stocks, bills of exchange (Claessens and Kose, 2013).

[2] A triple crisis in year t can be defined as a banking crisis in year t combined with a currency crisis during the period $[t - 1, t + 1]$ and a sovereign debt crisis during the period $[t - 1, t + 1]$.

[3] Crisis depth is defined as the peak-to-trough percentage decline in the GDP. Similarly, crisis depth is proxied by the cumulative loss in GDP over the length of the crisis, as a fraction of the pre-crisis level, whereas duration is defined as the number of years an economy's output takes to recover to pre-crisis levels.

Table 1.
Duration and Depth of Financial Crisis

This table provides a broad comparison of crises based on duration and depth, collected from Bordo et al. (2001) and Cecchetti et al. (2009). The average duration of crisis in an year is around 2.4, and the depth ranges from 5.2% to 20% during the costliest crises that occurred in the world from 1880-2008.

Period/Events	Avg. Duration of Crisis in Years	Avg. Crisis Depth (In terms of cumulative GDP loss relative to peak in percent)
1880-1913 (Barings crisis of 1890, New York Panic of 1907)	2.4	9.8
1919-1939 (Great Depression)	2.4	13.4
1945-1971	1.8	5.2
1973-1997 (Latin American crisis of the 1980sthe , ERM crisis of 1992 , the Asian and Russian crisis of 1997-98)	2.5-2.6	7.8-8.3
2007-08 (Global financial crisis of 2008)	2.5	20

In the mean time, two forms of globalization, trade and financial integration, have created fear among investors since the GFC due to the possibility of contagion.[4] Given an integrated economy, the balance sheet channel assisted by the so-called wake-up call hypothesis[5] (Goldstein, 1998) and the "unholy trinity of financial contagion" (Kaminsky et al., 2003) exacerbate the international transmission of shocks. Following an adverse shock in one economy, financial intermediaries operating in other economies are forced to correct their balance sheet by adjusting their equity-to-debt ratio. In this context, due to the transmission of shocks, credit availability in both economies declines, and integrated economies will face similar financial turbulence. The stronger the balance sheet channel, the stronger the transmission will be (Davis, 2014). Similarly, Kaminsky and Reinhart (2000) highlight the importance of the international bank lending channel as an international transmission mechanism. Further, Imbs (2010) identifies financial linkages among economies as directly responsible for the transmission of the GFC and the reason a housing bubble and subprime crisis in the United States became "the first global recession in decades."[6] This transmission of financial crisis has highlighted the role of financial contagion in driving the consequences, and it seems to be effective in identifying future events, even if a country does not have a direct linkage with the crisis-affected country. Even if the argument against

[4] The word *contagion* means the spread of market disturbances observed through comovements in exchange rates, stock prices, sovereign spreads, and capital flows.

[5] This hypothesis offers an explanation for contagion, wherein a financial crisis in one region is a wake-up call for investors in another region who assess their investment based on fundamentals. See Goldstein (1998) for more details.

[6] The GFC originated in the United States, but became a global shock, whose consequences affected most economies. This event led the world economy into a recession and can be compared to the Great Depression of 1929. For more details, see Imbs (2010).

contagion had existed before 2008 in the consideration of contagious variables in policy action (Berg et al., 2004; Rose and Spiegel, 2009, 2010), the major transition in the world economy caused by the GFC reignited the fear of financial contagion, motivating the search for instruments to recognize the signs.

To identify the leading indicators of a financial crisis, governments, banks, and international financial institutions have especially emphasized the construction of early warning models (EWMs)[7] to fend against the crisis prior to its occurrence or to dampen the consequences if not completely avoided. However, these models were unable to predict the GFC (Davis and Karim, 2008; Rose and Spiegel, 2009, 2012; Christofides et al., 2016). In this context, the following questions arise: 1) Are current EWMs capable of predicting future financial events? 2) Will there be an ironic repetition of "this time is different"?[8] 3) Can crisis generation models capture the dynamic behavior of a financial crisis? 4) Do existing EWMs require augmentation?

The successful prediction of a financial crisis depends solely on the ability of EWMs to identify the leading indicators of financial turbulence. EWMs are needed to predict vulnerability events and are helpful in accurately framing warnings to predict whether an event will turn into a crisis or to minimize the consequences if an event cannot be completely avoided (IMF, 2010). The careful implementation of EWMs can be helpful in policy formulation in maintaining the stability of an economy. The development of an accurate and reliable EWM is a challenging task for policymakers to obtain an accurate signal to avoid the occurrence of financial turbulence or to mitigate the consequences. Greater EWM accuracy will result in lower costs associated with financial crisis, and vice versa. The failure of EWMs in predicting financial crises not only will have costly consequences, but will also raise questions about the efficiency of the EWMs themselves within their operating framework. However, the irony of this time being different has created more difficulty in the construction of EWMs for policymakers. Nonetheless, existing EWMs must be augmented to accurately predict financial crises. In this scenario, we propose a future agenda for constructing EWMs that could enhance their efficiency.

Our study is motivated by the incidence of the GFC, an event that the existing EWMs failed to forecast. First, the consequences of the failure of EWMs in predicting financial crises is more costly if the EWM fails to predict a crisis than if a crisis is predicted but does not occur (Bussiere and Fratzscher, 2006). If the event was predicted, then the economy will be aware of the future occurrence of the event and preventive measures are implemented prior to its occurrence. Conversely, if a crisis is not predicted, then the unnoticed occurrence of financial turbulence will have lead to the EWMs' complete failure. In this case, the efficiency of EWMs is in doubt, since whether these models are really capable of predicting financial crises is in question (Rose and Spiegel, 2009, 2010, 2011).

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[7] The IMF (2002) explains early warning systems as an approach to the identification of vulnerabilities/causative factors of financial crisis in the economy and useful in predicting future financial events.

[8] Every financial crisis is different by nature and difficult to identify by following past patterns of financial crisis. Reinhart and Rogoff (2009a) explain this concept in more detail.

Second, theoretical crisis generation models also lose their predictive powers in identifying explanatory variables that effectively driven financial crises in the past. This demonstrates the existence of new variables that are not included among existing explanatory variables for financial crises. Further, a fourth-generation crisis model is needed to include stem variables in the EWMs, to enhance their efficiency (Candelon et al., 2014). Finally, the dynamic nature of financial crises in today's globalized world has highlighted the need to augment current EWMs so that they will be able to not only capture the dynamic nature of financial turbulence, but also enhance their efficiency in predicting events. In this context, this paper tries to answer the following questions: 1) How can the effectiveness of EWMs be enhanced? 2) How can a new agenda for the construction of EWMs be framed?

Our approach in this study is as follows. First, we document the history of EWMs and their theoretical background. Second, we focus on the need for a new agenda in relation to the failure of the EWMs, the dynamic nature of financial crises, and the irony of this time being different. Finally, we propose a new agenda consisting of the need for hybrid measures of financial crisis, for a fourth-generation crisis model to capture stem variables, and for the inclusion of interconnectedness variables in the EWMs.

In the line with this approach, we followed several steps: (1) We identify the literature related to EWMs. This search resulted in 62 papers in journals (*IMF Economic Review*, *Journal of International Money and Finance*, *Journal of Monetary Economics*, *Journal of Political Economy*, *Review of International Economics*, *International Journal of Finance and Economics*, *Journal of Financial Stability*, *Journal of Applied Economics*, *Journal of Applied Economics*, *Journal of Monetary Economics and Banking*, *European Economic Review*, *Journal of Economic Surveys*, *Open Economic Review*, *Journal of Economic Perspectives,* and *American Economic Review*), 19 working papers from international institutions (the International Monetary Fund, the National Bureau of Economic Research, the Bank for International Settlements, and the European Central Bank), seven chapters and discussion papers from banks and other financial institutions (the Czech National Bank and the National Bureau of Economic Research), four occasional and discussion papers (the Bank of Finland and the Reserve Bank of India), nine books from different publishers (MIT Press, University of Chicago Press, Princeton University Press, and the Institute for International Economics), one conference paper, and one PhD dissertation. This filter technique can be attributed to the steps of EWMs; the occurrence of the GFC, which weakened the predictive power of EWMs; and theoretical arguments for improving the efficiency of EWMs. (2) We focus on the reasons for the failure of EWMs in line with the GFC, the most costly financial event that ever occurred. (3) Finally, we propose a future agenda for the construction of EWMs to overcome the lacuna associated with existing EWMs.

We contribute to the literature in the following ways. First, this study could be the first attempt to document the history of EWMs with their theoretical background. Second, it is the first to propose a future agenda for the construction of EWMs based on the inclusion of all three stages. Third, the proposed agenda complements the ideas of the dynamic nature (Eichengreen, 2003; Reinhart and Rogoff, 2009a), joint occurrence (Kaminsky and Reinhart, 1999), and financial

contagion (Rose and Spiegel, 2009, 2010; Imbs, 2010) associated with financial crises. Finally, this study is in line with that of Claessens and Kose (2013) and Peltonen et al. (2015), who emphasize the nature of spillover/contagion as being appropriate in designing crisis mitigation and response policy and potentially enhancing the efficiency of EWMs.

The remainder of the paper is organized as follows. Section II contains a brief overview of EWMs and their historical evolution. Section III demonstrates the need for a new agenda for the construction of EWMs for financial crises. Section IV presents the proposed agenda for the construction of EWMs. Finally, Section V concludes the paper.

II. REVIEW OF EWMS

Kindleberger (1978) introduces the EWM and attempts to determine its importance. Salant and Henderson (1978) then develop a model that can predict a financial crisis when speculator self-interest is leading to a market-based dismantling of unsustainable policies. The purpose of EWMs is to detect the vulnerabilities responsible for financial crises to allow for the implementation of preventive policies (IMF, 2010).

The construction of an EWM involves three procedures. First, the primary step in formulating a model is to define financial crisis. Second, the explanatory variables are selected, that is, those variables that are very likely to lead a financial crisis if they cross a threshold. Finally, various econometric/statistical methodologies provide the models a finishing touch. Given all these stages, an EWM is thereby set to identify the leading indicators of a financial event.

EWMs face several challenges during their construction. First, defining a financial crisis is always difficult, because of the different forms of crisis in different countries over different periods (Kaminsky et al., 1998; Abiad, 2003). Second, the explanatory variables for the financial crisis must be identified, along with the underlying economic reasoning (Krugman, 1979; Obstfeld; 1986; Radelet and Sachs, 1998). Third, the appropriate choice of statistical/econometric methodology must be made or because that can alter the results.

A. Definitions of the Financial Crisis

The financial crisis can be classified into two broad categories, quantitative and qualitative. The quantitative category includes currency crises and sudden stops, where the crisis can be measured quantitatively. The qualitative category includes banking and debt crises, where the crisis can be measured using a judgmental definition (Reinhart and Rogoff, 2009a). The literature on EWMs has suggested several definitions of financial crises, including currency crises (Frankel and Rose, 1996; Milesi-Ferretti and Razin, 1998; Berg and Pattillo, 1999a, 1999b; Kaminsky and Reinhart, 1999), sudden stops (Calvo, 1998; Milesi-Ferretti and Razin, 2000), banking crises (Laeven and Valencia, 2012), and sovereign debt crises (Manasse and Roubini, 2009; Dawood et al., 2017). Sometimes crises are correlated with

each other and emerge as a twin crisis[9] (Kaminsky and Reinhart, 1999) or triple crisis (Reinhart and Rogoff, 2009b), which becomes difficult to define in a simple manner.

A1. Currency Crisis

A currency crisis is defined as a speculative attack on the foreign exchange value of a currency that either results in a sharp depreciation or forces the authorities to defend the currency by selling foreign exchange reserves or raising the domestic interest rate (Claessens and Kose, 2013). Frankel and Rose (1996) define a currency crisis as a normal depreciation of 25% or more that is at least 10% greater than the depreciation in the preceding year. Similarly, Milesi-Ferretti and Razin (1998) define a currency crisis as involving, in addition to a depreciation of 25% or more, at least a doubling of the rate of depreciation the previous year and a rate of depreciation below 40% that of the previous year, to avoid capturing the large exchange rate fluctuations associated with periods of high inflation. In this context, Kaminsky and Reinhart (1999) use an index of exchange rate pressure[10] to measure currency crises. Examples of currency crises include the breakdown of the Bretton Woods system in 1971–1973, the crisis of the British pound in 1976, the breakdown of the European exchange rate mechanism in 1992–1993, the Latin American tequila crisis following Mexico's peso devaluation in 1994–1995, the East Asian financial crisis in 1997–1998, and the GFC.

A2. Sudden Stops

A financial crisis characterized by sudden stops is due to disruptions in the supply of external financing. This concept of sudden stops was first proposed by Calvo (1998) and is defined as a large and unexpected halt in the financing of the current account deficit, triggered by an systemic external event, such as a generalized increase in sovereign spreads throughout emerging markets. The author's argument is that economies experiencing large current account deficits are potentially exposed to large and unexpected stops in the financing of the current account, or sudden stops. Calvo (1998) and Calvo and Reinhart (2000) identify the sudden reversal of capital flows as a potential cause of a liquidity crisis. Sudden stops can be captured by a spike in emerging market bond index spreads. Examples of sudden stops can be traced back to crisis events such as the Mexican crisis of 1994 (the tequila effect), the East Asian financial crisis of 1997–1998, and the Russian crisis of 1998, where capital inflows ended with sudden stops and also resulted in capital outflow.

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[9] A twin crisis in year t is a banking crisis in year t combined with a currency crisis during the period $[t - 1, t + 1]$. For more details, see Kaminsky and Reinhart (1999).

[10] The index of exchange rate market pressure is a weighted average of exchange rate changes and reserve changes. A financial crisis can be identified as when the index exceeds a country-specific threshold level. The index takes into account exchange rate depreciation and reserve losses, with equal weighting to influence the index. See Eichengreen et al. (1995) for an overview.

A3. Banking Crisis

In a systemic banking crisis, actual or potential bank runs[11] and failures can induce banks to suspend the convertibility of their liabilities or compel the government to intervene to prevent this by extending liquidity and capital assistance on a large scale (Claessens and Kose, 2013). As a bank run starts, it generates its own momentum, leading to a self-fulfilling prophecy: as more people withdraw their deposits, the likelihood of default increases, which encourages further withdrawals. This can destabilize a bank and lead to its bankruptcy if it cannot liquidate assets quickly enough to cover its short-term liabilities, because a bank's investment or loan consists of long-term deposits, whereas liabilities consist of short-term deposits. When a bank run becomes complementary to bank run psychology,[12] it makes the situation more difficult for the banking sector. In a nonfundamental way, bank runs could arise because of the expectations of individual depositors (Diamond and Dybvig, 1983). On the other hand, Reinhart and Rogoff (2009a) date the beginning of banking crises by two types of events: first, bank runs that lead to the bank's closure and, second, the merger or takeover by the public sector of one or more financial institutions. The Ecuador banking crisis of 1998, the Russian crisis of 1998, and the UK rescue package of 2015 are a few examples of banking crises.

A4. Sovereign Debt Crisis

The inability or unwillingness to pay, that is, default, is the primary source of a debt crisis, which increases the probability of losing all the money that has been given to or invested in a country. In the absence of gunboat diplomacy,[13] lenders cannot seize collateral from another country, or at least from a sovereign, if it refuses to pay its debt obligations. In the absence of an enforcement mechanism—that is, the analog of domestic bankruptcy, economic reasons, and the absence of legal arguments and so on—a debt crisis is a matter of great concern (Claessens and Kose, 2013). However, Kletzer and Wright (2000) argue that a country defaults when the opportunity cost of not being able to borrow again is low and the terms of trade are good and are expected to remain so. Countries default in bad times to smooth consumption, but few countries are able to escape default on domestic debt, with often adverse economic consequences. An empirical study on debt intolerance and serial default by Reinhart and Rogoff (2009b) suggests that safe debt thresholds hinge on country-specific factors, such as a country's record of default and inflation; when the external debt level of an emerging country is above

[11] Bank runs arise because of panic, rather than a bank's absolute insolvency. A run occurs when a large number of customers withdraw their deposits because they believe the bank is or could become insolvent (Simorangkir, 2006, 2011; Anwar and Ali, 2018).

[12] The bank run psychology is associated with bank runs, where the depositors are not willing to be the last person to withdraw money from the bank if they perceive vulnerability in the banking sector and the bank can default any time. This is more of a psychological than an economic phenomenon. equal weighting to influence the index. See Eichengreen et al. (1995) for an overview.

[13] Forcing a debtor to pay back a loan using threats about the consequences of or creating the circumstances for war is a bureaucratic political decision.

30–35% of the gross national product, the likelihood of an external debt crisis rises substantially. Examples of sovereign debt crises are the Brazilian crisis of 1991, Argentina's default of 2001, and Greece in 2015.

Currency crises have a close association with financial crises and are often associated with banking crises. The joint occurrence of a currency and a banking crisis together is called a twin crisis (Kaminsky and Reinhart, 1999), and if the twin crisis occurs together with a sovereign debt crisis, it becomes a triple crisis. Examples of twin crises include the crises in Thailand, Indonesia, Malaysia, and Korea from 1997 to 1998, and the GFC comprised a triple event.

In the presence of multiple types of financial crisis, we use the broader term *financial crisis* in this paper because our objective is to frame an agenda for EWMs, with a focus on improving their effectiveness. The use of any different term will limit the concept of EWMs to a specific type of crisis. The use of the term *financial crisis* is in line with the occurrence of multiple financial events and the interlinkages among various financial events.

B. Potential Candidates for Explaining Financial Crisis: The Search for Regressors

The identification of explanatory variables for financial crises is the second step of EWM construction. The factors that determine a financial crisis can be derived theoretically, empirically, or both. Theoretical models suggest three generations of financial crisis models for the fundamental explanation of crises, while the empirical literature provides various variables related to financial crises.

B1. First-generation Crisis Model

The first theoretical model associated with financial crisis, popularly known as the first-generation crisis model, is that of Krugman (1979). The author explains that the government's inconsistent policies, such as financing the budget deficit by printing excessive money under a fixed exchange rate system, will gradually lead to low levels of international reserve holdings and a currency crisis. Overall, this model identifies weak fundamentals, such as budget and trade deficits, and uses the appreciation of the real exchange rate as the primary indicator of first-generation speculative attacks. Flood and Garber (1984) augment Krugman's model by generating a distribution of the size and timing of the speculative attack, broadly known as the KFG model in the crisis literature. The first empirical study using the KFG model is that of Blanco and Garber (1986), who analyze the currency devaluations in Mexico in 1976 and 1981–1982. The authors find that a speculative attack induces the policy authority to implement a preemptive and state-dependent currency devaluation to help mitigate reserve losses. Similarly, a higher trade deficit signals a crisis, since it leads to currency depreciation and renders the current account deficit unsustainable (Roubini and Wachtel, 1998) and subject to greater vulnerability (Bucevska, 2011). Following the first-generation crisis model, Kaminsky and Reinhart (1999) show that growth rates in the money supply and credit that exceed certain thresholds increase the likelihood of a banking crisis. Similarly, Goldstein et al. (2000) find an appreciation of the real

exchange rate, a decline in equity prices, a drop in exports, and a high ratio of broad money to international reserves to be major determinants of financial crisis.

The first-generation model failed to determine the cause of the European exchange rate mechanism crisis. In Europe, the fundamentals were quite healthy and showed no signs of weakness, but the crisis still occurred. As a result, a new generation of crisis model evolved.

B2. Second-generation Crisis Model

After the failure of the first-generation model, a second-generation crisis model was proposed by Obstfeld (1986, 1996) that implies that a crisis can occur even given strong fundamentals. The occurrence of a crisis ultimately depends on the self-fulfilling prophecy that investors will attack the currency if they expect others will do the same. Accordingly, doubts about whether the government is willing to maintain its exchange rate target can lead to multiple equilibria, and a speculative currency attack can take place and succeed even if the current policy is consistent with the exchange rate commitment. Policies implemented to maintain a particular exchange rate level, such as those increasing domestic interest rates, can also raise costs by dampening economic activity or increasing bank funding costs. The main innovation of the second-generation model consists of identifying the role that the expectations of economic agents could play in precipitating currency crises. In the empirical literature, Flood et al. (1996) show how to recast the KFG model to account for interest rate pegging, whereas Chang and Velaso (2000) argue that the government's guarantee of shifts in expected arbitrage[14] has led to financial crisis.

The second-generation crisis model failed to explain the East-Asian financial crisis, cause by balance sheet deterioration and capital account liberalization in the presence of a weak financial system. Finally, a third-generation crisis model evolved to explain the nature of the financial events experienced by East Asian economies.

B3. Third-generation Crisis Model

In the wake of the 1997–1998 East Asian financial crisis, the emergence of the third-generation crisis model highlights how financial liberalization and government guarantees of private sector liabilities lead to moral hazard[15] and unsustainable fiscal deficits, which become the leading factors of a financial crisis. This model explores how rapid balance sheet deteriorations associated with fluctuations in asset prices, including exchange rates, can trigger currency crises (Radelet and Sachs, 1998). McKinnon and Pill (1996) argue that capital flows in the financial liberalization of an unregulated banking sector can cause a financial crisis. When a country opens its capital account, it becomes an important receiver of foreign capital in the initial period. If the domestic financial system is not healthy enough to

[14] Arbitrage is the process of buying and selling the same product in different markets to reap the benefits from the price differential.

[15] Moral hazard is a phenomenon wherein borrowers engage in risky behavior, knowing that someone else will pay for their mistakes.

absorb it, this will create a problem such as overborrowing syndrome[16] (McKinnon and Pill, 1996). The details of the explanatory variables for all three generations of crisis models are reported in Table 2.

Table 2.
Explanatory Variables of Financial Crises

This table presents details of studies on the explanatory variables of financial crises, identified by different crisis generation models and supporters of crisis generation models.

Crisis-generation model	Supporters	Explanatory variables
First-generation crisis model	Krugman (1979)	Fixed exchange rate
	Blanco and Garber (1986)	Fiscal deficit
	Roubini and Watchtel (1998)	Inflation
		Trade deficit
		Declining foreign reserves
		Growth rate of money
		Credit to reserve ratio
Second-generation crisis model	Obstfeld (1986)	Including the explanatory variables of the first-generation model,
	Obstfeld (1996)	Govt. guarantees for arbitrage expectation shift
	Flood et al. (1996)	Interest rate pegging
	Chang and Velaso (2000)	
Third-generation crisis model	McKinnon and Pill (1996)	Including explanatory variables of the above two models,
	Radelet and Sachs (1998)	Capital account liberalization
		Growth in M2 multiplier
		Growth in credit/GDP
		Ratio of domestic bank loan to GDP
		Liabilities/GDP ratio
		Fall in bank deposits/GDP ratio
		Contagion dummy
		Short-term capital flows/GDP

In the presence of a variety of explanatory variables in line with the crisis generation models, EWMs are set to provide the predictive indicators of a financial crisis, using various statistical/econometric methodologies.

[16] The premature opening of a capital account will lead to a sudden increase in capital inflow. The premature opening of a capital account in a weak financial system of low institutional quality can lead to the outflow of foreign capital as well as domestic capital. This situation is called the overborrowing syndrome (McKinnon and Pill, 1996).

C. Statistical/ Econometric Methodologies

The third stage of EWMs consists of statistical/econometric analyses for a given crisis definition and set of explanatory variables. Three conventional empirical approaches are associated with EWMs: the indicator approach (Kaminsky and Reinhart, 1999) and/or signaling approach (Kaminsky et al., 1998) and the limited dependent variable probit/logit model (Eichengreen et al.,1995; Frankel and Rose, 1996). Other categories of approaches include the use of innovative techniques for the identification and explanation of financial crisis, such as Markov switching models (Cerra and Saxena, 2002; Martinez, 2002; Abiad, 2003), artificial neural networks (ANNs) and genetic algorithms (Nag and Mitra, 1999; Apoteker and Barthelemy, 2000), binary recursive trees (Ghosh and Ghosh, 2003; Frankel and Wei, 2005), and unit root testing (Virtanen et al., 2016).

C1. Indicator and Signal Approaches

The first category of approaches is nonparametric and includes the indicator approach and/or signal approach, introduced by Kaminsky et al. (1998) and augmented by Bruggermann and Linne (1999) and Edison (2003). Given a number of leading indicators of a crisis, these approaches determine the threshold level beyond which an event is classified as a crisis. The approaches face serious difficulties, because it is not possible to determine the significance of the indicators directly, since thresholds are determined in sample. Determination of the optimal threshold level involves striking a balance between failing to predict a crisis that actually occurs (type I error) and predicting a crisis that does not actually occur (type II error). Accordingly, if the threshold is set too low, then the indicators will catch all the crises but will produce many false signals (noise). Conversely, if the threshold is too high, the indicator will never issue a false alarm, but it will miss all the crises. Hence, for each variable, the optimal threshold is selected to optimize the signal-to-noise ratio. Another solution is to rank the usefulness of the indicators in declining order of their signal-to-noise ratios (more details are reported in Table 3). Further, the out-of-sample performance[17] of the signal approach has been tested by Berg and Patillo (1999a, 1999b), Bussiere and Mudler (2000), and Berg et al. (2005), who find it provides a moderate level of prediction of financial crises.

Although the signaling approach occupies a prominent place in warning about a signal, we still drop it because of a few shortcomings. First, when each variable is evaluated separately, it neglects interrelated sets of conditions. Second, it ignores potential correlations between different indicators. Third, this approach issues only binary signals, which are either that an indicator is above its threshold, denoting a signal, or below its threshold, denoting no signal of a potential crisis. Consequently, there is no measure of the strength of the signal that is potentially related to the extent to which it exceeds its threshold.

[17] Out-of-sample forecast performance is used to evaluate the forecasting performance of a statistical test and is generally considered more trustworthy than evidence based on in-sample performance, since in-sample performance can be sensitive to outliers and data mining.

Table 3.
Signal-to-noise Ratio Matrix

The table reports the noise-to-signal ratio matrix associated with the signal approach (Kaminsky et al., 1999). The cell named A indicates that a signal is considered accurate if a variable signal and a crisis occur in the following 24 months. On the other hand, the cell named B is said to be a false alarm if a variable signal and no crisis occurs in that time frame. Hence, a perfect indicator would only have entries in cells named A and D. In general, the noise-to-signal ratio for any indicator is traced by the number of entries:

[B (B+D)] / [A (A+C)]

It is the ratio of false signals to all possible bad signals divided by the ratio of good signals to all possible good signals. The extreme noisy indicator would have few entries in cells named A and D, and more in cells named B and C.

Description	A crisis occurs in the following 24 months	No crisis occurs in the following 24 months
Indicator issues a signal	A	B
The indicator does not issue a signal	C	D

C2. Logit and Probit Model

The second category of approaches, that is, linear regression or limited dependent variable estimation methods such as probit and logit techniques, are the most popular category in the literature. Eichengreen et al. (1995), Frankel and Rose (1996), and Sach et al. (1996) are among the first studies to have used these techniques to test the statistical significance of various indicators in determining the probability of a future financial crisis. Eichengreen et al. (1996) adopts a probit model to predict currency crises and finds that speculative attacks on a fixed exchange rate play a significant role in predicting the incidence of a currency crisis. Further, Demirguc-Kunt and Detragiache (1998) analyze factors associated with the emergence of systemic banking crises and find banking distress to be associated with low economic growth, high inflation, and high interest rates. Similarly, Joyce (2011), Frost and Tilburg (2014), Hamdi and Jlassi (2014), and Kulkarni and Kamaiah (2015) have used this method extensively to predict financial crises. Additionally, Berg and Pattillo (1999b) highlight the advantages of probability models to overcome the difficulties of a signal approach. First, they provide a framework for the separately testing of the statistical significance of individual explanatory variables. Second, they consider the correlation between the regressors and combine informative indicators into a single composite indicator of crisis. Third, their model allows for the estimation of the probability of a crisis. Fourth, it allows for the introduction of various functional forms between the binominal dependent variable and explanatory variables.

Although logit/probit models have been extensively used, they are still subject to shortcomings. First, the definition of financial crisis as a dummy variable leads to an ad hoc assumption when constructing the model. Second, this approach is subject to the loss of information. Third, single-step estimation can also lead to biased results.

C3. Markov Switching Approach

The Markov switching approach was pioneered by Jeanne and Masson (2000) and used by Cerra and Saxena (2002) to model contagion in the context of Indonesia

in 1997. Mariano et al. (2000) and Abiad (2002, 2003) were the first to use this approach in EWMs and introduced it as an alternative approach for predicting a currency crisis.

The Markov switching approach of Abiad (2003) applies time-varying probabilities in modeling a speculative attack, which allows the model to utilize information involved in exchange rate dynamics. Abiad highlights the advantages of this approach over previous ones, such as its avoidance of the many ad hoc assumptions required by previous models, as well as the loss of information caused by the transformation of variables into binary crisis dummy variables in the logit/probit model. First, Abiad's Markov switching approach can be derived directly from the second-generation crisis model. Second, the approach includes an endogenous crisis determination period rather than the dummy assigned by other models. Third, easily forecast and multistep crisis events can be calculated. Fourth, the inclusion of latent variables captures the exchange rate dynamics. Fifth, the approach determines the longevity of probable crisis period and does not require exclusion windows. Finally, the approach focuses on a set of reliable observable variables, multi-period forecasting horizons, and an empirical framework for analyzing the contagion effect of the crisis to improve short-term forecasts. The model's major weakness is its difficulty of creation. A powerful program is needed to run the algorithms, since they are not part of any econometric package. Further, this approach is highly computational, with difficulties in the case of no switching and failing to cooperate with more explanatory variables.

C4. Artificial Neural Networks and Genetic Algorithms

The ANN approach is capable of learning through a process of trial and error that can be approximated as a statistical estimation of model parameters. The use of neural network analysis in the context of EWMs is due to Nag and Mitra (1999), who constructed an early warning system for currency crises and compare its performance to the indicator approach using monthly data for Indonesia, Malaysia, and Thailand in 1980–1998. Similarly, Frank and Schmied (2004) suggest predicting speculative attacks by using the ANN approach and test the predictability of crises in Russia and Brazil. In addition, Apoteker and Barthelemy (2000) use a genetic algorithm to fend against sudden changes in economic indicators to improve the predictive capacity of the risk ratings of risk monitoring services in emerging economies.

The primary advantages associated with ANNs are their flexible specification and ability to capture complex interactions among variables. Nonetheless, disadvantages of the ANN approach include greater danger of overfitting, compared to other methodologies, the lack of coefficient estimation, and complicated interactions between the variables. Finally, it is difficult to identify potential indicators that are abnormal or the drivers of forecasting probabilities.

C5. Binary Recursive Trees and Unit Root Tests

Ghosh and Ghosh (2003) use a binary recursive tree to examine the role of structural factors, corporate financing structure, and macroeconomic variables in

causing a currency crisis for 40 industrialized and emerging countries from 1987 to 1999. The authors find that structural vulnerabilities played an important role in leading to a deep currency crisis and there were complex interactions between these structural vulnerabilities and macroeconomic imbalances. Although a binary recursive tree allows for interactions between the various explanatory variables, accounting for structural factors that do not change much, it will be difficult for it to generate a warning and it will thus have limited application in the real world. A binary recursive tree is similar to an ANN, in that it requires computational programming to identify the interlinkages between the structural vulnerability and macroeconomic variables.

In a different approach, Virtanen et al. (2016) use unit root–based EWMs for the ex ante prediction of financial crises for 15 European Union countries, combining early warning signals from multiple time series into a composite indicator. They find that unit root–based methods are successful at predicting financial crises, in both in-sample and out-of-sample estimations. Since the unit root tests of EWMs are computed using a set of parametric values such as window lags and numbers of lags, they are subject to determinative choices of these values and specification uncertainty.

In the presence of a variety of statistical/econometric methodologies of EWMs, it is difficult for academicians and policymakers to choose a suitable method for the empirical exercise. However, the choice of empirical method in handling EWMs depends only upon the researcher's perspective. The details of the statistical and empirical methodologies of EWMs are presented in Table 4.

Table 4.
Statistical/Econometric Methodologies of EWM

The table reports the various empirical methodologies used for the third stage of the early warning models. The table covers the details about model types, authors, methodology, and limitations of the various methodologies used for the construction of early warning models. The * denotes the founder of the empirical methodologies.

Type	Authors	Methodology	Limitations
Indicator and Signal Approach	Kaminsky-Linzondo-Reinhart (1998)*	Threshold level of an indicator.	- Neglect interrelations.
	Bruggermann and Linne (1999)		- It's a warning, no signal about crisis appearance.
	Edison (2003)		
	Eichengreen et al. (1995)*	Dummy for financial crisis.	
Logit and Probit Model	Frankel and Rose (1996)	Statistical testing and statistical significance of individual variables.	- Ad-hoc assumption
	Sach et al. (1996)		- Loss of information
	Eichengreen et al. (1996)		- Single step estimation
	Demirguc-Kunt and Detragiache (1998)	Estimation of probability of occurring a financial crisis.	

Table 4.
Statistical/Econometric Methodologies of EWM (Continued)

Type	Authors	Methodology	Limitations
Markov-Switching Approach	Mariano et al. (2000)* Abiad (2002) Cerra and Saxena (2002) Abiad (2003)	Allows for time-varying probabilities. Multi-stage estimation. Endogenous determination of crisis period. Inclusion of latent variable.	- Difficulty in model creation. - Highly computation and need strong programing language. - Not a part of econometric packages. - Fails to cooperate more explanatory variable.
Artificial Neural Network (ANN) and Genetic Algorithms	Nag and Mitra (1999)* Apoteker and Barthelemy (2000) Frank and Schmied (2004)	Neural network predictability. Genetic algorithms.	- Danger of overfitting. - No coefficient estimation. - Difficulty in identifying indicators. - Complicated interaction.
Binary Recursive Tree	Ghosh and Ghosh (2003)*	Decision-theoretic classification technique.	- Difficulty in generating warnings.
Unit-Root Test Based	Virtanen et al. (2016)*	Convert multiple time series into composite indicators. Window lags	- Exposed to deterministic choice. - Specification uncertainty.

EWMs evolved over time, given various definitions, explanatory variables, and statistical/econometric methodologies. Starting with the definition of empirical methodologies, EWMs needed to be augmented. The failure of the first-generation crisis model to explain the European exchange rate mechanism crisis resulted in the second-generation model, and the failure of the second-generation model to explain the East Asian financial crisis resulted in the evolution of the third-generation crisis model. Such evolution has not only improved the predictive power of EWMs, but also supported the further need for EWMs, even after an event. The failure of EWMs to predict national or regional financial events has been questioned before as well. Therefore, different crisis generation models have evolved to further improve their predictive power. In the context of GFC, the complex nature of the occurrence and quick transmission of shocks has led to the failure of EWMs worldwide. Finally, this is not the time to question the general effectiveness of EWMs; rather, the effectiveness of existing models should be improved by eradicating the lacunae associated with them. In this paper, we provide a research agenda to enhance the effectiveness of existing EWMs.

III. SEEDS FOR THE BIRTH OF A NEW AGENDA

A1. Motivation from the Failure of Identification

EWMs to analyze and predict leading indicators or the accurate timing of the occurrence of a crises are essential for policy formulation. The failure of EWMs to identify the GFC (Davis and Karim, 2008; Rose and Spiegel, 2009, 2010, 2012; Christofides et al., 2016) has raised questions about their efficiency within their operational framework. However, the solution is not to abandon the existing EWMs, but, rather, to eradicate the weaknesses associated with them, enhancing their efficiency. Further, the accuracy of early models cannot be underestimated, since they accurately predicted the occurrence of a financial crisis in the case of the Chilean crisis in 1982, Brazil in 1994, the Korean crisis in 1997–1998, the Argentinean crisis in 2001, and the Turkish case in 2001.

Stagewise specifications in the EWMs should be carried out with caution, since the stage's accuracy will determine the final accuracy. Given the dynamic nature of financial crises, it is harder to define a financial crisis and identify the explanatory variables in comparison to choosing a method of statistical/econometric analysis to associate with the models. A more accurate specification of the operating framework of EWMs in the first two stages will lead to accuracy depending on the choice of statistical/econometric methodologies. The failure of EWMs to at least notice the GFC (Rose and Spiegel, 2009, 2012) clearly indicates their failure at every stage of the operating framework. Finally, to augment the existing EWMs, we need to augment all the stages according to the dynamic nature of the financial crisis.

A2. Dynamic Nature of Crisis Models

The evolution from past crises, indicating changes in the leading factors causing the financial crisis over various periods (Eichengreen, 2003; Reinhart and Rogoff, 2009a). Thus, the formation of policy to control financial crises based on the leading indicators of an earlier form of financial crisis might not result in efficient policy actions (Reinhart and Rogoff, 2008). Further, the efficiency of policy tools in controlling financial crises depends entirely on how accurately the financial crisis is defined and the nature of the occurrence identified.

The next question that arises is whether the current measurement of the financial crisis is efficient in its identification procedure or whether any augmentation is needed to enhance the performance of such measurements. The financial crisis in the late 1970s in the Latin American countries emphasizes the role of weak macroeconomic fundamentals, whereas the case of European countries in the 1980s emphasizes multiple equilibria and the self-fulfilling prophecies of investors as the leading indicators (Eichengreen, 2003). The mismanagement of capital flows, moral hazard, and private sector liabilities caused the East Asian financial crisis in 1997–1998 (Radelet and Sachs, 2000). On the other hand, the GFC, was caused by subprime mortgage lending and housing bubbles. In this context, Rose and Spiegel (2009) identified three causes of the predictive failure of EWMs. First, the different causes of the 2008 crisis across countries could be the leading factor of the financial crisis, and, second, the GFC could be the result of a global shock, rather than unregulated country-specific financial and macroeconomic

fundamentals. Finally, the shock originated in the United States but transmitted across its borders.

The changing nature of financial crises must be considered to accurately identify upcoming financial crises. In this regard, the crisis generation models should be dynamic to capture the dynamic nature of crises. Additionally, there is no need to justify why crisis generation models should evolve over time.

A3. The Subprime Lending Crisis: A Burning Example of this Time Being Different

In the context of the subprime lending/mortgage crisis in 2007–2008, Shiller (2005) notes the inability of long-term domestic economic factors to explain the rise in housing prices since 1998, where the Case–Shiller Home Price Index[18] rose to 67% from 1998-2006, in comparison to a normal increase from 1890 to 1998, but with no such change in the real GDP, population, long-term interest rate, and so forth. This rise in housing prices looks unsustainable and ultimately turns into a global financial crisis. Shiller emphasizes the role of psychological bias and social processes such as overoptimism, overconfidence, contagion, and herd behavior in framing the irrational exuberance[19] that led to the crisis in the presence of media stories of a new era, where market participants and policymakers believed in an indefinite rise in housing prices in the future. Similarly, Connor et al. (2010) identifies irrational exuberance and related asset price bubbles as a crucial factor responsible for the banking crises in the United States and Ireland. On the other hand, Rajan (2010), in his book *Fault Lines,* explains that the low- and middle-income groups reduced their savings and increased their debt since income inequality started shooting up in the United States. This led to not only a temporary increment in private consumption and employment but also the creation of a credit bubble. The downturn in the housing market led to the seed of the subprime mortgage crisis in 2007, and the rest was fostered by the expansion of debt-financed private demand, turning this event into the global recession of 2008. Further, Rajan (2005) blames misguided government policies in promoting credit expansion to households in the absence of adequate collateral.

This supply-side argument of the so-called Rajan (2010) hypothesis and the psychological-social arguments of Shiller (2005) in the context of irrational exuberance explain more asset bubbles in the United States. This irrational exuberance has increased the need for homes that consumers perceive as being costly in the future, whereas the credit expansion by the government through overindebtedness has led to the easy availability of money, which has led to further raising housing prices. At the same time, different financial innovations such as shadow banking,[20] securitization, and the entry of new financial intermediaries have increased the likelihood of turmoil induced by the finance sector.

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[18] The Case–Shiller Home Price Index is the index of housing prices in the United States. Its construction is due to Karl Case and Robert Shiller, who measured the housing pricing boom in Boston and tried to describe similar trends across the United States.

[19] Irrational exuberance describes the situation in which investors' enthusiasm becomes the reason for raising asset prices that are not supported by fundamentals. See Shiller (2005) for more details.

[20] A shadow banking system is the term used for the system of a group of non-bank financial intermediaries that facilitates services similar to those of a banking system, but without being subject to banking regulation.

Allen and Moessner (2011) argue that the GFC was transmitted to various countries through three channels: the shadow banking system, collateral squeeze[21], and carry trade unwinding.[22] The GFC differs from the global recession of 1929–1931 because the liquidity commitment of commercial banks was a serious problem during the GFC, whereas the global recession in 1929 witnessed a restriction in channeling the liquidity created by the gold standard period. The GFC was a fiery example of this time being different, weakening the crisis generation models' identification of the leading factors for the financial crisis. The GFC was a repetition of this syndrome (Reinhart and Rogoff, 2008) and proof of why an early warning system should be dynamic (Candelon et al., 2014). This situation not demonstrates the dynamic occurrence of a financial event, but also highlights the need for a new generation of models that can capture the dynamic nature of financial crises (Goldstein and Razin, 2013).

IV. RESEARCH AGENDA AND FUTURE DIRECTIONS

We now suggest a future research agenda, on the following grounds.

A1. The Need for a Hybrid Measure of Financial Crisis

The various typologies of financial crisis have themselves created a puzzle in the way to define what a financial crisis is all about. A currency crisis is defined as a depreciation of currency of 25% or a depreciation of 15% with 10% inflation, whereas a banking crisis is identified by bank runs and liquidity crash. A sovereign debt crisis is all about the repayment of debt and defaults, whereas sudden stops involve the halt of capital flows, specifically in relation to emerging countries that finance their current account deficit using foreign capital. Differently, a balance of payment crisis is likely to occur in conjunction with a currency crisis and not considered to be a single type of financial crisis. The joint occurrence of a currency crisis and a banking crisis, that is, a twin crisis, will make a country's economic situation worse than in a single-crisis case. Finally, the global recession of 2008 has its own significance in making financial crises costlier in the form of a triple crisis.

The accuracy of measuring financial crisis is a challenging task in the presence of various financial crisis typologies. The choice of financial crisis measurement is not difficult in the case of a single financial crisis event (Claessens and Kose, 2013). Conversely, the joint occurrence of financial crises, as in twin and triple crises, is difficult to measure when constructing EWMs, since the mixture of

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[21] A collateral squeeze is a process aimed at reducing counterparty risk where, if the borrower defaults, the collateral will be seized and paid to the creditor. It is part of the regulation of financial systems, where the loans must meet criteria for eligibility, that is, the level of collateral is decided based on property valuation.

[22] For example, since US and European interest rates are low, Japanese investors started to sell their dollar and euro investments and return their money to Japan. Yen carry trade becomes unprofitable, and investors can lose substantial amounts if the yen rises against the dollar or euro. Consequently, with a rising yen, people sell their foreign investments and end their carry trades. This increases demand for the yen even more, causing a further rise in the yen. This is the scenario of carry trade unwinding.

quantitative and qualitative measurements of financial crisis might not be accurate and can lead to the model's failure (Kaminsky and Reinhart, 1999). In this context, with the presence of quantitative and qualitative measures of financial crisis, the construction of hybrid measures based on a certain weighting will be more productive in forecasting the future occurrence of twin or triple crises or the probability of leading to another form of financial crisis.

A2. Identifying Potential Explanatory Variables for the Financial Crisis: The Need for a Fourth-generation Crisis Model

The failure to identify the leading factors of crisis emphasizes the need for a fourth-generation crisis model to explain the leading factors of a new financial crisis (Goldstein and Razin, 2013). Identification of the dynamic nature of financial crises and inclusion of the leading factors become a difficult task, since none of the three crisis generation models are able to explain the leading factors that caused the GFC (Candelon et al., 2012, 2014). The GFC was a distinct event in the history of financial crises, not only in terms of depth and duration but also in terms of its leading factors. Economic factors alone were not able to explain the hike in housing prices after 1998, and psychosocial factors fostered soaring inequality (Shiller, 2005), which finally turned into the global financial crisis (Imbs, 2010). This event was triggered by misguided government policies and an unregulated financial system (Rajan, 2005, 2010). The crisis was difficult to foresee because of the distinct nature of its occurrence, which certainly requires additional narrative in terms of factors causing the financial crisis and identification of the links between psychosocial factors and macroeconomic crises. The various links between real estate prices, credit expansion through government policies, and consumer expectation–tracking theories of consumption require a clear theoretical framework to explain the occurrence of the housing bubble. Thus, capturing the dynamic nature of the financial crisis requires the fourth-generation crisis model to accurately identify the financial crisis, a challenging task for both academicians and policymakers. Specifically, the crisis generation models are related to the currency crisis; however, the explanatory variables follow a similar pattern in explaining various other forms of crisis. Further, the occurrence of twin and triple crises affirms that a particular explanatory variable can have predictive power for various financial crises (Kaminsky and Reinhart, 1999). We therefore suggest the need for a fourth-generation crisis model.

A3. Contagion/interconnectedness as an Explanatory Variable

The word *contagion* generally denotes the spread of market disturbances from one country to another and is a process observed through comovements in exchange rates, stock prices, sovereign spreads, and capital flows, and so forth. The GFC has amplified the importance of contagion, originating from the collapse of Lehman Brothers and spreading to most countries (Imbs, 2010). In line with the failure of EWMs to foresee the financial crisis of 2007–2008, financial contagion has its own significance in predicting the financial crisis. Furthermore, Babecky et al. (2011,

2012) emphasize the increasing role of global factors and interconnectedness among markets as leading risk factors in today's integrated world.

Examples of the channel of transmission of shocks include the role of insurance (Allen and Gale, 1998), the wake-up call hypothesis (Goldstein, 1998), the role of common creditors (Pritsker, 2013), and bank run psychology (Summers, 2000). Kaminsky et al. (2003) also note the role of information cascades,[23] causing global spillover. Thus, identifying the nature of spillover is essential in the appropriate design of both crisis mitigation and crisis management responses (Claessens and Kose, 2013).

The role of contagion in transmitting financial crises while increasing trade and financial integration has been identified in the literature in various ways. Eichengreen et al. (1996) find that the contagion effect remains significant, whereas Fratzscher (1998) supports the contagious nature of the currency crisis with a comparison of the Latin American crisis with the East Asian crisis. Similarly, Cerra and Saxena (2002) and Mendoza and Quadrini (2010) confirm the significant role of contagion in transmitting shocks. Similarly, Hermansen and Rohn (2015) emphasize the role of global risk indicators outperforming domestic indicators in terms of highlighting the role of international development. Finally, the spread of the crisis to other countries indicates that financial integration plays an important role in transmitting financial crises, since one country's vulnerable financial market can have an impact on other countries through their interlinkages in either macroeconomic transmission or the shock transmission channel (Bordo and Helbling, 2003). Additionally, Minoiu et al. (2015) examine the connectedness of financial linkages in predicting banking crises. Connectedness plays an important role in the transmission of crisis, because the failure of one economic agent leads to direct failure (insolvency) and indirect failure (cross-border panic) as well. In line with Peltonen et al. (2015), we argue that the inclusion of quantitative contagion indexes can enhance the efficiency of existing EWMs. Although the role of financial contagion has been highlighted in the literature, there is still ample room to fill the gap associated with the weaknesses of existing EWMs. Thus, the inclusion of contagion indicators can fill the lacuna of existing EWMs and proves to be a crucial tool in enhancing the efficiency of EWMs, instead of a dummy index of contagion subject to post-crisis bias (Bussiere and Fratzscher, 2006).

Table 5 provides the five definitions and measurements highlighted by Pericoli and Sbracia (2003). The EWMs' inclusion of these quantitative contagion indicators could enhance their efficiency.

[23] An information cascade is a situation in which a person makes a decision/choice based on the observations or choices of others, without knowing the reality and circulates the information, assuming it is true.

Table 5.
Definition and Measurements of Contagion

The table covers the five definitions and measurements of contagion as highlighted by Pericoli and Sbracia (2003).

No.	Definition	Measurement
1	When a significant increase in the probability of a crisis in one country, conditional on a crisis occurring in another country.	Exchange rate pressure index
2	When the volatility of asset prices spillover from the crisis country to other countries.	Multivariate GARCH model
3	When cross-country co-movements of asset prices cannot be explained by fundamentals.	Jumps in multiple equilibria
4	When a significant increase in co-movements of prices and quantities across markets, conditional on a crisis occurring in one market or group markets.	Markov-Switching approach Correlation
5	When the transmission channel intensifies or, more generally, changes after a shock in one market.	Data generating process

V. CONCLUSION

In this paper, we propose a new agenda for augmenting existing EWMs that could capture the dynamic nature of financial crises. We propose an agenda based on three aspects: measurement of a hybrid index of the financial crisis, the need for a fourth-generation crisis model, and the role of contagion/interconnectedness in the model. This agenda could be helpful in the construction of EWMs to predict the occurrence of a financial event. Finally, there is an essential need to augment EWMs to fend off a financial crisis.

This paper's proposed agenda for the construction of EWMs certainly does not constitute final steps toward a comprehensive EWM of financial crises. Rather, it suggests the construction of an EWM by eradicating the various lacunae associated with the existing models that can outline the difficulties. By suggesting a new agenda for the construction of EWMs to resolve these difficulties, this paper proposes various steps toward augmenting the existing EWMs, which could become more powerful tools in predicting financial crises. Future research could focus on the construction and empirical examination of this new agenda.

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