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Systemic Risk Assessment in Low Income Countries: Balancing Financial Stability and Development

by Daniela Marchettini and Rodolfo Maino

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Systemic Risk Assessment in Low Income Countries – Balancing Financial Stability and Development[1]

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Abstract

We propose a toolkit for the assessment of systemic risk buildup in low income countries. We show that, due to non-linearity in the relationship between credit and financial stability, the assessment should be conducted with different tools at different stages of financial development. In particular, when the level of financial depth is low, traditional leading indicators of banking crises have poor predictive performance and the analysis should be based on indicators that account for financial deepening while taking into consideration countries' structural limits. By using this framework, we provide a preliminary assessment of systemic risk buildup in individual SSA countries.

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I. BACKGROUND

The recent global financial crisis has led researchers and policy makers to dedicate considerable attention to understanding and predicting banking crises. A major finding from this vast research is that, while banking crises can be driven by a variety of different inner causes—including a weak macroeconomic environment, contagion, balance-sheet imbalances, limited competition[2]—they are often preceded by asset and credit booms that, eventually, turn into busts.

The critical issue has been, therefore, to identify episodes of excessive credit growth as signals of systemic risk buildup. Empirical research from the Basel Committee on Banking Supervision (BCBS) has shown that this assessment can be undertaken by using the credit-to-GDP gap, defined as the difference between the credit-to-GDP ratio and its long-term trend. This indicator has indeed proven to be a valuable leading indicator of systemic banking crises and, as such, has been endorsed as a guide to set the countercyclical capital buffer in Basel III (BCBS, 2010).

There is no doubt that this literature has the undeniable merit to have helped build a framework for a *prima facie* assessment of systemic risk buildup and for the calibration of macroprudential tools. Nonetheless, it is also important to acknowledge that most of the results have been based on the experience of advanced economies and, to a lesser extent, large emerging markets with a developed financial sector. Scant or null attention has been dedicated to low income countries (LICs). This derives from the fact that the recent global financial crisis originated in advanced economies, in addition to large data limitations in LICs that make conducting analytical work on those countries difficult.

Investigating whether in LICs there is evidence of distinct patterns in the evolution of credit and in its relationship with banking crises is, nevertheless, a matter of importance for the exegesis of banking crises and the calibration of macroprudential instruments in these countries. This issue is also relevant for the understanding of the relationship between financial stability and financial deepening. In LICs, rapid credit growth may indeed reflect healthy episodes of financial deepening rather than systemic risk buildup, making the nexus between credit and financial stability more complex.

In this paper, we aim to fill this void in the literature. Our main goal is to develop an analytical toolkit to assess whether credit growth in LICs is indicative of financial deepening

[2] The literature on the drivers of financial crises is extensive. Classic references are Minsky (1977), Tirole (2002), Kindleberger and Aiber (2005), Allen and Gale (2007), Allen, Babus, Carletti (2009), and Reinhart and Rogoff (2009). See Claessens and Kose (2013) for a comprehensive, but not exhaustive, review of this literature.

or poises risks to financial stability. To this end, we proceed in steps. Firstly, we assess to what extent the credit-to-GDP gap endorsed by the BCBS—defined as the difference between the credit-to-GDP ratio and its long-term trend—represents a good leading indicator of banking crises across income levels and regions. Secondly, we gauge whether an alternative measure of excess credit, which considers the structural characteristics of an economy, may stand as a better leading indicator of banking crises in countries at an early stage of financial development. Our focus is placed, in particular, on Sub-Saharan Africa (SSA), as this region is characterized by distinctive features, including large heterogeneity in its level of economic development and a rapidly changing financial landscape.

Our main results can be summarized as follows. First, when measuring excess credit with the gap with respect to the long-term trend in LICs, the analysis shows no apparent link between credit booms and banking crises in the Middle East and North Africa (MENA) and SSA regions. This finding reflects the fact that, in economies in the early stages of financial development, rapid credit expansions are mostly connected to financial deepening rather than to the buildup of financial vulnerabilities, thus calling into question the use of the gap with respect to the long-term trend as an indicator of financial stress in LICs.

Excess credit, however, can be a source of risk also in low income countries. There are limits to a country's capacity to absorb financial deepening at each point in time. Our second result shows indeed that complementing the measure of excess credit based on the historical trend with an indicator that links a country's financial development to its structural characteristics enhances the capacity to predict banking crises and distinguish "bad" from "good" booms in LICs.

Finally, as both the measures of excess credit are subject to caveats—heightened by large data limitations in LICs—this paper illustrates the need not only to combine the two examined approaches, but also to perform an in-depth analysis of qualitative factors that would allow a judgment as to whether we observe healthy deepening or risky expansions.

The results in this paper provide us with a framework to assess systemic risk buildup at different stages of financial development. We use this framework for a preliminary assessment of systemic risk buildup in individual SSA countries. On the one hand, this exercise shows that for a number of SSA countries—mainly the most advanced and/or politically stable—the linkage between financial crises and credit boom-bust is likely to become stronger going forward. In these countries, indeed, the rapid increase in credit extension goes hand in hand with a level of financial depth superior to what would be compatible with economic fundamentals. On the other hand, for other SSA countries with less developed financial systems, the increase in credit growth is brisk but remains compatible with economic fundamentals and with a healthy development of financial deepening. Nonetheless, financial vulnerabilities and systemic risk buildup may still originate from sources other than excessive credit growth.

This paper relates to two strands of literature. First, it is associated with the literature on the nexus between boom-bust episodes and financial crises (Reinhart and Rogoff, 2009, Dell'Ariccia *et al.*, 2013), and to the empirical research on early warning systems (EWSs) and indicators of financial crises (Kaminsky and Reinhart, 1999, Borio and Drehmann, 2009). Our work, however, differs from this empirical research in the fact that it focuses on the relationship between financial stability and financial development and proposes different leading indicators of systemic risk buildup depending on the stage of financial development. The paper is also connected to the literature on benchmarking financial systems (Beck *et al.*, 2008; Barajas *et al.* 2012), as it uses the financial possibility frontier concept to distinguish between episodes of financial deepening and occurrences of systemic risk buildup in LICs.

The rest of the paper is organized as follows. Section II reviews the literature on the nexus between excess credit, financial sector stability, and financial deepening. Section III tests whether excess credit is a good leading indicator of financial crises across income levels and regions. Section IV proposes a simple toolkit to assess systemic risk buildup in LICs. Section V presents some stylized facts on SSA financial crises and provides a preliminary assessment of systemic risk buildup in individual SSA countries, using the framework introduced in Section IV. Finally, Section VI discusses the findings and suggests future research.

II. Booms, Crises and Gaps

A. On booms and crises

The early warning literature relates the concept of excess credit to the notion of financial cycles and suggests that "peaks in the financial cycle (i.e. booms) are closely associated with systemic banking crises" (Borio, 2012). A number of theoretical papers provide explanations for why lending booms may lead to financial stress. One chain of causation links credit booms and banking crises to excessive risk taking during the upswing of the financial cycle. This, in turn, may be stimulated by accommodative monetary policies, especially those in place for extended periods (Stiglitz and Weiss, 1981). These dynamics tend to be amplified by a financial accelerator mechanism, where the supply of credit increases and credit standards are loosened *pari passu* with an improvement in collateral values (Bernanke and Gertler, 1989; Kiyotaki and Moore, 1997; Gilchrist and Zakrajsek, 2008).

The empirical research on credit booms and financial crises is vast and generally finds evidence of a positive link between rapid credit expansion and financial stress (Gourinchas *et al.*, 2001; Mendoza and Terrones, 2004; Dell'Ariccia *et al.*, 2012; Crowe *et al.*, 2013). Booms, however, seem to be more dangerous in advanced economies or emerging markets than in developing countries. For instance, a sample of 100 countries for the period 1980-

2004, Barajas *et al.* (2007) found that only 11 percent of the booms that occurred in LICs were followed by a crisis against 36 percent in emerging markets. Analogously, Dell'Ariccia *et al.* (2012) estimated that booms that start at a lower level of financial depth are less likely to end badly. Also, Arena *et al.* (2015), examining credit booms in a sample of 135 developing countries, showed that boom episodes associated with a financial crisis are more frequent in upper-middle income countries (50 percent) than in LICs (10 percent).

These findings provide support to the idea that the relationship between credit and financial stability might be non-linear. In countries with a developed financial system, rapid credit expansion frequently reflects systemic risk buildup. Instead, in LICs, fast credit growth is mainly connected to healthy financial deepening. In this case, credit expansion should be associated with a permanent take-off in the level of financial depth, rather than with upswings in the financial cycle.

B. On the Identification of Credit Booms

Based on the evidence that rapid credit growth frequently precedes banking crises in advanced economies and emerging markets, empirical research has dedicated considerable efforts to develop methodologies for the identification of credit booms. In general, the boom phase is captured by deviations of a credit measure from its historical trend, thereby defining a gap. Methodologies, however, differ substantially in the choice of the credit measure and in the computation of the trend. Mendoza and Terrones (2008) split real credit per capita in each country into its cyclical and trend components, identifying a credit boom as an episode in which credit exceeds its long-run trend computed using the Hodrick-Prescott (HP). Borio and Drehmann (2009) proposed a credit gap measure based on the credit-to-GDP ratio, using also the HP filter as an estimate of the trend with a high smoothing parameter. Dell'Ariccia *et al.* (2012) advanced a credit gap measure as the percentage deviation of credit-to-GDP ratio from a backward looking, rolling, cubic trend estimated over a 10-year period.

Among indicators of credit booms, the early warning literature assigns a particularly prominent role to the gap computed as the difference between the credit-to-GDP ratio and its long-term trend, where the trend is calculated with a backward looking HP filter with a high smoothing parameter.[3] Empirical research from the Basel Committee on Banking Supervision has shown that, indeed, this gap is a valuable leading indicator of systemic

[3] The HP filter is a decomposition that removes the cyclical component of a time series from a set of data, thus providing a representation of the time series more sensitive to long-term fluctuations. The technical literature suggests that lambda (i.e., the adjustment of the sensitivity of the trend to short-term fluctuations) is set according to the expected duration of the average cycle and the frequency of observation (Ravn, M. O. and H. Uhlig, 2002).

banking crises in advanced economies (Borio and Lowe, 2002b; Drehmann *et al.*, 2010; Drehmann *et al.*, 2011), and, as such, Basel III has endorsed it as a guide to set countercyclical capital buffer (BCBS, 2010).

Nonetheless, it is difficult to assert whether a positive credit-to-GDP gap is enough to raise expectations of future financial distress in LICs. As highlighted above, and argued by a number of commentators (Geršl and Seidler, 2012; IMF, 2014b), rapid credit growth in low income countries and emerging markets may simply reflect improved economic fundamentals and financial deepening. In this case, the signaling power of the credit-to-GDP gap would not be compromised only if financial deepening occurs at a steady pace, as this would be embedded in the long-term trend and would not impact on the gap (Drehmann and Tsatsaronis, 2014). If, instead, financial deepening takes the form of sudden and rapid increases in credit growth, these would not be captured in the trend and might be signaled by the gap as buildup of financial vulnerability.

To date, the predictive performance of the credit-to-GDP gap has been mainly tested on advanced economies (Appendix Table 1). When the analysis has been extended to LICs and emerging markets, results are mixed. A study by the IMF (2011b), which assessed the performance of the credit-to-GDP gap on a very large sample including advanced economies, emerging markets and low income countries (169 countries in total), found that, for both emerging markets and low income countries, the credit-to-GDP gap did not perform well as a signaling variable. Drehmann and Tsatsaronis (2014), instead, using a sample including both advanced economies and emerging markets, find evidence that in emerging markets the credit-to-GDP gap remains a good indicator of financial stress, albeit the performance is not as strong as in advanced economies.[4]

C. On Cycles versus Structure

As Borio and Drehmann (2009) point out, the key issue lies in identifying in a reliable way when credit growth is not sustainable in the long run and may lead to the build-up of imbalances. In LICs, this assessment is made more complex by the fact that credit expansions may be associated with positive developments that support the growth of the economy. Indicators of excess credit confronting a credit measure against its long-term trend might be unable to tell the difference between good booms and bad. The question then arises, whether there exists an indicator of excess credit that can distinguish healthy episodes of financial deepening from systemic risk buildup.

[4] It must be noted however that the emerging markets included in the sample have mainly a developed financial sector. The only SSA country included in the sample is South Africa.

The literature on benchmarking financial systems offers an approach that looks promising, based on the concept of *financial possibility frontier*. According to this research strand, the development of a country's financial system is critically influenced by structural factors that are invariant in the short term and often lie outside the purview of policy makers (Beck *et al*., 2008; Al Hussainy *et al*., 2011). Those factors impose an upper limit to financial deepening in an economy at a given point in time, represented by the financial possibility frontier. This is a constrained optimum level of financial development, derived from the a panel regression that estimates the relationship between a measure of financial development Y and a set of structural indicators X:

$$Y_{i,t} = \alpha_i + \beta X_{i,t} + \varepsilon_{i,t}$$

The difference between actual and predicted levels of financial development provides important information on the status of a country's financial sector. A negative gap would signal an inefficient financial sector that doesn't operate at capacity. Instead, overshooting the predicted level of financial development would be associated with overheating pressures and financial stress (Barajas *et al*., 2013). The gap with respect to the frontier is, thus, a structural indicator of financial performance, as opposed to the gap with respect to the long-term trend, which is a cyclical measure. Could this alternative indicator provide a better measure of excess credit in LICs, by flagging whether financial deepening has gone too far? The next section will deal with this issue.

III. Systemic Risk Assessment across levels of Financial Development

A. Scope of the Analysis and Policy Relevance

In this section we analyze the relationship between excess credit and systemic risk buildup in a sample of countries covering all income levels and regions. The purpose of this analysis is twofold:

- Should excess credit be measured with different indicators depending on the level of financial development?
- What is the role played by credit growth in systemic banking crises across levels of financial development?

Both these topics are policy relevant. The first issue is important for the activation and calibration of macro-prudential tools in each country. Based on the empirical evidence from advanced economies and large emerging markets, the Basel Committee on Banking Supervision suggests using the credit-to-GDP gap (hereafter referred to as "BIS gap") as guidance to set and calibrate the countercyclical capital buffer (BCBS, 2010). This mechanical application of the buffer would be, however, inappropriate if the analysis reveals

that the gap is not a good leading indicator of systemic risk buildup in countries at a low level of financial development. In these countries, a positive gap with respect to the long-term trend may reflect financial deepening instead of systemic risk buildup and, therefore, activating macroprudential tools based on this indicator might hinder financial development.

The second issue, instead, is relevant to gauge whether systemic risk buildup and banking crises show similar features across levels of financial development. Should the analysis suggest that factors other than excess credit are the source of financial stress in countries at a certain level of financial development, alternative early warning indicators of crises must be sought for those countries. This issue is particularly relevant for low income countries. As will be discussed in the next section, the risk is that, by using a leading indicator of crises based on excess credit, sources of systemic risk peculiar to LICs would pass unnoticed if they don't manifest themselves as credit booms.

For our analysis we will proceed in steps. First, we analyze the performance of the BIS gap across income levels and regions. Then, we complement that analysis with an indicator that measures excess credit against a structural benchmark and assess which of the two indicators has the highest predictive performance at different levels of financial development. Based on the results of this exercise, we propose a simple toolkit for a first assessment of systemic risk build up across levels of financial development, with a particular focus on LICs.

B. Dataset and Definition of Systemic Banking Crisis

Our analysis is conducted on a sample that includes 81 countries belonging to all income levels and regions (Appendix Table 2). For 24 countries,[5] mainly advanced economies and large emerging markets, we use the new BIS series of total credit to the private sector, adjusted for structural breaks.[6] Quarterly data have been averaged to form an annual series. For the rest of the countries, we use the annual series of domestic credit to the private non-financial sector from the IMF's International Financial Statistics.[7] We require that the series

[5] Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, India, Indonesia, Ireland, Italy, Japan, Korea, Netherlands, Norway, Portugal, Singapore, South Africa, Sweden, Thailand, U.K., and the U.S. BIS data cover total credit, including also cross-border finance to the private non-financial sector.

[6] C. Debiermont, M. Drehmann and S. Muksakunratana "How much does the private sector really borrow – a new database for total credit to the private non-financial sector", BIS Quarterly Review, March 2013.

[7] We use row 32d in the old IFS classification (domestic credit to private sector by banks). A potential drawback is that this measure captures only bank credit to the private sector. Credit booms driven by nonbank provision of loans may thus be missed. According to Drehmann (2013), the credit gaps based on total credit, outperform those based on bank credit as EWS for banking crisis. The discrepancy between bank credit and total credit is however larger in countries with market-based, rather than bank-based, financial systems. For those financial sectors we mainly use the BIS series of total credit. In LICs, credit to the private non-financial

(continued…)

of each country is at least 25 years long and doesn't include data gaps.[8] We also require that the data are available for at least ten years prior to a crisis.

The identification and timing of banking crises is based on the systemic banking crises database by Laeven and Valencia (2013). The authors define a banking crisis as an event that satisfies two conditions: *i*) significant signs of financial distress in the banking system (as indicated by significant bank runs, losses in the banking system, and/or bank liquidations) and *ii*) significant banking policy intervention measures in response to significant losses in the banking sector.[9] We extend Laeven and Valencia's database based on Reinhart and Rogoff (2010) that uses a wider definition of a banking crisis, as an event that satisfies one of the following two conditions: *i*) bank runs that lead to the closure, merging, takeover, or takeover by the public sector of one or more financial institutions; or *ii*) if there are no runs, the closure, merger, takeover, or large-scale government support of the banking sector. Reinhart's database covers 70 countries in the period 1800-2010.[10]

C. Methodology

To assess the capacity of an indicator to predict banking crises, we use the signal detection approach pioneered by Kaminsky and Reinhart (1998). According to this methodology, when the indicator takes a value that exceeds a certain threshold, this is a signal that the event of interest (in our case a financial crisis) will materialize within the forecast period.[11] Comparing the signal with the actual realization of the event allows an assessment of the predictive capacity of the indicator for a given threshold (See Appendix A).[12] Forecast errors

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sector is mainly extended by banks, bank credit may be thus been considered a reliable proxy for total credit in those countries.

[8] It must be noted that the exclusion of countries whose series are shorter than 25 years or are characterized by data gaps induces a sample selection bias, causing fragile countries, the most likely to have short data series and structural breaks, to be not adequately represented in the sample.

[9] According to Laeven and Valencia (2013) necessary conditions for a crisis to be systemic is that the share of non-performing loans is above 20 percent and fiscal recapitalization costs exceed 5 percent of GDP. Hence, they propose a definition based on a combination of financial distress indicators and policy measures, such as extensive liquidity support and bank guarantees, nationalizations, bank restructuring and financial purchases.

[10] Reinhart and Rogoff (2010) database may be found at http://www.carmenreinhart.com/data/browse-by-topic/topics/7/.

[11] As it is very difficult to predict the exact timing of a crisis, we assume a forecast window of one-to-three years, instead of a fix forecast period.

[12] There is large evidence (Demirgüç-Kunt, Detragiache, and Gupta, 2000; Laeven and Valencia, 2013) that credit to GDP ratios don't always fall during crises episodes. In many circumstances they actually increase. This might happen when the decline in GDP growth due to the crisis is higher than the slowdown in lending because of preexisting credit lines that are drawn upon during the crisis. This "statistical" increase in the credit-to-GDP

(continued…)

can be divided in two categories: *i*) the indicator has not signaled a crisis that actually occurred in the forecast horizon ("missed crisis" corresponding to *Type I error*), and *ii*) the indicator has incorrectly signaled a crisis that will not materialize in the forecast horizon ("false alarm" corresponding to *Type II error*). The indicator is tested in this way on a fine grid of different thresholds.

For the assessment of the performance of the indicator on the full range of possible thresholds we use the Receiver Operating Characteristic (ROC) curve. This is a useful graphical instrument that illustrates the tradeoff between the "sensitivity" of the indicator and its "accuracy." For very conservative (low) thresholds we expect that the sensitivity is high and the accuracy is low. This means that the indicator would detect most of the crises (true positive rate on the vertical axis) but also send a lot of false alarms (false positive rate on the horizontal axis). For lax (high) thresholds, instead, we expect the opposite (i.e. the indicator misses most of the crisis but doesn't send many false alarms).

The area under the curve (AUC) synthesizes the signaling power of the indicator. An AUC of 0.5 indicates that the indicator is not informative, as for any positive signal the probability that the event of interest will materialize in the forecast horizon is equal to the probability of a false alarm. This case corresponds to an ROC curve coincident with the 45-degree diagonal. The higher is the distance of the AUC from 0.5 the more informative is the indicator. Indicators that are expected to increase ahead of the crisis, such as the BIS gap, have the maximum predictive power when the AUC is equal to 1 (See Figure A2 in the Appendix). Indicators that are expected to decrease ahead of the crisis, say risk aversion, have the maximum predictive power when the AUM is equal to 0.

D. Predictive Performance of the BIS gap

The first set of results that we want to derive relates to the predictive performance of the BIS gap across income levels and regions. Following Drehmann *et al*. (2011) and BCBS (2010), we calculate the BIS gap for each country as the percentage deviation of the credit-to-GDP ratio from its long-term trend. The estimates of the long-term trend are obtained by using a one-sided (backward-looking) HP filter. The smoothing parameter λ is set equal to 1600[13].

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during crisis episodes, due to a contraction in GDP rather than to an expansion in credit, may induce noise in the credit-to-GDP gap indicator that might incorrectly signal another future crisis (false alarm). To reduce this source of error, for each series we don't consider the signals issued during crisis periods.

[13] For business cycle analysis, the standard smoothing parameter for quarterly data is 1600 (Hodrick and Prescott, 1997). To adjust λ when the frequency of the data is different from quarterly, Ravn and Uhlig (2002) multiply λ with the fourth power of the frequency ratio. Thus, in case of annual data the parameter λ should be set to $(¼)^4*1600=6.25$. This value, however, would be inappropriate for the analysis of the financial cycle that is

(continued…)

We compute "real-time" estimates of the gap by running the HP filter recursively on each data point. This implies that to estimate the value of the long-term trend in a certain year the filter uses only the information up to that year, even if information for the following years is available. This allows reprising the operative environment of supervisors and policy-makers, who must decide when to activate the countercyclical capital buffer without knowing the future values of the credit-to-GDP ratio.[14] In addition, to obtain more robust estimates of the trend, we start the computation 10 years after the beginning of each series so that the HP filter can use a minimum of 10 observations for each data point estimate of the trend. In this way, however, we lose the first nine years of observations of each series.

Figure 1 and Table 1 show the ROC curve and the AUC metric for the BIS gap across income levels and regions.

- In the case of high income countries and, to a lesser extent, upper middle income countries and all regions with the exceptions of MENA and SSA, the BIS gap performs well as a leading indicator of financial crises. This result is in line with the mainstream literature based on the evidence of advanced economies and large emerging markets.

- In the case of lower income countries and the MENA region, instead, the credit-to-GDP gap is an uninformative indicator, scoring an AUC value between 0.55 and 0.47 (Table 1). This might reflect the fact that in LICs rapid credit growth is frequently connected to benign episodes of financial deepening that don't end in a crisis. This introduces noise in the indicator that might erroneously signal the onset of a crisis.

- Finally, the result for SSA is apparently pointless, as it suggests that the indicator has some predictive power only when the credit-to-GDP ratio is below trend (AUC equal to 0.39). As we will illustrate in Section V, this derives from the fact that crises in SSA frequently originated from sources different from credit booms and, incidentally, occurred in periods when the BIS gap was negative.

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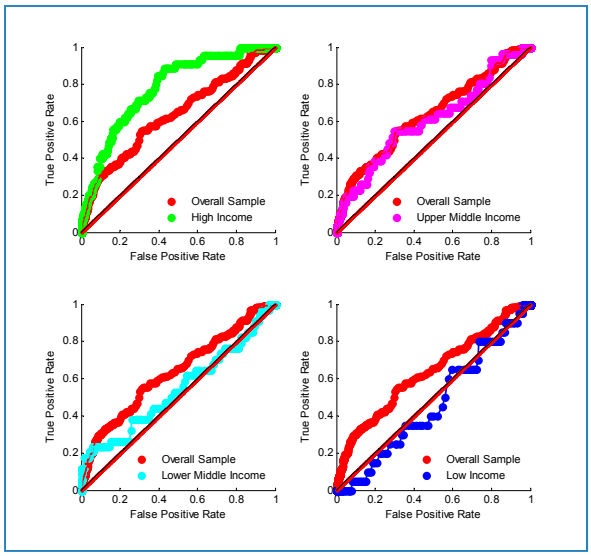
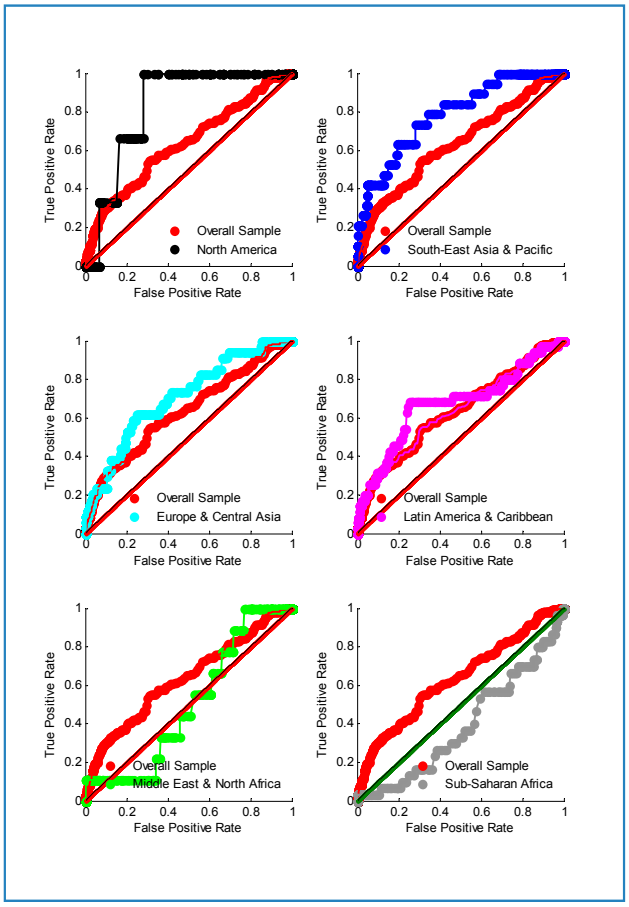
on average much longer than the business cycle (Drehmann *et al*., 2010). Assuming that credit cycles are four times as long as business cycles, we adopt a value of λ equal to $4^4*6.25=1600$.

[14] Edge and Meisenzahl (2011) observe that the "real-time" estimates of the gap are not reliable because they suffer of the "end-of-sample" problem, meaning that each point estimate might be revised when new information becomes available. Drehmann and Tsatsaronis (2014), however, show that for policy-relevant horizons the gap computed using a trend derived from a double-sided HP filter performs much worse than the gap obtained from a backward-looking one-sided HP filter.

Figure 1: Predictive Performance of the BIS Gap by Income Level (Left Panel) and by Region (Right Panel) –ROC Curves





Source: IMF IFS, BIS, and Authors' Calculations.

Table 1: Predictive Performance of the BIS Gap by Income Level and by Region – AUC Metric

Income Level	**AUC**
High Income	0.78
Upper Middle Income	0.61
Lower Middle Income	0.55
Low Income	0.47

Region	**AUC**
North America	0.83
South East Asia and Pacific	0.79
Europe and Central Asia	0.71
Latin America and Caribbean	0.68
Middle East and North Africa	0.51
Sub-Saharan Africa	0.39

Source: IMF IFS, BIS, and Authors' Calculations.

E. Complementing the Assessment of Systemic Risk Buildup: a Structural Indicator

Our evidence suggests that the BIS gap is a poor predictor of systemic risk buildup in countries at an early stage of financial development, as it is incapable of discriminating financial deepening from boom/bust episodes. In the rest of this section we will assess whether an alternative indicator of excess credit based on a country's structural characteristics might be more helpful to detect systemic risk buildup in LICs. For this purpose, we use the concept of *financial possibility frontier*, introduced by Beck *et al* (2008) and described in section II. The frontier is meant as the upper limit to a sound and efficient financial deepening, beyond which risks to financial stability may arise (Barajas *et al.*, 2013).

Frontiers for individual countries are estimated using FinStats, a tool developed by the World Bank and updated every year, that implements the methodology in Beck *et al*. (2008) and estimates the financial benchmarks for the quasi-totality of countries in the world (177 countries).[15] We use the gap between the actual level of financial depth and the frontier (hereafter referred to as the "frontier gap") to assess whether a country has gone too far in promoting financial deepening and systemic risk is building up.

As illustrated before, an indicator may be considered informative when its AUC is superior to 0.5. Using this criterion, Figure 2 contrasts the predictive performance of the BIS and frontier gaps (Figures 2a and 2b, respectively) in individual countries sorted by level of financial development. The measure of financial development adopted hereafter is the credit-to-GDP ratio at the time of the crisis, which relates the extent of financial intermediation to the size of the economy.

In Figure 2, the observations in red correspond to countries for which both indicators are uninformative (AUC below 0.5). For these countries, excess credit—however measured—was not the driver of financial stress. It is worth noting that these observations are concentrated at low levels of financial development (credit-to-GDP ratio up to 60 percent), illustrating the fact that in countries where financial systems are not developed, banking crises can frequently originate from other sources of vulnerability, including the composition of credit (high concentration, related lending, large exposures), government intervention in the banking sector, governance issues, external shocks, and political instability.

The observations in green correspond to the countries where each respective indicator outperforms the other in terms of predictive capacity. As expected, for countries at an early

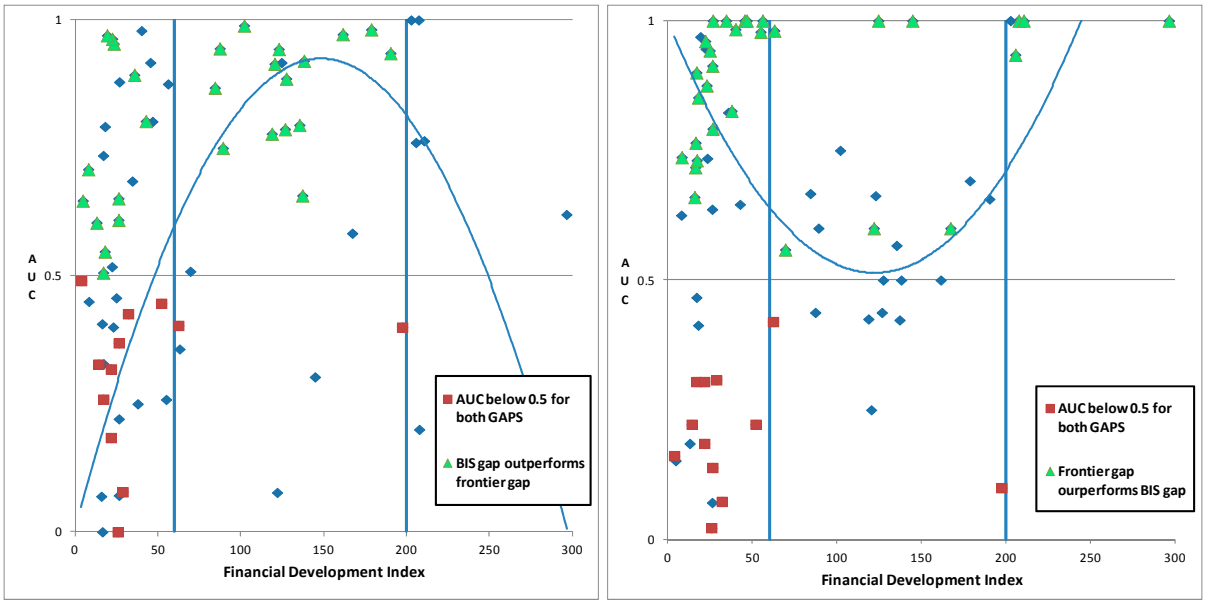
[15] FinStats benchmarking methodology estimates the frontier through a pooled quantile (median) regression. The structural variables included in the FinStats regression are: log of GDP per capita and its square, log of population, population density, age dependency ratio, offshore center dummy, transition economy dummy, and oil-exporting country dummy. See Feyen *et al.*, 2015.

stage of financial development (credit-to-GDP ratio up to 60 percent), the frontier gap performs, on average, better than the BIS gap. For countries at an intermediate and advanced stage of financial development (credit-to-GDP ratio between 60 and 200 percent), instead, the BIS gap clearly outperforms the frontier indicator. Finally, for countries with an oversized financial sector (credit-to-GDP ratio above 200 percent), the frontier gap has the highest predictive performance.

Figure 3 synthesizes these results by comparing the median predictive performance of the BIS and frontier gaps by level of financial development.

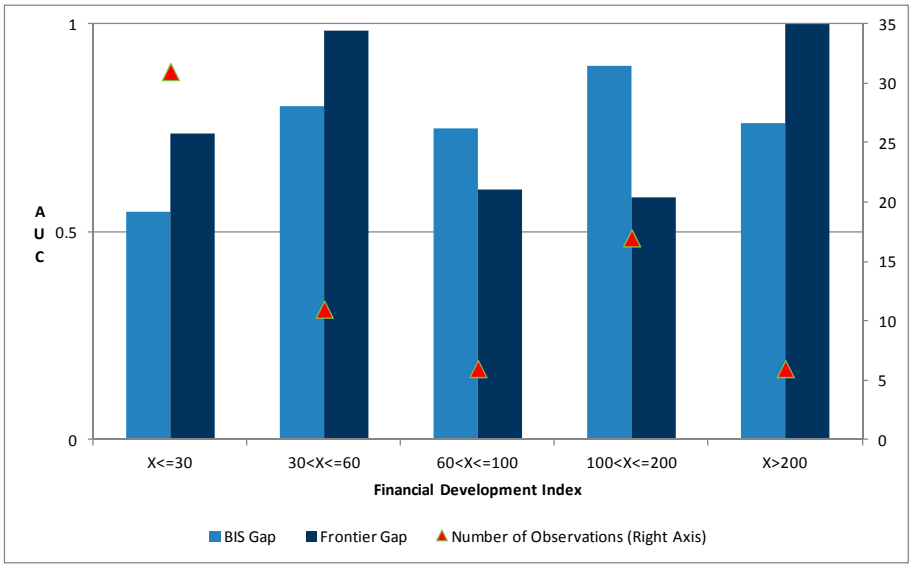
Figure 2: Comparison of the Predictive Performance of the BIS Gap and of the Frontier Gap in Individual Countries

a. BIS gap **b. Frontier gap**



Source: IMF IFS, FinStats, and Authors' Calculations.

Figure 3: Comparison of the Median Predictive Performance of the BIS and Frontier Gaps by Level of Financial Development



Source: IMF IFS, FinStats, and Authors' Calculations.

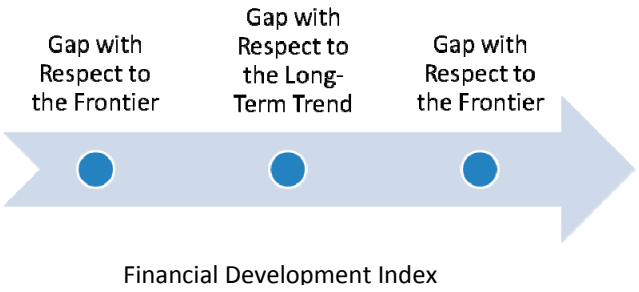
F. Putting the Results Together

These findings allow us to provide an answer to the questions raised at the beginning of this section.

1. Excessive credit should be measured with different indicators at different stages of financial development.

   In our sample, the BIS gap showed an inverted U-shape performance across levels of financial development (Figure 2a), while the frontier gap had a U-shape performance (Figure 2b). This evidence suggests that for countries at an early stage of financial development, the frontier indicator is more informative than the BIS gap, as it helps to discriminate financial deepening from systemic risk buildup, but the more the financial sector develops in size and sophistication, the more the risks of additional financial deepening exceed the benefits and the BIS gap becomes the best indicator to discriminate good booms from bad booms. Finally, for oversized financial sectors, both indicators performed well, but the frontier gap seems to be the most powerful predictor, suggesting that, for these financial systems, the exceptional size of the financial sector is a risk, *per se*, independent from additional credit growth (Figure 4).

Figure 4: Best Indicators of Financial Stress at Different Levels of Financial Development



2. Systemic banking crises frequently originated from sources other than excess credit in countries at an early stage of financial development.

   For a number of countries at low levels of financial development, both measures of excess credit are a poor predictor of financial crises (red observations in Figure 2). In those countries, financial stress originated from other sources. In part, this might be related to the fact that in LICs the institutional environment is weaker, as are also bank supervision and risk management practices, leading to fragile bank balance-sheets. In these circumstances, domestic and/or external shocks may be sufficient to spur a banking crisis, even in the absence of excess credit.

IV. AN EARLY WARNING SYSTEM FOR LICS

Based on the evidence in the previous section, we can build an EWS for the preliminary assessment of systemic risk buildup in LICs.

As the frontier gap has, on average, a higher predictive performance in countries at an early stage of financial development, this should be the first indicator to look at to assess systemic risk buildup in LICs. Complementing the analysis with the BIS gap is, nevertheless, advisable. This is so for three reasons. First, for a number of LICs the BIS gap outperformed the frontier gap in our sample (Figure 2). This may reflect the fact that despite financial development being below capacity (negative frontier gap), the acceleration of credit was too fast (strongly positive BIS gap) and led to the buildup of vulnerabilities, particularly in the absence of strong supervision. This is consistent with the IMF (2014b) which says a structural credit gap might not help to assess whether a rapid catch-up relative to the structural benchmark may pose systemic risk. Second, when both gaps are positive, financial stress could be higher. Barajas *et al.* (2013) notice, indeed, that when financial depth exceeds the frontier as the result of very rapid credit expansion, the likelihood of instability increases even further. Finally, the frontier gap is a static indicator, which gives a snapshot on the level of systemic risk buildup at a certain point in time, but doesn't provide information on whether vulnerabilities are either rising further or correcting. The BIS gap, which is a

dynamic indicator, can thus be an important complement to the analysis by giving information on whether the imbalances detected by the frontier gap are aggravating further or reducing.

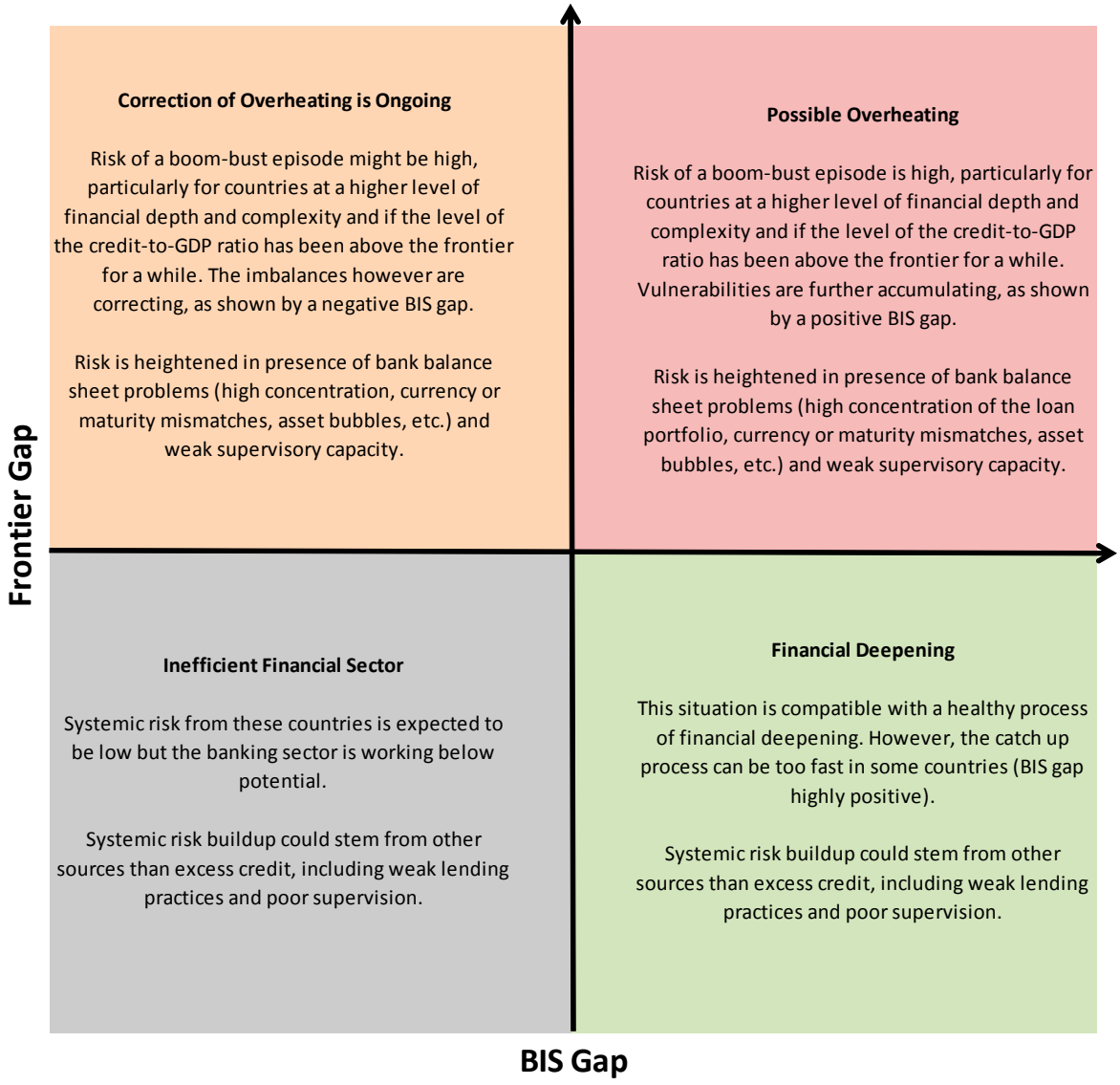
Figure 5 illustrates how systemic risk assessments for LICs could be conducted using the two indicators. In detail, the BIS and frontier gaps define four zones, corresponding to the four quadrants in the Cartesian plane, which might signal different levels of systemic risk buildup and financial deepening. In the upper right quadrant, both gaps are positive. This might be a warning sign of overheating. In the lower right quadrant, the BIS gap is positive, while the frontier gap is negative. This would be compatible with a sound process of financial deepening. In the lower left quadrant, both gaps are negative. This signals an inefficient financial system that works below potential and is not able to expand credit. Finally, in the upper left quadrant, the BIS gap is negative, while the frontier gap is positive. This is compatible with a system that is correcting existing overheating.

As mentioned in the Figure, the assessment of systemic risk buildup based on the two gaps needs to be complemented by an in-depth analysis of bank balance sheets, regulatory and supervisory environments, and macro-financial vulnerabilities. Indeed, risk from excess credit is heightened in the presence of bank balance sheet problems, weak supervisory capacity, simultaneous asset bubbles (stock market, real estate, commodity prices), and macroeconomic vulnerabilities. In addition, we have shown that in some occasions systemic risk buildup in LICs stems from sources other than excess credit. In those circumstances, the framework based on the two gaps would not raise red flags, despite the fact that vulnerabilities are accumulating in the system. Thus, complementing the analysis with bank balance sheet analysis and other indicators is critical.

To conclude this section, a few caveats. First, the relation between credit and GDP should be expected to be less stable in LICs than in other countries due to large output volatility. Drops in GDP—which are not mirrored by a fall in credit to the private sector of the same size—would result in an increase of both the BIS and frontier gaps that might, therefore, erroneously signal overheating.[16]

[16] According to the World Bank (2010), for example, in low- and middle-income countries the application of the rule for the activation of the countercyclical capital buffer based on the BIS gap may "result in erratic activations and de-activations of the buffer" due to the higher volatility of credit and GDP growth in those countries.

Figure 5: Risk Assessment Matrix in LICs



In addition, data limitations are extensive in LICs. Quarterly series of credit and GDP, commonly used to test the performance of the BIS gap, are available only for a very limited number of LICs. Also, to date the number of systemic financial crises in LICs has been rather limited. This can result in wide confidence bands for the estimated ROC curves. Finally, the series of credit and GDP in LICs may be marred by data gaps and structural breaks (due to

civil wars, changes in the compilation of statistics and large swings in exchange rates) that can significantly impact the measurement of the credit-to-GDP ratio.[17,18]

Finally, the benchmark estimates used in this paper, and derived from FinStats, are based on a limited number of structural variables, while a vast array of other relevant factors, that might be critical to the development of the financial system, are excluded. Analysts and policy makers must, therefore, be mindful of country-specific (idiosyncratic) components while interpreting the assessment based on the frontier estimated from FinStats. Alternatively, analysts may re-estimate the frontier including additional structural variables considered critical for the development of the financial sector (i.e. diversification of the economy, institutional factors, and infrastructure development). This would permit a more precise estimate of the frontier gap.[19]

With these caveats in mind, the next section will illustrate the role of excess credit in SSA banking crises, using the proposed EWS for LICs for a preliminary assessment of systemic risk buildup in individual SSA countries as of today.

V. SYSTEMIC RISK BUILDUP IN SSA: A CHANGING LANDSCAPE

A. Drivers of Financial Crises in SSA: Stylized Facts

Financial crises in SSA have shown different patterns across decades. During the 1970s, banking crises were rare, given the highly-regulated environment and limited development of the banking sector. The landscape changed dramatically in the 1980s and 1990s with the eruption of numerous banking failures that coincided with an unfavorable background of rapidly deteriorating economic and financial conditions. The large costs associated with these crises pushed countries across the continent to improve their regulatory and supervisory framework. Consequently, banking systems have become more resilient. Since 2000, only

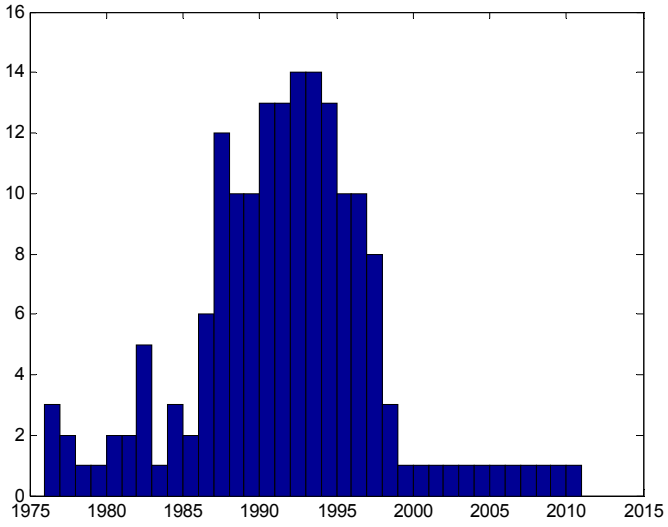
[17] In this context, it is relevant mentioning the rebasing exercise performed by a number of SSA countries in 2014, which led to significant revaluations of their GDP. Nigeria's 2013 GDP nearly doubled, Tanzania's grew by a third, Kenya's and Zambia's increased by a quarter, and Uganda's rose by 13 percent.

[18] Drehmann and Tsatsaronis (2014) show through a simulation exercise that the effect of a jump in the credit-to-GDP ratio of 10 percentage points on the computation of long-term trend, and thus on the credit-to-GDP gap, may take more than 20 years to dissipate.

[19] Introducing additional structural variables comes however at the cost of reducing the sample size of the frontier regression.

Nigeria has recorded a systemic event (Reinhart and Rogoff (2010); Laeven and Valencia, 2013) (Figure 6).[20]

Figure 6: SSA Systemic Banking Crisis, 1975-2011



Source: Reinhart and Rogoff (2010) and Laeven and Valencia (2013).

Sub-Saharan banking crises during the 1980s and 1990s are particularly interesting for this paper because they present some distinct features, specific to the region and different from banking crises elsewhere. Financial stress mostly originated from governance problems at the bank level, weak supervision, large government involvement, and poor lending practices (Daumont *et al.*, 2004, Honohan and Beck, 2007, Beck *et al*., 2011). These factors were, in many cases, amplified by macroeconomic shocks and the limited diversification of SSA economies that made countries and banking sectors particularly vulnerable to internal and external shocks.

During this period, credit booms were rarely a source of financial stress. The Laeven and Valencia database (2013) identifies 37 systemic banking crises in SSA for the period 1980-1999, of which only three were preceded by a credit boom.[21] Using the method outlined by

[20] According Reinhart and Rogoff (2010) database, while Zimbabwe's crisis started in 1995, it came to an end only in 2008.

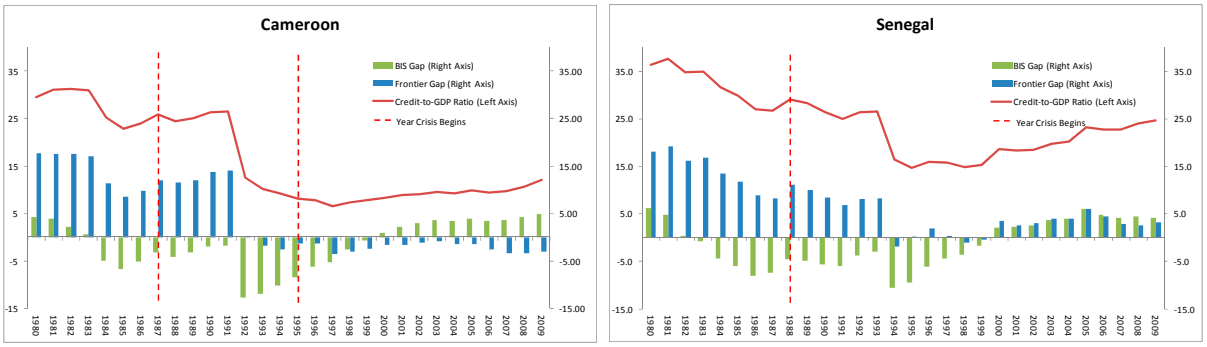
[21] Following Dell'Ariccia *et al*. (2012), Laeven and Valencia (2013) defines credit boom years as those during which the deviation of credit-to-GDP ratio relative to its trend is greater than 1.5 times its historical standard

(continued…)

Mendoza and Terrones (2012),[22] it is possible to identify three additional occurrences where SSA crises where preceded by a credit boom (Arena *et al.*, 2015) (Appendix Table 3). In the other cases, credit actually stagnated or even decreased ahead of crises (Reinhart and Tokatlidis, 2013).

Figure 7 illustrates the cases of Cameroon and Senegal. In these countries, the crises were not preceded by credit booms, as evidenced by the fact that the BIS gap was negative in the years before the crisis. In terms of levels, however, credit was above the frontier in two cases out of three. This evidence suggests that, despite the fact that credit didn't accelerate ahead of crises, it was still too high given the countries' structural characteristics. This source of vulnerability was exacerbated by poor lending practices, as banks had been plagued by poor management, government interference, and lack of internal controls on lending decisions (World Bank, 1986 and 1989). In the case of the 1995 crisis in Cameroon, factors other than excess credit were the drivers of financial stress, as illustrated by the fact that both gaps were negative.

Figure 7: Cameroon and Senegal: Gaps and Banking Crises



Source: IMF IFS, FinStats, and Authors' Calculations.

The examples of Cameroon and Senegal shed light on the poor performance of the BIS gap as a leading indicator of crises in SSA (Figure 1 and Table 1). This derives from the fact that, in many cases, the BIS gap was negative ahead of crises, and positive in periods that were

---

deviation and its annual growth rate exceeds 10 percent, or years during which the annual growth rate of the credit-to-GDP ratio exceeds 20 percent. A country-specific cubic trend is computed over the preceding 10-year period.

[22] According to the criteria outlined in Mendoza and Terrones (2012), a country experiences a credit boom when the deviation in (log) real credit per capita from its long-run trend exceeds the standard deviation of the cyclical component by a factor of 1.65. The authors compute the long-run trend of real credit per capita by using the Hodrick-Prescott filter.

not followed by financial stress (financial deepening episodes). The examples of Cameroon and Senegal also show how the frontier gap can be a more reliable indicator of systemic risk buildup in countries with a low level of financial development. Also, in a number of instances the quality—rather than the level or the acceleration of credit—was the major driver of financial stress.

While boom-bust episodes have historically played a minor role in sub-Saharan banking crises, the linkage between financial crises and credit booms is likely to become stronger going forward. Over the past decade, the banking sector of some SSA countries has, indeed, witnessed dramatic growth in depth and sophistication, driven by positive economic conditions and rising commodity prices. These are positive developments, as they can contribute to economic growth and poverty reduction in the region. However, they also carry the risk of weakening bank asset quality in the absence of adequate supervision, making the banking sector more vulnerable to financial stress. To illustrate this point, we use the experience of Nigeria.

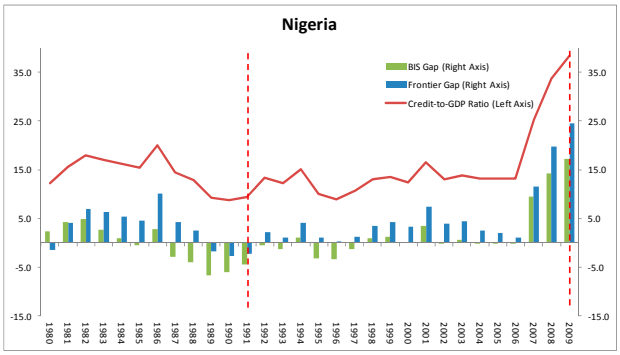
According to Laeven and Valencia (2013), Nigeria witnessed two systemic financial crises. The first crisis (1991-1995) had the characteristics of the typical African banking crisis of the 1980s and 1990s, as illustrated above; excessive credit growth didn't play a role and bad (in some cases fraudulent) banking practices were the major source of financial stress. The second crisis (2009) shared some features with the typical African banking crisis—namely weak and uneven supervision and poor governance—but also had the distinctive characteristics of a boom-bust episode turned badly.

The crisis followed a consolidation of the sector in the years 2005–06, forced by the introduction of stricter capital requirements.[23] The consolidation spurred a large credit expansion, further fueled by large oil-related inflows and a loose monetary policy stance. The regulatory and supervisory frameworks were not upgraded to sustain and monitor bank growth and ensure proper enforcement of prudential standards. In the two years before the crisis, both the BIS and the frontier gaps increased considerably, reaching more than 15 percentage points in 2009 (Figure 8).

A large share of this expanding credit was used to purchase equities; in many cases, with commercial banks extending the credit. Another significant share financed un-hedged oil imports. When the stress generated by the global financial crisis burst the equity bubble and oil prices collapsed, many stock-backed and oil-related loans became nonperforming and the credit boom ended in a full-fledged banking crisis (Sanusi, 2010).

[23] The Central Bank of Nigeria announced on July 2, 2004 that banks would be required to achieve a minimum capital level of Naira 25 billion up from Naira 2 billion, by December 31, 2005.

Figure 8: Nigeria: Gaps and Banking Crises



Source: IFS, FinStats, and IMF calculations.

The experience of Nigeria suggests that, as the financial systems of SSA countries expand and become more sophisticated, the possibility of boom-bust episodes increases. Nigeria's financial deepening, in particular, was far too rapid for the real economy to benefit. The economy was not able to absorb the additional credit in productive sectors. This resulted in significant flows to non-priority sectors and to the capital markets, setting the stage for an asset bubble. The information embedded in both gaps was relevant to assess financial stress buildup. The BIS gap flagged a too rapid increase in credit, while the frontier gap signaled that financial deepening went too far given the structural characteristics of the country. The case of Nigeria also suggests that rapid changes in the banking sector structure have to be carefully monitored and accompanied by the necessary regulatory and supervisory upgrades, as well as proper corporate governance.

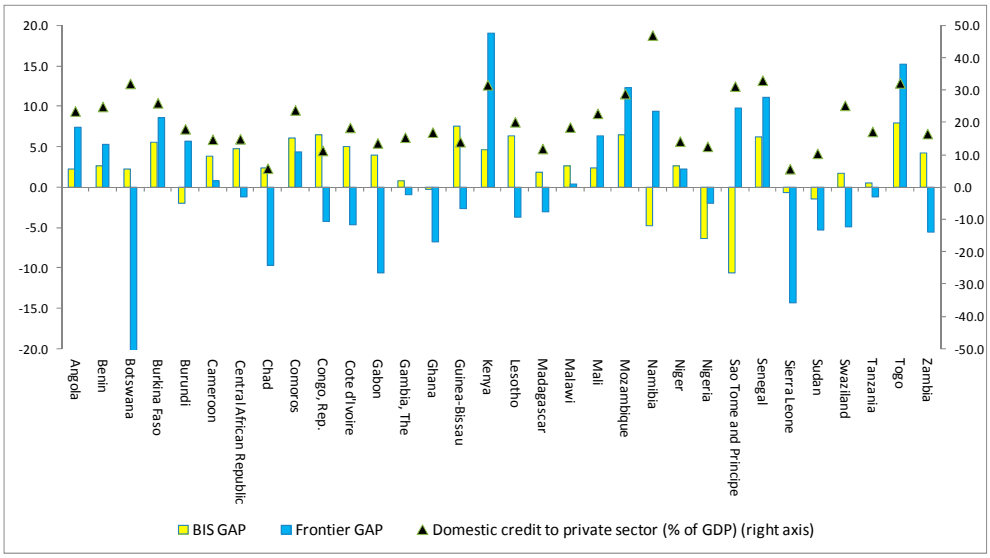
B. Systemic Risk Assessment in Individual SSA Countries[24]

The remaining part of this paper provides a preliminary assessment of systemic risk buildup in individual SSA countries as of today. The focus is on countries at an early stage of financial development (credit-to-GDP ratio up to 60 percent) and the assessment is conducted by using the EWS for LICs introduced in Section IV.

At end-2013, the majority of SSA countries had a credit-to-GDP ratio above historical trends (yellow bars in Figure 9). In many cases, this seems to reflect a healthy process of financial deepening, as countries start from a very low level of financial depth (black triangles) and are catching up with respect to the financial possibility frontier (blue bars). In some countries, however, financial depth is well above its benchmark level and the simultaneous acceleration of credit may signal systemic risk buildup.

[24] For countries that in 2014 completed the rebasing exercise, we have used the new GDP series.

Figure 9: Measures of Excess Credit and Financial development in SSA (2013)



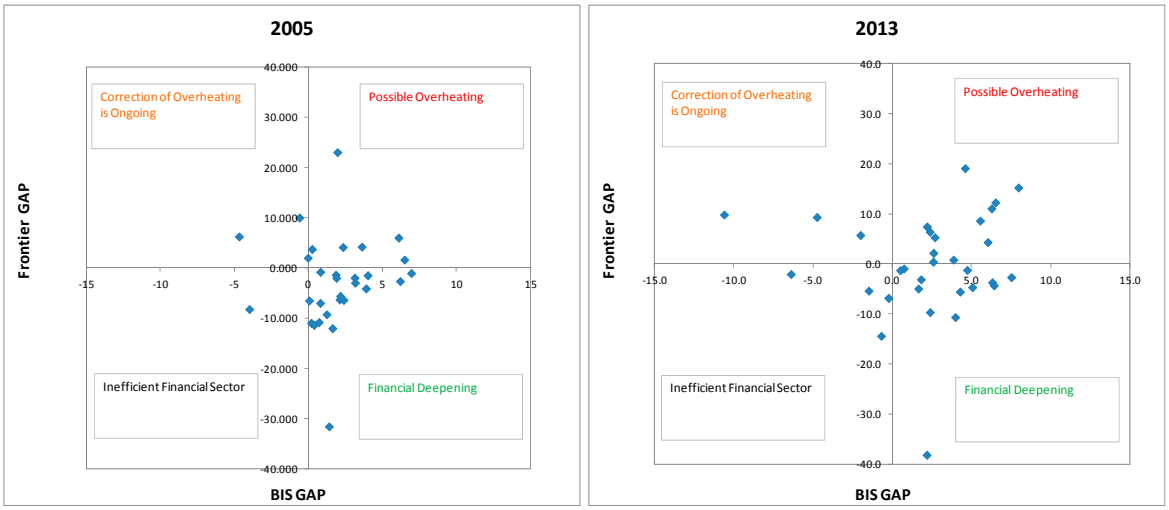
Source: IFS, FinStats, and IMF calculations.

Based on these two indicators of excess credit, SSA countries can be, thus, classified in four groups with respect to their risk assessment ("possible overheating", "correction of overheating is ongoing", "financial deepening", "inefficient financial sector"), as illustrated in the "risk assessment matrix" in Figure 5.

Figure 10 and Table 2 draw a comparison in the changes between 2005 and 2013. This analysis suggests that many SSA countries have gone a long way in the process of financial deepening, as shown by the fact that between 2005 and 2013 the share of countries with a positive frontier gap grew from 30 percent to 47 percent (Table 2). Risks to financial stability have also increased, as illustrated by the higher percentage of countries with both gaps positive (from 20 percent in 2005 to 37.5 percent in 2013). Countries in the upper right quadrant of Figure 10 with large positive frontier and BIS gaps would deserve particular monitoring.

This EWS provides a helpful preliminary assessment of systemic risk buildup in individual countries. As mentioned, however, analysts and policy makers must be mindful of country-specific factors while interpreting the assessment based on the two gaps. For instance, the frontier gap might be overstated for countries with a diversified economy (such as Kenya), which might be able to absorb a larger amount of credit than indicated by the frontier estimated from the Finstats regression.

Figure 10: Systemic Risk Assessment in SSA Countries – Comparison 2005-2013



Source: IFS, FinStats, and IMF calculations.

Table 2: Gaps Sign: Comparison 2005-2013 (% of total observations)

Gaps Sign	2005	2013
(+ positive, - negative)	(%)	(%)
Frontier Gap (+) BIS gap (+)	20.0	37.5
Frontier Gap (+) BIS gap (-)	10.0	9.4
Frontier Gap (-) BIS gap (+)	66.7	40.6
Frontier Gap (-) BIS gap (-)	3.3	12.5
Frontier Gap (+)	30.0	46.9
BIS Gap (+)	86.7	78.1

Source: IFS, FinStats, and IMF calculations.

The assessment based on the two gaps also needs to be complemented with a comprehensive analysis of bank balance sheets, regulatory and supervisory frameworks, and macro-financial vulnerabilities. As the case of Nigeria shows, risk from excess credit is heightened in the presence of bank balance sheet problems, weak supervisory capacity, simultaneous asset bubbles (stock market, real estate, commodity prices), and macroeconomic vulnerabilities.

VI. Conclusion

In this paper we provided evidence that systemic risk assessments based on measures of excess credit should be performed with different indicators at different stages of financial development. Measures that compare the level of credit with its historical trend are good proxies for systemic risk buildup in countries at an advanced stage of financial development. Instead, indicators that contrast actual credit to a benchmark level based on a country's

structural characteristics work better for low income countries. This fills a void in the EWS literature, as the existing analytical work on this subject has mainly tested the predictive performance of leading indicators of financial crises in advanced economies, where crises are expected to present common patterns and similarities.

The findings in this paper also shed light on the relationship between credit, financial stability, and deepening. Our results support recent empirical evidence suggesting that the relationship between credit and growth and between credit and financial stability might be non-linear. In particular,

- In countries at an early stage of financial development, credit expansion is mainly positively associated with economic growth (financial deepening) (Levine, 2005; Pagano and Pica, 2012). Systemic risk may, however, arise when credit expansion exceeds the absorption capacity of the economy, as determined by its structural characteristics.

- In countries with a developed financial system, on the other hand, rapid credit growth is frequently associated with excessive risk-taking, weaker lending standards, and the likelihood of a systemic banking crisis. In these countries, an acceleration of credit growth above its secular trend is likely to reflect systemic risk buildup rather than additional financial deepening (Arcand *et al.*, 2012). This result is also in line with the empirical finding showing that booms that start at a higher level of financial depth are more likely to turn into a financial crisis (Dell'Ariccia *et al.*, 2012).

- Finally, for countries with an oversized financial sector, the size of that sector is a source of systemic risk, *per se*, independent from acceleration in credit growth. This may reflect the fact that large financial systems are likely to be accompanied by riskier business models, larger interconnectedness, and higher vulnerability to global shocks (ESRB, 2014). In addition, larger financial systems tend to have more systemically important banks that, on average, create more individual and systemic risk than smaller banks (Laeven *et al.*, 2014, and IMF, 2014).

For some LICs, systemic risk buildup stems from sources other than excess credit. This paper showed, indeed, that in these countries, banking crises may occur even if credit is not excessive by any measure. This reflects the fact that banking sectors in LICs are frequently more fragile than in advanced economies. Thus, there remains a need for the development of additional leading indicators and early warning models that are LIC-specific and focus on sources of vulnerability that are different from excess credit. The identification of these risk factors is important also in the case of crises preceded by excessive credit expansion, as they could heighten the severity of financial disruption connected to the bursting of the credit bubble. We leave a systematic examination of this issue for future research.

Finally, this paper avoided the issue of determining the threshold levels of the BIS and frontier gaps that may pose significant risks to financial stability in LICs. Previous empirical research on this subject is based on the evidence of advanced economies and large emerging markets, or on large samples including countries at different levels of financial development. Two factors, pulling in opposite directions, should be taken into consideration when extending the analysis to LICs. On the one side, financial deepening could justify higher BIS gap thresholds than in advanced economies. On the other, financial systems and supervisory and regulatory frameworks are frequently more fragile in LICs. In these circumstances, even small deviations of the credit-to-GDP ratio from its long term trend, or from the frontier, can be sufficient to spur a banking crisis. This issue also remains open for *future research.*

APPENDIX –THE SIGNALING DETECTION APPROACH

In Section III we use the signal detection approach pioneered by Kaminsky and Reinhart (1998) to test the predictive performance of two indicators of excess credit. According to this methodology, when the indicator takes a value that exceeds a certain threshold, this is a signal that the event of interest (a financial crisis) will materialize within the forecast period. Comparing the signal with the actual realization of the event permits to assess the predictive capacity of the indicator for a given threshold.

In detail, we define a signaling variable S_t that takes value 1 (i.e. signal a crisis) when the indicator variable (a measure of excess credit) exceeds an arbitrary threshold θ in the signaling window:

$$S_t = \begin{cases} 1 & if\ \ x_{t-j} > \theta,\ \ j \in \{1,2,3\} \\ 0 & otherwise \end{cases} \quad ,$$

where x_t refers to the indicator variable, which is expected to be a monotonically increasing function of crisis probability. The signaling window is set to three years.

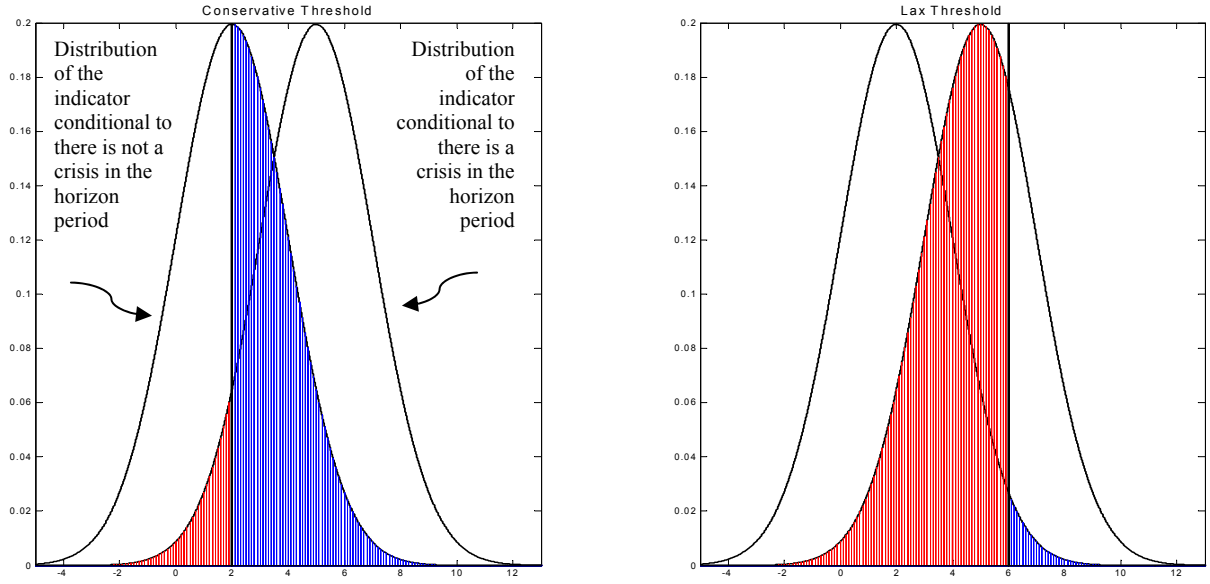
Given the binary variable C_t that takes value 1 when a crisis occurs at time *t* and zero otherwise, for each data point of the indicator and for each threshold, the signaling approach gives rise to four possible outcomes: *i*) the indicator has correctly signaled a crisis in the forecast horizon (i.e. S_t=1 & C_t=1, "success" or *true positive*), *ii*) the indicator has not signaled a crisis that actually occurred in the forecast horizon (i.e. S_t=0 & C_t=1, "missed crisis" or *false negative* corresponding to *Type I error*), *iii*) the indicator has incorrectly signaled a crisis in the forecast horizon (i.e. S_t=1 & C_t=0, "false alarm" or *false positive*, corresponding to *Type II error*), *iv*) the indicator has correctly signaled that there will be not a crisis in the forecast horizon (i.e. S_t=0 & C_t=0, "negative success" or *true negative*). The results of this analysis can be summarized in a "confusion matrix" (upper part of Table A1, in white).

Table A1: Confusion Matrix

	Crisis	No Crisis
Signal is issued	# of True Positives (TP)	# of False Positives (FP) Type II Error
Signal is not Isssued	# of False Negatives (FN) Type I Error	# of True Negatives (TN)
	True Positive Rate = $\frac{TP}{TP+FN}$	False Positive Rate = $\frac{FP}{FP+TN}$
	False Negative Rate = $\frac{FN}{TP+FN}$	True Negative Rate = $\frac{TN}{FP+TN}$

The credit-to-GDP gap is tested recursively on a grid of different thresholds with the goal of assessing the predictive performance of the indicator across all the range of possible thresholds. In general, low thresholds allow to detect most of the crises (low type I errors) but also lead to many false alarms (high type II error) as the indicator emits signals most of the time. The opposite scenario applies for high threshold values. Figure A1 illustrates this tradeoff. A low threshold (left panel) allows for a low probability to miss a crisis (area in red), but also for a high probability to call a crisis when this will not materialize in the forecast horizon (area in blue). A higher threshold (right panel) would bring to the opposite result.

Figure A1: Trade-off between Type I and Type II Errors



Source: Authors' Calculations.

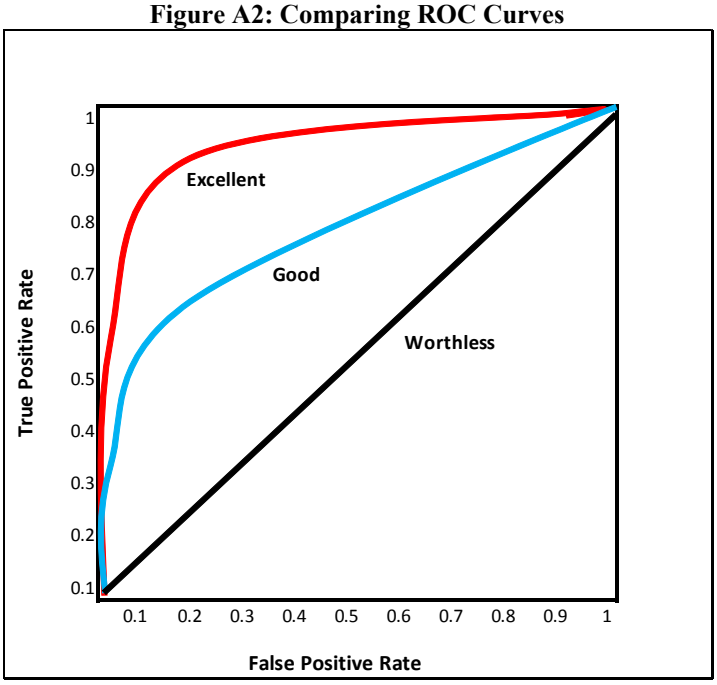
The predictive performance of an indicator is higher the more it is able to discriminate the onset of a crisis from false alarms. This depends on the level of overlapping of the two conditional distributions. In a noisy indicator, the two distributions overlap almost completely while in the case of a perfect indicator there is no overlapping of the distributions.

Empirically, the discriminatory capacity of an indicator can be assessed by means of the ROC curve (Metz, 1978). This is a statistical instrument that permits to synthesize an indicator's signaling quality by using the statistical relation between the "true positive rate" (fraction of crises correctly predicted) and the "false positive rate" (fraction of cases incorrectly classified as crises) (Lower part of Table A1, in red). The first ratio is also called "sensitivity"; it is an estimate of the probability of a positive signal conditional to the fact a crisis will materialize [Pr(S=1|C=1)], and relates to the test *ability to identify a condition correctly*. The second ratio is the complement of the "true negative ratio", also called "specificity"; it is an estimate of the probability of incorrectly predicting a crisis

[Pr(S=1|C=0)] and relates to the test's *ability to exclude a condition correctly*. These two ratios are not independent and are connected to type I and type II errors: the higher is the sensitivity of the indicator, the lower is its specificity, meaning that the indicator will correctly predict most of the crises but will also send many false alarms.

The ROC curve synthesizes this trade off by reporting the true positive and the false positive rates for any possible threshold. For very conservative thresholds we expect that both the positive rate and the false positive rate are high (i.e. the credit to GDP gap detects all the crises but also sends a lot of false alarms), for lax thresholds instead we expect that both the true and false positive rates are low (i.e. the credit to GDP misses most of the crisis but doesn't send many false alarms). The area under the curve (AUM) synthesizes the signaling power of the indicator. An AUM of 0.5 indicates that the indicator is not informative, as for any positive signal the probability that the event of interest will materialize in the forecast horizon is equal to the probability to send a false alarm. This case coincides with the complete overlapping of the two conditional distributions. The higher is the distance of the AUM from 0.5 the more informative is the indicator. Indicators that are expected to increase ahead of the crisis, such as the credit to GDP gap, have the maximum predictive power when the AUM is equal to 1. In this case there is no overlapping of the conditional distributions. Indicators that are expected to decrease ahead of the crisis, say risk aversion, have the maximum predictive power when the AUM is equal to 0.

Figure A2: Comparing ROC Curves



Source: Authors' calculations.

Appendix Table 1. Empirical Research on the Credit-to-GDP Gap

	Caveats	Sample Used	Indicator	Methods
Gourinchas et al (2001)	Find no association between financial crises and credit booms.	1960-1996 for advanced and emerging economies.	Credit Gap (threshold) based on nominal credit to nominal GDP.	Detrend data on credit using an expanding HP trend with a lambda of 1000. Define a threshold level of credit invariant to all countries.
IMF (2011b)	Among slow-moving indicators of the buildup of risk, credit aggregates are useful but need to be complemented by other indicators.	Laeven and Valencia (2010) dataset for 169 countries.	Credit-to-GDP gap and change in the credit-to-GDP ratio	Using event study, noise-to-signal ratio and receiver operating characteristic (ROC) to analyze credit aggregates.
Mendoza and Terrones (2008)	Splits real credit per capita into cyclical and trend components, identifying credit booms by the size of a credit expansion relative to trend.	48 countries (advanced and emerging economies) for 1960-2006.	Real credit per capita to GDP ratio (gap).	Detrend credit data using the HP filter with a lambda of 100 (annual data)
Borio and Lowe (2002)	Simple composite leading indicators based not only on credit gaps but on asset prices gaps as well.	34 countries (21 industrial and 13 emerging markets) for 1960-99.	Credit gap, exchange rate gap, equity gap.	Trends calculated recursively using HP with a lambda of 400,000.
Borio and Drehmann (2009)	Out-of-the-sample performance of leading indicators of banking system distress provides reliable signals of potential crises.	18 industrial countries.	Credit gap, equity and property prices.	Percentage deviation from a one-sided recursively calculated HP trend with lambda se to 1600.
Drehmann (2009)	Indicators may signal crises "too early" and not all vulnerabilities end in a crisis. Also, international exposures rather than domestic (gap) vulnerabilities may trigger crises.	UK and Germany.	Credit-to-GDP gap is a powerful early warning indicator for systemic crises.	Trends calculated with a one-sided HP filter with a lambda of 400,000.
Drehmann and Tsatsaronis (2014)	Credit-to-GDP gap is a robust indicator for the build-up of financial vulnerabilities.	26 countries (advanced and emerging market economies) for 1980-2012.	Credit gap.	Using AUC (ROC curve) to assess performance of signals that forecast events.

Appendix Table 2. Sample Composition

Country	Income Level	Region	Data Source	First Observation	Last Observation
Algeria	UMI	MENA	IFS	1964	1991
Argentina	UMI	LAC	IFS	1960	2013
Australia	HI	EAP	BIS	1960	2013
Austria	HI	ECA	BIS	1960	2013
Bangladesh	LI	EAP	IFS	1974	2013
Belgium	HI	ECA	BIS	1971	2013
Benin	LI	SSA	IFS	1960	2013
Bolivia	LMI	LAC	IFS	1960	2013
Burkina Faso	LI	SSA	IFS	1962	2013
Burundi	LI	SSA	IFS	1964	2013
Cameroon	HI	MNA	IFS	1960	2013
Canada	LMI	SSA	BIS	1960	2013
Centr. Afric. Rep.	LI	SSA	IFS	1960	2013
Chad	LI	SSA	IFS	1960	2013
Chile	HI	LAC	IFS	1960	2013
China	UMI	EAP	BIS	1977	2013
Colombia	UMI	LAC	IFS	1960	2013
Congo, Dem. Rep.	LI	SSA	IFS	1963	2013
Congo, Rep.	LMI	SSA	IFS	1960	2013
Costa Rica	UMI	LAC	IFS	1960	2013
Cote d'Ivoire	LMI	SSA	IFS	1962	2013
Cyprus	HI	ECA	BIS	1975	2013
Denmark	HI	ECA	BIS	1960	2013
Dominican Republic	UMI	LAC	IFS	1960	2013
Ecuador	UMI	LAC	IFS	1960	2013
Egypt, Arab Rep.	LMI	MENA	IFS	1965	2013
El Salvador	LMI	LAC	IFS	1965	2013
Finland	HI	ECA	BIS	1970	2013
France	HI	ECA	BIS	1969	2013
Germany	HI	ECA	BIS	1970	2013
Ghana	LMI	SSA	IFS	1960	2013
Greece	HI	ECA	BIS	1960	2013
Guatemala	LMI	LAC	IFS	1960	2013
Guyana	LMI	LAC	IFS	1960	2013
Honduras	LMI	LAC	IFS	1960	2013
Iceland	HI	ECA	BIS	1960	2013
India	LMI	EAP	IFS	1960	2013
Indonesia	LMI	EAP	IFS	1976	2013
Ireland	HI	ECA	BIS	1971	2013
Israel	HI	MENA	IFS	1960	2011
Italy	HI	ECA	BIS	1960	2013
Jamaica	UMI	LAC	IFS	1960	2013

Appendix Table 2. Sample Composition (Continued)

Country	Income Level	Region	Data Source	First Observation	Last Observation
Japan	HI	EAP	BIS	1964	2013
Jordan	UMI	MENA	IFS	1965	2013
Kenya	LI	SSA	IFS	1961	2013
Korea, Rep.	HI	EAP	BIS	1962	2013
Kuwait	HI	MENA	IFS	1962	2012
Madagascar	LI	SSA	IFS	1962	2013
Malaysia	UMI	EAP	IFS	1964	2013
Mali	LI	SSA	IFS	1967	2013
Mauritania	LI	MENA	IFS	1962	2012
Mexico	UMI	LAC	IFS	1980	2013
Morocco	LMI	MENA	IFS	1960	2013
Myanmar	LI	EAP	IFS	1960	2004
Netherlands	HI	ECA	BIS	1961	2013
New Zealand	HI	EAP	BIS	1960	2010
Niger	LI	SSA	IFS	1962	2013
Nigeria	LMI	SSA	IFS	1960	2012
Norway	HI	ECA	BIS	1960	2013
Paraguay	LMI	LAC	IFS	1960	2013
Peru	UMI	LAC	IFS	1960	2013
Philippines	LMI	EAP	IFS	1960	2013
Portugal	HI	ECA	BIS	1960	2013
Senegal	LMI	SSA	IFS	1960	2013
Sierra Leone	LI	SSA	IFS	1960	2013
Singapore	HI	EAP	BIS	1963	2013
South Africa	LMI	SSA	IFS	1965	2013
Spain	HI	ECA	BIS	1960	2013
Sri Lanka	LMI	EAP	IFS	1960	2012
Swaziland	LMI	SSA	IFS	1973	2013
Sweden	HI	ECA	BIS	1961	2013
Switzerland	HI	ECA	IFS	1960	2013
Thailand	UMI	EAP	BIS	1960	2013
Togo	LI	SSA	IFS	1962	2013
Tunisia	UMI	MENA	IFS	1965	2013
Turkey	UMI	ECA	IFS	1986	2013
United Kingdom	HI	ECA	BIS	1963	2013
United States	HI	MNA	BIS	1960	2013
Uruguay	HI	LAC	IFS	1960	2013
Venezuela, RB	UMI	LAC	IFS	1962	2013
Zimbabwe	LI	SSA	IFS	1979	2006

Note: LI, LMI, UMI, HI stand for low income, lower middle income, upper middle income, and high income, respectively. SSA, MENA, LAC, EAP, SA, NA, and ECA stand for Sub-Saharan Africa, Middle-East and North Africa, Latina America and Caribbean, East Asia and Pacific, South Asia, North America, and Europe and Central Asia, respectively. Income level classification is from the World Bank and refers to 2013.

Appendix Table 3. Sub-Saharan Africa: Systemic Banking Crises, 1970-2011

Country	Start	End	Output Loss	Fiscal Costs
Angola[◊]	1992	1998		
Benin[▲]	1988	1992	14.9	17.0
Burkina Faso[▲]	1990	1994	-	-
Burundi[▲]	1994	1998	121.2	-
Cameroon[▲]	1987	1991	105.5	-
Cameroon[▲]	1995	1997	8.1	-
Cape Verde[▲]	1993	1993	0.0	-
CAR[▲◊^]	1976	1982	0.0	-
CAR[▲◊+]	1988	1999	1.6	-
Chad[▲]	1983	1983	0.0	-
Chad[▲]	1992	1996	0.0	-
DRC[▲]	1983	1983	1.4	-
DRC[▲]	1991	1994	129.5	-
DRC[▲]	1994	1998	79.0	-
Congo[▲]	1992	1994	47.4	-
Cote d'Ivoire [▲◊*]	1988	1992	-	25.0[1]
Equatorial Guinea[▲]	1983	1983	0.0	-
Eritrea[▲]	1993	1993	-	-
Ghana[▲◊#]	1982	1989	14.1	6.0
Ghana[◊]	1997	1997		
Guinea[▲]	1985	1985	0.0	3.0
Guinea[▲]	1993	1993	0.0	-
Guinea-Bissau[▲]	1995	1998	15.7	-
Kenya[▲◊~]	1985	1989	23.7	-
Kenya[▲◊□]	1992	1995	50.3	-
Liberia[▲]	1991	1995	-	-
Madagascar[▲]	1988	1988	0.0	-
Mali[▲]	1987	1991	0.0	-
Mozambique[▲]	1987	1991	0.0	-
Niger[▲]	1983	1983	97.2	-
Nigeria[▲◊]	1991	1995	0.0	-
Nigeria[◊]	1997	1997		
Nigeria[▲]	2009	2011	11.8	25.3
Sao Tome & Principe[▲]	1992	1992	1.9	0.0
Senegal[▲]	1988	1991	5.6	17.0
Sierra Leone[▲]	1990	1994	34.5	-
South Africa[◊]	1977	1978		
South Africa[◊]	1988	1988		
Sri Lanka[▲]	1989	1991	19.6	5.0
Swaziland[▲]	1995	1999	45.7	-
Tanzania[▲]	1987	1988	0.0	10.0
Togo[▲]	1993	1994	38.5	-
Uganda[▲]	1994	1994	0.0	-
Zambia[▲◊○]	1995	1998	31.6	1.4
Zimbabwe[▲◊∨]	1995	2008	10.4	-

Source: [▲] Laeven and Valencia (2013), [◊] Reinhart and Rogoff (2010).

Crisis dates differ in RR and LV: (^) RR (1976-82) LV (1976); (+) RR (1982-89) LV (1982-83); (*) RR (1988-91) LV (1988-92); (#) RR (1982-89) LV (1982-83); (~) RR (1985-89) LV (1985); (□) RR (1992-95) LV (1992-94); (○) RR (1995) LV (1995-98); (∨) RR (1995-08) LV (1995-99).

1/ Cost according to Daumont et al (2004). Laeven and Valencia reported only a cost of 6.9 percent of GDP.

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