sciendo

UDK: 330.14.01:338124.4(73)
DOI: 10.2478/jcbtp-2022-0017

Journal of Central Banking Theory and Practice, 2022, 2, pp. 145-164
Received: 19 October 2020; accepted: 01 June 2021

Diptes C. P. Bhimjee *

** ISCTE – University Institute of Lisbon, Lisbon, Portugal*

E-mail: Diptes_Bhimjee@iscte-iul.pt

Adaptive Early Warning Systems: An Axiomatic Approach[1]

Abstract: The U.S. Subprime Crisis and the subsequent Great Recession have highlighted a renewed interest in the proper design and implementation of Early Warning Systems (E.W.S.), in order to help deter the onset of subsequent extreme financial events, through the implementation of adequate crisis detection mechanisms. The present article describes the Adaptive Early Warning Systems (A.E.W.S.) axiomatic approach, as a natural operational extension to E.W.S. testing. This novel protocol upholds the operational dimension of implementing an efficient holistic crisis detection mechanism, a domain which has been hitherto overlooked by the E.W.S. literature. The paper first describes the major axiomatic principles sustaining the A.E.W.S. protocol, which seek to establish universal principles in support of the said protocol. Second, the article also describes a basic universal template for an A.E.W.S. surveillance platform, which duly describes how multiple testing procedures can be integrated into a single crisis detection framework, while targeting multiple segments of the financial markets (such as the conventional and non-conventional segments of the financial markets). Third, the paper also describes the major advantages and disadvantages associated with the implementation of this novel protocol. It is hoped that the effective implementation of the A.E.W.S. protocol as a novel operational framework in the global macroprudential toolkit might help deter the onset of future extreme financial events, by enabling a greater cohesiveness in E.W.S.-related central banking procedures, as well as promoting a greater international central banking cooperation prior to and during financial distress episodes.

[1] The opinions expressed herein are those of the author and do not necessarily reflect those of his employers.

Keywords: Adaptive Early Warning Systems, Forecasting, Financial Crises, Central Banks, Financial Stability, Macroprudential Regulation, Monetary Policy.

JEL classifications: G1, G01, E32, E58.

1. Introduction

The U.S. Subprime Crisis constituted a disruptive and extreme financial event that profoundly impacted the performance of the U.S. financial industry and the U.S. economy as a whole. Moreoever, the U.S. Subprime Crisis lay at the origin of the Global Financial Crisis[2] (hereinafter GFC), through the "deflating of a speculative bubble in the housing market that began in the United States in 2006 and has now cascaded across many other countries in the form of financial failures and a global credit crunch" (Shiller, 2008). Powerful national and international financial contagion processes facilitated the crisis transmission process to a global scale, namely through, for example, the country banking industries of advanced economies and emerging market economies (Bhimjee, Ramos, & Dias, 2016). In more extreme circumstances, severe financial contagion processes might even end up negatively impacting the complex financial intermediation-economic growth nexus, through sub-optimal credit expansion (Asanović, 2020). The impact of these extreme events is particularly relevant for the design and implementation of monetary policy, whenever potential governance issues related to bank-based systems might lead to greater financial and macroeconomic instability through highly complex inter-linkages (Singh & Sarma, 2020), further prompting greater Central Bank oversight[3].

Conservative estimates related to the Subprime Crisis of 2007-2009 point to an interval of projected economic and financial losses equivalent to approximately USD$6 trillion to USD$14 trillion, which translates into approximately USD$50,000 to USD$120,000-worth of financial losses for every U.S. household

---

[2] The present article draws on a fundamental distinction between the Subprime crisis (as a localized U.S. event) and the ensuing Global Financial Crisis or Great Recession (as a truly global financial event associated with severe international financial contagion processes).

[3] Furthermore, taking into consideration the potential widespread adoption of new quantitative techniques in risk management areas - such as Artificial Intelligence and Machine Learning techniques - by financial sector participants, the corresponding positive impact on these risk management areas (e.g., credit, market, liquidity, and operational risk) might depend on the efficient solutions to the prevailing open questions and issues presently surrounding the application/use of these techniques within the financial industry (Milojević & Redžepagić, 2021). Accordingly, financial industry innovation further justifies central banks' adoption of more proactive Early Warning Systems.

(Atkinson, Luttrell, & Rosenblum, 2013). The estimated loss of potential output for the U.S.A. in 2015 is equivalent to 7.7 percent of its economic output, and further similar estimates have also been advanced and confirmed by other credible sources[4].

The U.S. Subprime Crisis (and the subsequent GFC) has thus highlighted the need to reinforce financial stability as an important monetary policy goal, in complement to the conventional price stability goal, enabling both goals to co-exist simultaneously (Shoenmaker & Wierts, 2016); accordingly, the advancement of the financial stability goal has also prompted the implementation of a more recent set of macroprudential instruments in support of the said goal (Claessens, 2015).

Thus, from a monetary policy perspective, one of the more recent monetary policy instruments in support of the financial stability goal addresses the design and implementation of effective Early Warning Systems (hereinafter E.W.S.). Building an effective E.W.S. framework has thus become the first line of defence for the central banking community seeking to implement economic policies in contravention of extreme financial events (such as the U.S. Subprime Crisis). E.W.S. systems thus constitute a fundamental operational tool associated with the said macroprudential toolkit, in order to provide widened pre-emptive support to the above-mentioned financial stability goal.

As a preventive macroprudential policy tool, E.W.S. frameworks allow central banks to timingly detect and potentially countervail the onset of future episodes of devastating economic and financial impact, ranging from minor financial stress episodes to full-blown systemic events, (such as the Subprime Crisis). E.W.S. empirical frameworks are thus able to alert central banks to the imminence of impending financial distress events that might subsequently evolve into protracted financial crises, with devastating spillovers to real economies. For example, where the prediction of financial episodes is concerned, E.W.S. frameworks thus potentially elicit a more proactive regulatory response from monetary authorities to an impending potential shock of financial extraction (i.e. before an extreme financial event might occur).

This paper fills an important literature gap by providing a holistic view on the operational implementation of E.W.S. frameworks and giving a comprehensive

[4] For example, Ball (2014) observes that the average loss in potential output for this crisis for a set of 23 O.E.C.D. economies is approximately 8.4%. For a classical primer on the anatomy and impact of earlier financial crises, please consult Kindleberger & Aliber (2005).

interpretation of previous E.W.S.-related literature, which has been typically concerned with advancing a more focused set of state-of-the-art methodologies and datasets that contribute to the design of increasingly more refined (i.e., specialised) E.W.S. detection systems. That is, the main goal here is to provide a more holistic perspective on how E.W.S. frameworks might be generically built and integrated, within a common operational framework that captures the distinctive dimensions of financial crises' detection processes, while also taking into consideration the literature's evolution towards more specialised methodologies and datasets.

The paper is structured as follows: section 2 briefly reviews the main seminal literature associated with the development of E.W.S. systems; section 3 essentially describes the motivation for the implementation of the protocol herein proposed - the Adaptive Early Warning Systems or A.E.W.S. framework, which encompasses multiple dimensions of crisis detection; while section 4 presents the axiomatic approach underlying the A.E.W.S framework, describing a basic axiomatic template, as well as pointing out the potential advantages and disadvantages associated with the A.E.W.S.; section 5 concludes. The A.E.W.S. framework proposed herein is axiomatic in nature in order to be adapted to the wide range of idiosyncratic situations where it might be applicable by the central banking community.

When taking into consideration: (i) the massive financial and economic fallout associated with the latest global systemic event; and (ii) the real economy impact associated with the 'sudden stop' related to the COVID-19 extreme event, it is hoped that the this paper might shed some light and contribute to a more wholesome understanding of the more operational aspects of implementing a more flexible, but holistic approach to the timely detection of both real economy and financial distress episodes, as per the A.E.W.S. protocol herein proposed. This protocol should also be quite useful in all types of economic/financial extreme events.

2. A brief literature review: major historical trends within E.W.S. - related research

The seminal literature on E.W.S. has evolved quite considerably in order to encompass increasingly sophisticated approaches to the prediction of extreme financial episodes (a brief historical review is scrutinised herein).

Kaminsky, Lizondo, & Reinhart (1998) first introduced the 'signals' approach whereby the imminence of financial distress episodes is foretold by a simple statistical methodology that aptly monitors the performance of multiple economic and financial variables subject to financial stress. Moreover, Kaminsky (1999) and Goldstein, Kaminsky, & Reinhart (2000) expand the 'signals' approach in order to include the scrutiny of both banking and currency crises. In the wake of the U.S. Subprime Crisis, Davis & Karim (2008) aptly expand the EWS framework to the detection of banking crises through the deployment of more evolved econometric approaches; more recently, Sarlin (2013) and Alessi & Detken (2014) discuss the usefulness of policymakers' loss functions to E.W.S., thus narrowing down the debate about the proper design of E.W.S. frameworks around forecasting accuracy. Lastly, and since Kaminsky, Lizondo, & Reinhart (1998) was introduced, multiple authors have expanded E.W.S. frameworks for the central banking community, namely through the development of new methodologies (e.g., Alessi & Detken (2014); Sarlin (2013)); more evolved datasets (e.g., Liu & Moench (2016); Ng (2014)); and/or more updated crisis definitions (e.g., Babecky et al.,2012; Frankel & Saravelos, 2012).

Nevertheless, scant attention has been paid to the more operational aspects of E.W.S., a line of argumentation that is central to the present article, which seeks to propose a more holistic and inclusive perspective on this fundamental operational dimension.

3. Need for an integrative approach: the case of A.E.W.S.

As the previous section clearly illustrates, the evolution of E.W.S.-related literature is essentially characterised by the development of three main pillars of intervention (the E.W.S. dimensions): i) increasingly sophisticated empirical methodologies; ii) more comprehensive and evolving datasets of potential indicators; and, lastly, iii) the use of distinct financial crises definitions in support of different EWS frameworks. All of these dimensions have co-evolved simultaneously within the academic literature, leading to increasingly sophisticated, but often segmented perspectives associated with the design of highly sophisticated crisis detection (or 'signalling') mechanisms.

Nevertheless, scant attention has been paid to the operational dimension of multi-layered E.W.S. testing, which would ultimately serve to efficiently bridge the gap between academic research and policy makers' needs to obtain accurate and prompt information on a real time basis, in order to promote adequate and timely policy making decisions in the context of the pursuit of the financial stability goal.This

is especially relevant for the central banking community, which needs to address these extreme events both internally and externally (i.e., through the implementation of coordinated efforts). Currently, the implementation of existing E.W.S. frameworks is typically achieved through the isolated deployment encompassing a multiplicity of heterogeneous methodologies that might individually shed light on impending episodes, but which do not necessarily facilitate coordination policies at an international level. These coordinated efforts have become increasingly needed given the strong negative impact associated with contagion processes related to real economy contagion processes (such as the present COVID-19 pandemic) and/or financial contagion processes (such as the Great Recession).

The A.E.W.S. protocol integrates otherwise idiosyncratic E.W.S. procedures by pursuing a holistic approach to crisis detection. It does so by implementing a generalised operational framework whereby the application of multiple methodologies (each possessing its own specificities and degree of complexity) might be more easily integrated into a comprehensive and multi-dimensional protocol. It should be further observed that this paper aims to provide a broad operational template, as per the operational protocol suggested herein , using a multi-layered approach consisting of several layers of testing, which can be applied either simultaneously or sequencially.

Lastly, there is a significant need for an 'adaptive' E.W.S. protocol, insofar as the early detection of crisis episodes (whether stemming from the real side or the financial side of the economy) has become increasingly relevant in the context of the presence of severe national and/or international financial contagion processes that quite instantaneously facilitate the propagation of crisis transmission mechanisms to a global scale. To the best of our knowledge, this article constitutes the first such attempt in relation to this fundamental operational perspective, and the inclusion and relative importance of each specific methodology to a given central bank's toolkit is to be further calibrated, thus meriting further research.

4. Adaptive Early Warning Systems (A.E.W.S.) framework: an axiomatic approach

The present section proposes a novel approach by focusing on the design and implementation of an axiomatic operational EWS protocol – the Adaptive Early Warning Systems (A.E.W.S.) framework – which is specifically targeted to the central banking community. The proposed protocol is adaptive to the use of multiple methodologies, datasets, and/or crises definitions, and historic episodes,

and, ultimately, to multiple forecasting purposes, using a simultaneous or a sequential approach to crisis detection.

The Adaptive Early Warning Systems (A.E.W.S.) constitutes a central banking protocol intended to bridge the gap between the surveillance of impending financial distress episodes and the corresponding pursuit of appropriate policy making decisions implemented in contravention thereof. The said protocol is thus especially relevant in the context of the 'signalling' processes associated with the detection of financial crises whereby the design and implementation of appropriate crisis detection mechanisms might contribute to the timely pursuit of fundamented policy making decisions in the context of a multi-staged approach to crisis detection.

4.1. An axiomatic approach to A.E.W.S.

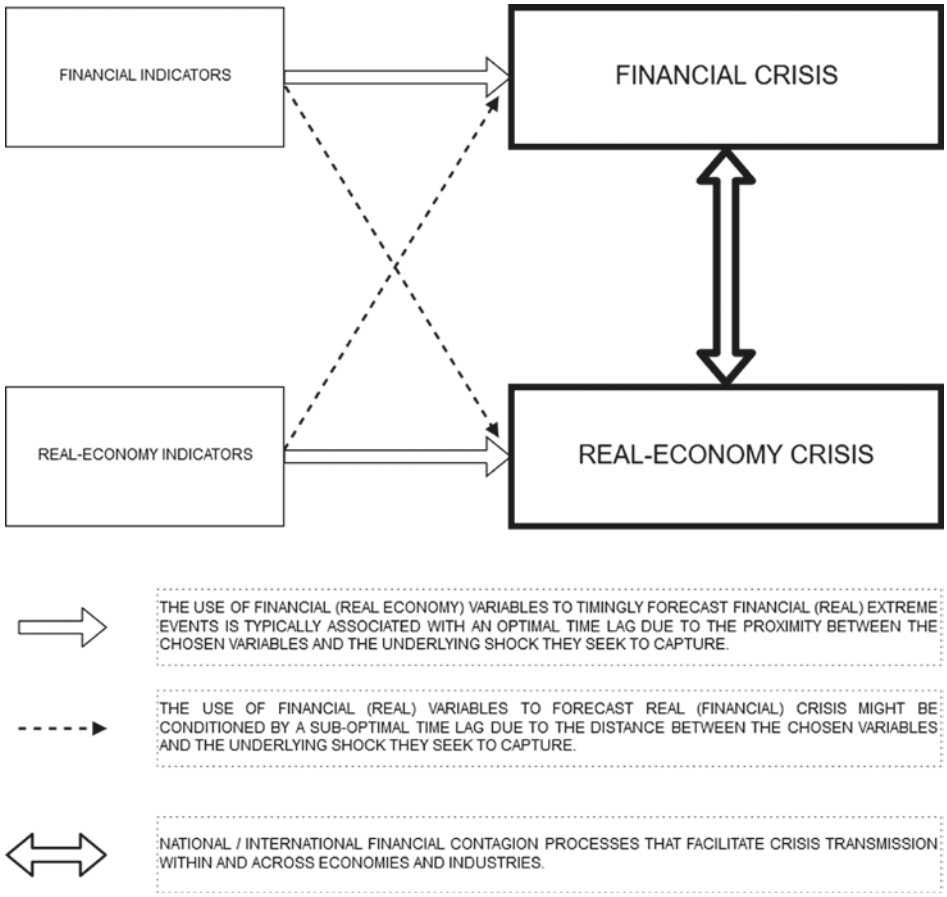
The A.E.W.S. rests on the following set of axiomatic principles to crisis detection, which will be hereinafter described and commented.

Axiom One (classification principle) - Economic crises may be broadly classified as financial crisis (e.g. banking, credit or sovereign debt crisis); or as real economy crises (e.g. negative productivity shocks).

This axiom (Figure 1) is fundamental in order to match specific E.W.S. methodologies to either one of the two broad types of crises, insofar as E.W.S. mechanisms might be sensitive to the idiosyncratic characteristics of a specific shock episode. Moreover, the pursuit of adequate regulatory countervailing responses is also critically dependent on the adequate and prompt detection of the proper source (i.e. the origin) of a given crisis episode. By focusing crisis detection mechanims on the specificities of underlying episodes, A.E.W.S. might yield more accurate and timely findings, which might subsequently be efficiently used within a policy making context.

Axiom Two (matching/adequacy principle) - Financial episodes prompt the use of financial indicators, whereas real economy crises prompt the use of real economy indicators in order to minimise the time length associated with crisis detection processes.

Figure 1: Axioms One and Two



Source: Author's design

This axiom (Figure 1) is justified by the fact that impending financial crises prompt the need to use financial data closely related to the source of origin of the episode under scrutiny. Analagously, real economy crises prompt the use of real economy data in order to address the focal stress point of the underlying real economy shock. For example, *efficiency optimisation (e.g., the quality of emitted 'signals') associated with the early detection of financial distress episodes in light of the subsequent pursuit of policy actions is critically dependent on the minimisation of the time lag between the initial shock and the crisis detection moment*. Accordingly, using financial indicators to detect the onset of financial episodes minimises the *time lag* associated with the financial crisis detection process; whereas the use of

real economy data in the detection of financial crises might present a longer time lag due to the greater 'distance' (i.e., the *time lag*) between the financial episode scrutiny and the variable set used to detect the episode. In this specific case, real economy variables might only be impacted once contagion processes set in, and policy makers' ability to significantly minimise the propagation of the said shock is greatly compromised. That is, the longer the 'distance' between the source of a given shock and the segment to which a given variable being scrutinised belongs to, the longer the corresponding *time lag* in detecting the underlying episode for EWS purposes, which ultimately decreases crisis detection efficiency, thus further inhibiting policy makers' countervailing policy actions.

By properly calibrating A.E.W.S., regulatory authorities should be in a position to strongly enhance the efficiency of crisis detection processes by efficienly matching the variable dataset to the source of the crisis episode[5].

Axiom Three (contagion principle) - Financial crises occur within specific segments of globalized financial markets, and the propagation of the negative shock occurs through national and international financial contagion processes simultaneously to both financial markets and real economies. Reciprocally, real economy crises originate in specific sections of the real economy[6] and typically propagate simultaneously to both globalised real economies and to financial markets.

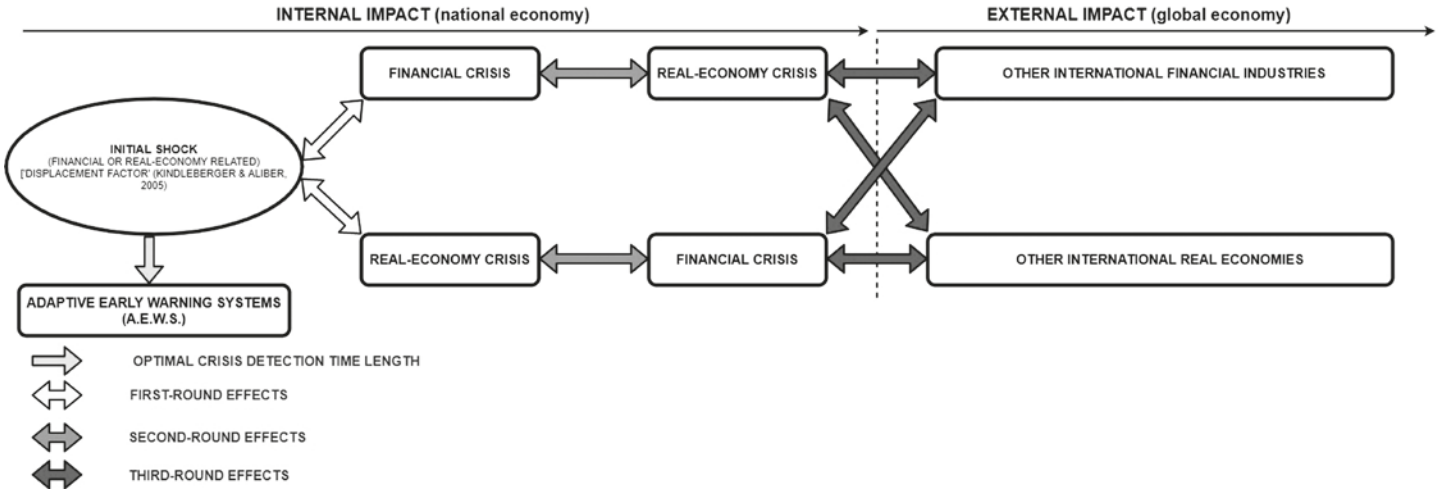
This axiom (Figure 2) is fundamental in the assessment of the sequenced transmission (through idiosyncratic transmission channels) of the negative financial shock asociated with financial/real contagion processes, which tipically amplify and propagate the initial shock. The need to countervail the initial shock as early as possible further prompts the use of the most adequate detection instruments in order to implement timely policy making decisions, as a response to specific types of shocks, taking into account the underlying shock source. This is especially relevant in the context of the diffusion/propagation of the initial shock (first round effect), which can gain momentum (through second of higher round effects), thus inhibiting policy makers ability to efficiently countervail responses to the initial episode,once financial/real contagion spreads the initial shock to the other parts of the macroeconomic/financial system.

---

[5] Furthermore, previous crisis episode responses might be used by central banks as a benchmark for responses to future episodes.

[6] In 'sudden stop' episodes (such as the present COVID-19 extreme event), real economy crises can stop/slow down a given economy temporarily, originating massive losses in GDP terms.

Figure 2: Axiom Three



Source: Author's design

By design, and if properly used, well-articulated A.E.W.S. systems should be able to track financial episodes[7] before financial contagion occurs, thus prompting regulatory action before the initial financial episode escalates to more severe states. Central banks might then promote adequate contagion deterrance in the early stages of crisis detection through adequately implemented and well-integrated A.E.W.S. frameworks.

Axiom Four (holism principle) – Financial episodes[8] might be more adequately monitored across a spectrum of juxtaposed detection procedures in multiple segments of the financial or real economy markets, in order to accurately detect the onset of financial/real crisis episodes.

This axiom observes that crisis episodes might be more adequately foretold when crisis mechanisms are holistically implemented across several segments of the financial markets or real economies, in order to either detect a given episode's initial shock or the propagation thereof to other segments of the financial markets or to real economies. Should an initial shock and/or a first round effect not be properly detected, a holistic approach might be more successful in detecting a potential shock episode. This juxtaposition is especially relevant once financial contagion propagates from the initial shock in a given segment to other segments of the financial markets or to the real economy.

Axiom Five (multi-layered principle) – Financial episodes[9] might be more adequately foretold using a multi-layered design mechanism to crisis detection, by implementing a simultaneously or a sequencial detection process.

This axiom stipulates that financial crisis detection mechanisms might be applied in a hierarchical procedure, in a simultaneous or sequential mode (or both, considering the use of multiple methodologies within the same protocol), in order to compensate for potential detection errors in relation to any single detection methodology. A multi-layered procedure should provide more accurate informational content than a single application of crisis detection mechanisms. Furthermore, and taking into consideration the interconnectedness among distinct segments of the financial markets, some degree of slightly overlapping A.E.W.S. procedures might be admissable in order to overcome the sensitivity of the A.E.W.S.

---

[7] A similar reasoning is applicable to real economy crises.

[8] Ibid.

[9] Ibid.

forecasting procedures to the Heisenberg uncertainty principle, when the said principle is applied to financial/real shock measurement[10].

4.2. The A.E.W.S.: a basic axiomatic template

In light of the overall evolution of the Early Warning Systems literature, the proposed protocol is essentially concerned with defining a comprehensive, yet pragmatical approach to crisis detection, thus allowing policy makers to pursue a specific set of policy making decisions in the context of fundamented decision making processes. The proposed A.E.W.S. framework constitutes a multi-stage approach to implementing a comprehensive and inclusive crisis detection framework.

It should be observed that A.E.W.S. might be viewed as an extension of E.W.S. systems. While E.W.S. systems are essentially concerned with a given process of crisis detection (e.g., 'crisis signalling') on an ad-hoc basis, using a specific methodology and dataset, and a corresponding crisis definition, the A.E.W.S. framework extends this reasoning by proposing a bespoke protocol – to be tailored to the specific regulatory needs associated with a given economy and central banking practices - that might encompass the use of multiple methodologies and multiple datasets, within a multi-layered approach, and with different detection goals in mind. These methodologies are to be deployed in order to capture the different stages of a given dynamic and evolving financial distress episode; moreover, these methodologies' implementation can be either simultaneous or sequential to a given financial distress episode. Figure 3 below describes the basic tenets associated with a A.E.W.S. template to implementing a functional, yet comprehensive, operational multi-step approach to crisis detection[11].

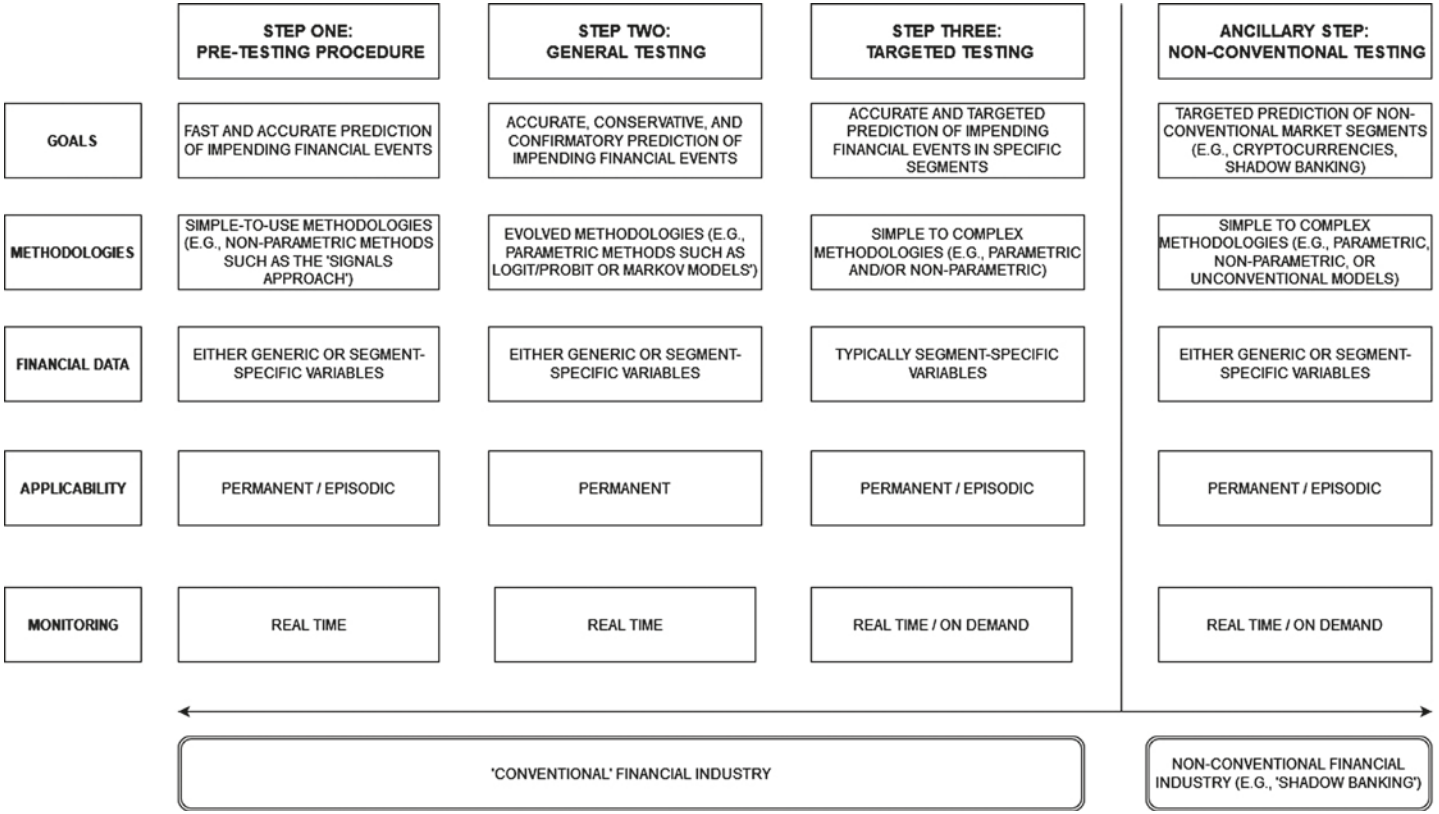
First, the pre-testing stage ('Step One') essentially comprises the application of easy-to-deploy empirical methodologies that might be useful in the early stages of crisis detection processes. The corresponding methodologies can be applied on a real time basis, and/or as a preliminary approach to applying a more sophisticated set of general testing procedures, and/or to more targeted testing procedures.

---

[10] That is, there is a trade-off between the speed of the financial/real shock and the need to pinpoint with some degree of accuracy where the focal stress points associated with the initial shock are located in a specific point in time, as this information is fundamental to the implementation of appropriate countervailing policies by the regulatory community.

[11] A similar approach can be undertaken for real economy crises, with slight changes to the type of data used. In real economy crises (such as the present COVID-a9 pandemic), data should revolve around real economy data.

Figure 3: The Adaptive Early Warning Systems (A.E.W.S.) framework – an axiomatic design: the specific case for the detection of financial episodes



Source: Author's design

The main specific goal of the pre-testing procedure[12] is to allow for the expeditious deployment of non-parametric approaches that might promptly detect the issuance of early 'signals'; while duly maintaining the separation of the 'signals' emission process from the subsequent policy decision analysis stage, in order to subsequently deploy more advanced and confirmed methodologies. The main overall goal associated with this stage is to forecast potential impending crises through 'signal' issuance before the said financial distress episodes escalate into more damaging and impactful crises, through expressive national/international financial contagion processes. Pre-testing procedures can also be applied simultaneously with other more advanced forecasting procedures. This would enable policy makers to obtain very timely information so as to allow them to obtain further 'signal' clarification/confirmation through more sophisticated procedures (to be implemented through general or targeted testing procedures) prior to the onset of any financial episode, thus preparing well in advance any policy intervention.

Second, the general testing procedures ('Step Two') would typically involve the use of more complex and technically cumbersome methodologies that require a more sophisticated approach to crisis detection. In relation to pre-testing procedures, general testing procedures should help validate (or disprove) the 'signals' emanating from pre-testing procedures, using more established crisis detection methodologies. There is nevertheless a trade-off between the need for testing accuracy and the time length necessary to fully confirm the onset and diffusion of a financial distress episode. The complementary use of both pre-testing and general testing procedures would allow for a more accurate, comprehensive and reliable overall detection of financial distress episodes, all the while reconciling mutually exclusive methodologies into a single forecasting A.E.W.S. platform.

Third, the targeted testing procedures ('Step Three') would be quite useful in specific segments of the financial markets, where certain variables might be important to gauge. For example, nascent, relatively small, opaque, and 'thin' financial market segments might present some additional regulatory issues, insofar as these segments might be in formation. Accordingly, any negative shock might impact liquidity in these specific segments, which might further leverage losses through temporary, but volatile 'fire sale' prices (Brunnermeier & Pedersen, 2009). These segments should be more responsive to targeted testing, using a specific type of methodologies and/or specific datasets destined to capture these market idiosyncracies. Nevertheless, targeted testing might also encompass the critical analysis of mature markets through the use of state-of-the-art localised methodologies

[12] Assuming minimum forecasting errors.

applicable to the said specific segments (the market for credit default swaps might constitute an important example).

Fourth, non-conventional testing procedures ('Step Four') should be deployed in non-conventional segments of the financial industry, where the inexistence of a clear-cut regulatory responsibility might ultimately require the application of state-of-the-art empirical methodologies, in light of these segments' novel importance to monetary policy setting. Two cases in point are related to the monitoring of the shadow banking industry and to the cryptocurrencies segment of the financial markets. In these markets, technological and financial innovation processes intersect, notwithstanding the uncertainty surrounding the regulatory perimenter. Given the existence of a potential regulatory gap in these segments of the financial markets, monetary regulators are becoming increasingly aware of the potential spillovers to systemic risk accruing from these markets. Under the A.E.W.S multi-layered framework, the adequate monitoring of these market activities is more facilitated, therefore enabling policy makers to pursue more fundamented policy decisions, by articulating these forecasts with those associated with conventional A.E.W.S. testing.

4.3. The advantages and disadvantages of the A.E.W.S. framework

The A.E.W.S. proposed herein has essentially six major operational advantages. First, this simple but comprehensive macroprudential protocol essentially bridges the potential communications gap between central banking research and macroprudential units and the corresponding policy makers during times of crisis, by introducing several comprehensive and inclusive layers of EWS testing, namely: i) pre-testing procedures; ii) general testing; iii) targeted testing; and iv) non-conventional testing. Each of these layers serves a specific purpose in the policy maker's regulatory agenda. From an operational standpoint these layers might encompass multiple empirical methodologies, corresponding data, as well as heterogeneous crisis definitions and corresponding historical episodes.

Second, the implementation of the A.E.W.S. framework (as a more comprehensive/holistic approach to crisis detection) might be ultimately useful in international cooperation associated with the forecasting of subsequent extreme financial episodes, where standardization pertaining to crisis detection mechanisms might be required. For example, this is the case involving central banking cooperation prior to the occurrence of extreme financial events, where standardization of crisis detection processes might be quite useful in order to facilitate regulatory communications involving multiple central banks in distinct geographical

locations. The corresponding decision making and policy implementation across the global central banking community, prior to, or even during financial crises episodes might be more facilitated. As the first and second advantages point to, the implementation of a holistic approach to international crisis detection (e.g., through the adequate implementation of A.E.W.S.) should bring about two major advantages to crisis detection procedures: i) internal (increasing the efficiency of inter-departmental cohesiveness within a given central bank); and ii) external (implementing a joint international regulatory policy intervention across central banks, before and throughout the occurrence of an extreme financial episode).

Third, the adoption of a holistic approach to crisis detection might contribute to a more thorough and informed policy decision implementation process during financial distress episodes, specially when the timing of policy making decisions constitutes a decisive factor in countervailing the potential negative impact of financial distress episodes that can easily evolve into systemic crises of expressive magnitude. In these circumstances, time does becomes a critical component in the effectiveness of monetary policy actions in contravention of impending financial episodes. By encompassing a wide range of empirical methodologies of varying degree of sophistication, which can be applied simultaneously or sequencially, the A.E.W.S. can provide policy makers with a balanced and timely informational toolkit that would allow the pursuit of appropriate policy actions (duly calibrated according to the severity of the financial distress episode under scrutiny), to the benefit of monetary policy effectiveness and speed of action. Fourth, thorough the balanced application of the collective set of heterogeneous testing procedures, the A.E.W.S. protocol might encompass and accommodate a wide range of heterogeneous empirical methodologies, ranging from consensual easy-to-deploy methodologies to more advanced and cumbersome time-consuming methodologies; while taking into careful consideration both conservative as well as state-of-the-art empirical methodologies advanced by the relevant academic literature. Fifth, the implementation of the A.E.W.S. operational protocol also contemplates the possibility of implementing both targeted and non-conventional testing procedures. The former contemplates the monitoring of highly regulated segments of the financial markets; whereas the latter might encompass, for example, the non-conventional shadow financial industry, or the cryptocurrencies markets, thus fully expanding central banks' regulatory perimeter, where crisis detection processes are concerned. Sixth, A.E.W.S. facilitates communicaions with outside (i.e. partisan) parties, further increasing the quality of the dialogue between the central banking community and civilian oversight agencies.

Where the disadvantages of the A.E.W.S. framework are concerned, there are three major drawbacks. First, the A.E.W.S. protocol remains untested. Second,

the adequate implementation of the A.E.W.S. framework is critically dependent on a steep learning curve that seeks to integrate multiple proven and state-of-the-art methodologies and datasets, and the proper calibration of the A.E.W.S. platform nevertheless constitutes a cumbersome time-consuming process. Third, and where the adequate policy-mix of methodologies/datasets is concerned, the weights being assigned to the relative importance of each A.E.W.S. component also has to be properly calibrated against the backdrop of previous historical extreme financial events, notwithstanding the protocol's forward-looking guidance stance. Notwithstanding, it is hoped that the merits herein previously described might outweigh these three disadvantages, in order for the A.E.W.S. protocol to create a value-added forecasting performance to the macroprudential toolkit.

5. Conclusion

The Global Financial Crisis of 2007-2008 constitutes an expressive extreme financial event that has unleashed a significant and devastating spillover to the global economy. In the aftermath of the said event, there has been a renewed interest in the build-up of effective Early Warning Systems (E.W.S.) by the global central banking community. The implementation of these systems should help prevent and/or mitigate the impact brought about by subsequent systemic crises, even including 'sudden stop' episodes such as the recent COVID-19 pandemic. Fortunately, in the aftermath of the Great Recession, the E.W.S. body of research has expanded quite significantly, notwithstanding the fact that the more operational aspects associated with the implementation of these forecasting (i.e. 'signalling') systems has been somewhat overlooked. A similar expansion should occur in relation to the present pandemic, although 'sudden stop' episodes might be more challenging, simply because E.W.S. systems should incorporate more complex risk definitions (such as the risk associated with global health crises and corresponding risk measurement variables). If adequately implemented, A.E.W.S should be more comprehensive in dealing with 'out-of-the-box' risks.

The present article expands this topic in a novel operational dimension by proposing a comprehensive central banking protocol for the early detection of such impactful episodes, the herein proposed Adaptive Early Warning Systems (A.E.W.S.) framework. The A.E.W.S. protocol constitutes a functional, yet comprehensive, operational multi-step approach to crisis detection, which might be easily integrated in existing macroprudential toolkits, to be tailored by a given central bank.

The A.E.W.S. protocol thus constitutes an inclusive but open operational framework that might congregate multiple crisis definitions, varied methodologies and datasets, duly targeted to heterogeneous segments of the financial markets (or even real economy markets). The central idea is to build a single unified, yet comprehensive approach to crisis detection whose efficiency might be tested calibrated in future systemic episodes, all the while maintaining the organizational idiosyncracies of each central bank.

The main goals associated with the implementation of this novel protocol are essentially linked to: i) bridging the communications gap between E.W.S. researchers, macroprudential units, and policy-makers' need for reliable information in financial stress periods, in order for the latter to be able to pursue timely economic policies in contravention of the said episodes; and ii) providing a widely accepted protocol of central banking cooperation prior to and during crisis periods, in order to promote more effective global policy coordination at an international level. To the best of our knowledge, this paper constitutes the first such axiomatic approach to address a multi-step operational protocol to crisis detection; as opposed to the present trend in the E.W.S. research literature of segmenting crisis detection techniques and instruments, a trend which might be overwhelming to effective monetary policy formulation, implementation, and cooperation in periods of extreme financial distress.?

On the other hand, the proposed A.E.W.S. framework might be useful in overcoming the Lucas critique, insofar as the protocol might blend multiple methodologies into a single, idiosyncratic, and unified approach that is not easily perceived by financial market agents in search of for-profit replication strategies that might ultimately countervail the pursuit of a more accurate and stern regulatory intervention during the onset or in the aftermath of extreme financial episodes.

Lastly, it is hoped that the A.E.W.S. protocol proposed herein might ultimately enhance the operational consolidation dimension of the macroprudential toolkit and ultimately contribute to: i) timely detection of extreme financial episodes; ii) timely implementation of countervailing regulatory policies in contravention thereof; and iii) averting costly and impactful episodes of severe financial distress events that might ultimately impact the global economy.

References

1. Alessi, L., & Detken, C. (2014). On policymakers' loss functions and the evaluation of early warning systems: Comment. *Economics Letters*, 12 4(3), 338-340.
2. Atkinson, T, Luttrell, D. & Rosenblum, H. (2013). How bad was it? The costs and consequences of the 2007–09 financial crisis. *Staff Papers*, 20 (July), Federal Reserve Bank of Dallas.
3. Asanović, Ž.. (2020). Essay on Finance-Growth Nexus. *Journal of Central Banking Theory and Practice*, 1, 97-109.
4. Babecky, J., Havranek, T., Mateju, J., Rusnak, M., Smidkova, K., & Vasicek, B. (2012). Banking, debt, and currency crises: early warning indicators for developed countries. European Central Bank Working Paper No 1485.
5. Ball, L.M. (2014). Long-Term Damage from the Great Recession in OECD Countries. National Bureau of Economic Research (N.B.E.R.) Working Paper No. 20185.
6. Bhimjee, D.C.P., Ramos, S.B., & Dias, J.G. (2016). Banking industry performance in the wake of the Global Financial Crisis. *International Review of Financial Analysis*, 48, 376-387.
7. Brunnermeier, M. & Pedersen, L.H. (2009). Market Liquidity and Funding Liquidity. *Review of Financial Studies*, 22 (6), 2201–2238.
8. Claessens, S. (2015). An Overview of Macroprudential Policy Tools. *Annual Review of Financial Economics*, 7, 397-422.
9. Davis, E.P. & Karim, D. (2008). Comparing early warning systems for banking crises. *Journal of Financial Stability*, 4, 89–120.
10. Frankel, G. & Saravelos, G. (2012). Can leading indicators assess country vulnerability? Evidence from the 2008–09 global financial crisis. *Journal of International Economics*, 87 (2), 216-231.
11. Goldstein, M., Kaminsky, G., & Reinhart, C. (2000). *Assessing Financial Vulnerability: an Early Warning System for Emerging Markets*. Peterson Institute for International Economics
12. Kaminsky, G. (1999). Currency and Banking Crises: The Early Warnings of Distress. International Monetary Fund Institute, Working Paper WP/99/178.
13. Kaminsky, G., Lizondo, S. & Reinhart, C. (1998). Leading Indicators of Currency Crises. *International Monetary Fund Staff Papers*, 45 (1), International Monetary Fund
14. Kindleberger, C. P. & Aliber, R.Z. (2005). *Manias, Panics, and Crashes – a History of Financial Crises*. John Wiley and Sons.
15. Liu, W., & Moench, E. (2016). What predicts US recessions? *International Journal of Forecasting*, 32, 1138–1150.

16. Milojević, N. & Redžepagić, S. (2021). Prospects of Artificial Intelligence and Machine Learning Application in Banking Risk Management. *Journal of Central Banking Theory and Practice*, 3, 41-57.
17. Ng, S. (2014). Viewpoint: Boosting recessions. *Canadian Journal of Economics*, 47 (1), 1–34.
18. Sarlin, P. (2013). On policymakers' loss functions and the evaluation of early warning systems. *Economics Letters*, 119 (1), 1-7.
19. Singh, S. & Sarma, M. (2020). Financial Structure and Stability: An Empirical Exploration. *Journal of Central Banking Theory and Practice, Special Issue*, 9-32.
20. Shiller, R., 2008. The Subprime Solution: How Today's Global Financial Crisis Happened, and What to Do about It. Princeton University Press.
21. Shoenmaker, D. & Wierts, P. (2016). Macroprudential supervision: From theory to policy. European Systemic Risk Board (E.S.R.B.) Working Paper No. 2 (February 2016).