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A REVIEW OF THE LITERATURE ON EARLY WARNING SYSTEMS FOR BANKING CRISES

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A REVIEW OF THE LITERATURE ON EARLY WARNING SYSTEMS FOR BANKING CRISES

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Resumen
Este artículo entrega una revisión de la literatura sobre sistemas de alerta temprana para la detección de crisis bancarias. Las metodologías propuestas tienen la ventaja que se pueden aplicar a sistemas financieros para países donde no existe evidencia de grandes crisis bancarias, pero que encaran un ambiente económico internacional inestable. Se presentan modelos de medición de estrés financiero tales como indicadores cualitativos, el enfoque de extracción de señales, la estimación de modelos de variables dependientes dicotómicas y finalmente modelos de duración.

Abstract
This paper presents a review of alternative methodologies for early detection of banking distress. The methodologies proposed are aimed to the early identification of financial distress for countries without an important recent history of bank failure, but facing an unstable international environment. We evaluate several indicators and methodologies to measure financial distress such as qualitative indicators, the signal extraction approach, limited dependent estimation and finally duration models.

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1. Introduction

This document presents a brief survey of the empirical literature in early warning systems for financial crises. The focus of this survey is in the prediction of banking crises, or in other methodological approaches that can contribute to the design of an early warning system (henceforth EWS) for banking distress.

The last two decades have witnessed an unprecedented increase in the number of financial distress episodes, both in developed and emerging market economies. A particularity of these episodes is that they have not been restricted to national boundaries, but have been spread to other countries through contagion, generating large costs not only at national levels, but also for the international financial system. These characteristics explain the concern of governments, regulatory institutions, international financial organizations and investors for developing a system that can anticipate problems in the financial system. The financial problems that have received more attention in the literature are currency and banking crises.

Although, banking crises can generate a large disruption of the economic activity because of the role played by banks in the allocation of resources, currency crises have received more attention in the literature. The importance of having a good prediction system for banking crises cannot be stressed enough. The bail-out costs of banking crises amounted to 10 percent of the countries GDP in a dozen of systemic banking crises.[1] Kaminsky and Reinhart (1999) study the links between currency and banking crises and they show that

[1] This is a pure bail-out cost, and it does not consider the disruption costs generated by the crises; see Goldstein et al. (2000).

banking crises are a good leading indicator of currency crises.

Most of the previous literature in banking crises was concentrated in assessing the risk of specific financial institutions based on indicators of bank soundness. However, the widespread banking failures in recent crises have generated larger concern in the determinants of systemic banking crises. Moreover, there is an increasing recognition of the relevance of the macroeconomic environment, and the health of the financial system in the performance of the individual indicators of individual bank soundness.[2]

The literature on early warning and prediction of banking crises can be classified according with the scope of the prediction (individual bank failure and systemic crises) and the methodology employed (qualitative indicators of distress, signal extraction approach, limited dependent estimation and duration models).

The document proceeds as follows section 2 presents some essential elements in the design of an early warning system for banking crises. Section 3 presents the literature on EWS for systemic banking crises. Finally, section 4 presents the microeconomic approach in the academic literature and the risk assessment and early warning systems developed by some institutional supervisors.

2. Elements of an Early Warning System

The design of an early warning system for banking crises requires the definition of the scope of the system, and some concepts and methodological issues. It is required to define whether the EWS is aimed to predict individual bank failure or the financial distress of

[2] See Gonzalez-Hermosillo (1999).

the complete banking system of a country. Based on the scope selected, the EWS must contain a precise definition of crises or bank failure.[3] It is also important to define what is the required and possible output of the system, whether it is required an assessment of the distress of the banking system, or only a signal of possible crises; and whether the system has the ability of generating forecasts of the timing of the crisis and its severity. Notice that a crisis is defined as a binary event, whereas an index of banking distress can take a continuum of values.

In addition to the clear definition of scope and events to predict, an EWS requires a mechanism for generating predictions, including a set of explanatory variables and a systematic method to obtain the prediction from those variables. The choice of the explanatory variables for banking distress should be guided by economic theory, in particular, from the recognized sources of financial fragility arising from the same functioning of banks.[4]

- Banks are efficient suppliers of liquidity (transform illiquid assets into liquid liabilities), this function makes banks vulnerable to liquidity crises, and hence, the set of explanatory variables must include measures of liquidity risk.
- Banks pool risk of different investment projects; variables that can proxy credit risk must also be included.
- Principal-agent problems, incomplete regulation and supervision, deposit insurance, capital inflow booms, and other factors can give rise to microeconomic inefficiencies,

[3] There is no an unambiguous definition of banking crisis. The literature[o] on EWSs proposes different definitions based on government intervention, non-performing loans, etc. The main references for the identification of banking crises are Caprio and Klingebiel (1996), and Lindgren, Garcia and Saal (1996).

[4] See Gonzalez-Hermosillo (1996) for a discussion of the different risks of banking, and Honohan (1997) for a broad discussion of the selection of indicators of banking distress for early warning.

and increase the market risk of the financial system. It is possible to include variables aimed to measure both the origins of the problem or its consequences in the balance of the banks.

- By pooling risk in their portfolio, banks insure themselves against idiosyncratic risk of different borrowers. However, banks cannot easily insure against aggregate shocks, making them vulnerable to macroeconomic developments.[5]
- Honohan (1997) has also stressed the role of regime changes in increasing the vulnerability of the banking system. Financial liberalization is the regime change that has a robust explanatory power in predicting banking crises (Kaminsky and Reinhart (1999) and Demirgüç and Detragiache (1998b)).
- The choice of explanatory variables to predict banking crises is severely constrained by the availability of data at the frequency required, as well as, by the accuracy of the information.[6]
- Finally, the efficiency of any model of early warning must be assessed by the accuracy of the predictions. The models should be tested for their out-of-sample performance.

3. EWS of Systemic Banking Crises

In this section we review the literature aimed to predict crises of the complete banking system of a country. We also include some methodological approaches that have been used as early warning systems for currency crises, but have a potential application for the

[5] Gorton (1988) has documented that most banking crises in the US are related with the business cycle.

[6] Rojas-Suarez (2001) warns on the use of the standard indicators of bank soundness for emerging markets. According with this author, the deficiencies in the accounting and the lack of liquidity in EM banking systems make the use of the capital-to-assets ratio to perform poorly in signaling problems in banks.

prediction of banking crises.

The prediction of banking crises by statistical methods requires a sample in which the events have appeared repeatedly. Since there has not been so may repeated episodes in any given country, the estimation must rely on a sample of different countries that have suffered banking problems.

The literature on indicators and EWS of systemic crises can be classified by their methodological approach: (1) Qualitative indicators, (2) Signal Extraction, (3) Limited Dependent Regression, (4) Other models.

3.1. Indicators

More than a complete methodological proposal for and EWS of banking crises, the existing literature propose several variables that can signal banking problems. One relevant recent paper of this class is Honohan (1997).

The author stresses the importance of distinguishing three types of banking crises according with their origins: macroeconomic epidemics, microeconomic deficiencies, and endemic crises. Different sources of banking distress will have different warning signals. This identification is crucial, because the policy response to signals of banking distress should differ depending of the origin of the problems. Banking crises frequently emerge also as a consequence of a regime change. Hence proper monitoring and regulation after such events is important.

The crises arising from macroeconomic epidemics are basically related to endogenous boom and bust cycles. However, the credit boom usually requires and is accompanied

with a loose policy of liquidity expansion, and to be realized as a credit boom requires some microeconomic inefficiencies. Sudden changes in the macroeconomic conditions that generated the cycle can produce large increases in non-performing loans. Among the main microeconomic deficiencies that can generate crises are excessive risk taking, looting and insider lending. The endemic banking crises are related to government-permeated banking system through quasi-fiscal mechanisms, directed credit and reserve requirements.

Finally, regime changes can increase the vulnerability of the banking system by altering incentives, increasing risk taking by competition or new financial opportunities, entrance of inexperienced players, and inheritance of bad loans. The main regime changes that can generate banking problems are financial repression, financial liberalization, drastic macroeconomic changes (e.g. exchange rate regime), structural economic transformation and privatizations.[7]

Honohan determines some arbitrary thresholds for the variables, and shows that the indicators proposed successfully signaled the type of banking problems for different crisis episodes. This indicator approach depends heavily on the discretionary judgment of the person evaluating the indicators, and requires the "feeling" of what a warning is. However, this approach is common practice among supervisors and investors alike.

Closely related with the indicator approach, but with a systematical statistical procedure is the signal extraction approach, first proposed for the prediction of currency and banking crises by Kaminsky and Reinhart in 1995.[8]

[7] The list of variables that can proxy the different types of crises are presented in the appendix.

[8] The first draft of the document was circulated in 1995, its final publication is in 1999 in AER.

3.2. The Signal Extraction Approach

Based on the methodology proposed by Diebold and Rudebusch (1989), and Stock and Watson (1989) for leading indicators, Kaminsky and Reinhart (1999) propose a leading indicators approach for currency and banking crises.

Their study the links currency and banking crises, and search for the origin of twin crises (the convergence of both types of crises). The main conclusion of the paper are: (1) the occurrence of twin crises and their deeper impact appears to be a consequence of the process of financial liberalization; (2) Banking crises precede and helps to explain the occurrence of currency crises; (3) However, currency crises deepen banking crises; (4) Both types of crises seem to have common causes, of particular relevance is the slow growth due to overvaluation, changes in the terms of trade and the cost of credit, stressing the importance of international shocks and the boom-bust story; (5) However, weak fundamentals are at the root of the crises.

This paper is a fundamental reference, both for the study of the determinants of banking and currency crises and for the literature in early warning of financial crises. The innovative methodology used has drawn a vast literature in early warning of financial crises. However, the most relevant contributions to this approach for early warning have been made by the authors in contribution with other researchers.[9] Goldstein, Kaminsky and Reinhart (2000) is the most comprehensive use of the methodology as an early

[9] Kaminsky (1998), Kaminsky (1999), Kaminsky, Lizondo and Reinhart (1998), Goldstein, Kaminsky, Reinhart (2000) and Edison (2000).

warning system. We briefly review the methodology employed in the original paper for banking crises and stress the main contributions of subsequent work.

Banking crises are identified and dated when two type of events occur: (1) bank runs that lead to the closure, merging or take over by the public sector of one or more financial institutions; and (2) if there are no bank runs, the closure, merging, takeover, or large-scale government assistance of an important financial institution.

The methodology stresses the abnormal behavior of some variables preceding and during crises episodes. These variables are selected from a set of candidates drawn from the theoretical literature of financial crises. When these variables attain certain levels they signal possible problems in the financial system. It is important to define what is considered to be "abnormal behavior" to light a signal, that is, what is the cut-off threshold that defines the frontier between financial distress and banking crises. A threshold is defined for each variable based on a sample of different countries that have experienced crises. This threshold is the value of the variable that minimizes the ratio of false alerts to good warnings of financial crises over a horizon of 24 months prior to the crises. At any time, the numbers of red lights that have been switched on are an indicator of the financial vulnerability of the system.

The candidate variables considered in the first paper are: Proxies for financial liberalization (M2 Multiplier, Domestic Credit/GDP, Real Interest Rate, Lending-Deposit Rate Ratio); other financial variables (Excess M1 Balances, M2/Reserves, Bank Deposits); External Sector (Exports, Terms of Trade, Real Exchange Rate, Imports, Reserves, Real Interest Rate Differential); Real Sector (Output, Stock Prices) and the Deficit/GDP.

Although the methodology does not allow for a test of the marginal contribution of each variable, those variables with a large noise-to-signal ratio (greater than 1) are considered to be less significant, with a minor marginal contribution, and sometimes completely discarded.

Kaminsky (1999) proposes a construction of different composite indexes of financial fragility based on the individual indicators. The first index is just the aggregate of all the indicators that signal a crisis. The second composite index account for the severity of signals by defining a second threshold for extreme values of the individual indicators. The third index is aimed to capture on-going deterioration of fundamentals by adding the signals that have been on in the recent past. Finally, the last composite index is a weighted average of the statistical significance of each explanatory variable (based on the noise-to-signal ratio). The weighted index performs better in terms of its predictive power. This index is then used to obtain a measure of the probability of crises. The resulting probability performs well as an in-sample predictor; however, the out-sample prediction for the Asian crises is poor (see Berg and Pattillo (1998)).

This paper also includes and tests some other variables not included in the original model. In particular it includes some external sector and foreign variables: world interest rate, foreign debt, capital flight and short-term foreign debt, and a bank liquidity variable (not significant).

Edison (2000) basically summarizes the methodology of leading indicators and incorporates into the list of candidate variables measures of short term debt as proportion of reserves, the spread between lending and deposit rates, and some global variables: Oil

prices, US rate and G-7 output.

3.2.1. The signal extraction approach

Goldstein et al. (1999) is the most comprehensive presentation of the signal extraction approach and its use as an early warning system for currency and banking crises. They evaluate the signal approach and other approaches used for early warning. It includes an out of sample test of the methodology and explores the issue of financial contagion among countries. Rely on monthly data allowing a permanent supervision of the banking system.

However, the high frequency used has the disadvantage of discarding information that is only available for less frequent observations. Forecasts must rely mainly on macroeconomic data and the possibility of including information on the structure of debt and of the banking system balance is limited.

Other problems with this methodology include: (1) the selection of variables used is arbitrary, and there is no way in checking its marginal contribution to the crises prediction; (2) the construction of any composite index is arbitrary since it cannot weight the individual contribution of each variable. Weighting the variables by their observed noise to signal ratio does not give information about its real contribution to the onset of crises; (3) the approach does not allow to study the severity of banking distress, and (4) it is impossible to allow for regional differences.[10]

3.3. Limited Dependent Model Approach

Since the occurrence of a crises is a binary discrete event, it is possible to use the limited regression approach (probit or logit) for estimating the incidence of crises. The crisis

[10] In the next section there are further comments about the methodology.

indicator is a binary variable (zero-one), estimated using a set of explanatory variables. Using the logit or probit estimation, the predicted outcomes are restricted to lie in the unit interval, and are interpreted as the probability of crises. An advantage of this methodology is that it is possible to assess the explanatory contribution of each explanatory variable and perform the usual inference based on statistical tests.

One of the earliest applications of this methodology for the prediction of financial crises is Frankel and Rose (1996), who use a probit model to estimate the probability of currency crises using annual data. The first two applications of this methodology for systemic banking crises are: Demirgüç and Detragiache (1998a) and Eichengreen and Rose (1998).

Eichengreen and Rose (1998) analyze banking crises in emerging markets using a multivariate binomial probit to estimate the probability of crises. The definition and the sample of crises were taken from Caprio and Klingebiel (1996), and consist of 39 episodes. The results highlight the importance of changes in foreign conditions in the emergence of banking crises in developing countries. In particular, the "Northern" interest rate has a large highly significant correlation with crises. The business cycle of the OECD countries also has a significant contribution to the probability of crises. The contribution of the domestic variables is less important, however, the overvaluation of the exchange rate, the domestic business cycle and high levels of foreign debt are significant and are considered to set the stage for financial problems. On the other hand, variables on fiscal policy, the exchange rate regime and the structure do not contribute to increase the probability of crises.

The crisis-period is considered just as the year in which the crises emerged. This definition

is likely to produce problems, especially when using annual data. If a banking system continues to be under crisis for more than a year, the observation would be considered a "normal" period generating a bias in the estimation. There are also endogeneity problems, except for the foreign variables; it is unclear whether the crisis is generated by a growth slowdown (for example) or voiceovers.

The use of annual data also generates that most increases in probability are contemporaneous with the emergence of crises, limiting the potential use of the probability estimated as a leading indicator of banking crises. The use of this methodology as and EWS would therefore require a forecast of the value of the explanatory variables.

Demirgüç and Detragiache (1998a, 1998b) study the determinants of systemic banking crises in both developing and developed countries using a multivariate binomial Logit. In a second stage the determinants of the severity of the crises is estimated by regressing the costs of crises with the same set of explanatory variables used for the probability of crises. The set of explanatory variables includes macroeconomic variables, financial variables and proxies for institutional development. The results indicate that the macroeconomic environment is an important determinant of banking fragility, specifically, the likelihood of crises increases with growth slowdowns, when inflation is high and when the rates of interest are high. The probability of crises is also higher when there is an explicit deposit insurance mechanism and when the institutional development is poor.

Financial liberalization tends to increase the probability of crises. In the second paper (1998b), the authors explore further this issue, and conclude that the financial fragility

generated by financial liberalization is persistent overtime. However, the increase in fragility is lower for those countries financially repressed before the liberalization. In this second paper they also explore the effects of financial liberalization on economic growth, and conclude that, for countries who experienced banking crises, the positive effects of financial development is cancelled with its negative effect in increasing financial fragility.

The authors try to tackle the endogeneity problem, described before, using two approaches. In the first, all the observations following a crisis are eliminated (at the cost of reducing the efficiency of the estimation). The second approach is to date the end of the banking crises, and eliminate the observations of the period of crisis. The best specification is then selected using the Akaike's information criterion. The use of annual data generates the same limitations than in the previous paper.

In Demirgüç and Detragiache (2000), even when the estimated model is similar to their original contribution, here the authors develop a methodology to use the probit estimation as and EWS. First, they do an exercise of decomposing the contribution of the different variables to the change in the probability of crisis for the preceding year in a case study (Mexican crisis of 1994). Next they describe the out-of-sample probability forecast.

Developing an early warning system, based on the probability of crises, requires the definition of a threshold probability. The definition of the threshold depends on three factors: the probabilities of type I and type II errors associated with the threshold, the unconditional probability of banking crises, and the cost of taking preventive action relative to the cost of having a crisis.

The paper develops two methodologies for choosing optimally the threshold. In the first,

the decision process is modeled using a loss function of a policy maker for a given threshold. The only information required, additional to the estimation, is the relative cost of taking preventive action versus having a crisis. Using estimates of the probabilities of type I and type II errors, and the unconditional probability of banking crises, given by the model, the optimal threshold is estimated. The probit model has gains in terms of accuracy for and EWS with respect to the KR methodology. Moreover, the criterion for choosing the threshold is based on economic considerations (the costs) and no in statistical considerations (noise to signal ratio). The indicator itself has an important and clear economic interpretation, while the K composite index is arbitrary. The second methodology proposed is a system for rating financial fragility. It is based on a partition of the probability of crises (although the criteria for the partition are sample dependent and ad-hoc).

The out-of-sample predictions for the Jamaican and Asian crises, however, do not perform as expected, and the model was able to predict only the Jamaican crisis. The use of the methodology as and EWS for predicting crises requires the forecast of the explanatory variables. The low frequency of the data used (annual), makes the forecasts of the variables less accurate. In a rigorous test of the methodology, the authors take the forecasts of the explanatory variables from the actual forecasts in the year preceding each crisis. Since the forecasts of the Asian in that year were optimistic, the model is unable to predict the financial downturn that occurred. This result highlights the high costs of using annual data in and EWS.

Hardy and Pazarbasioglu (1999) estimate a multivariate-multinomial Logit model to

forecast banking crises, using annual data. The multinomial model is used in an attempt to overcome the limitations of the probit a Logit approach in signaling early the occurrence of crises. They define a discrete variable that takes the value of 2 in the event of a crisis, a value of 1 in the previous year, and zero otherwise. They also include lags of the explanatory variables. With this methodology, it is possible to establish the predictive power of the leading indicators independently of what is known only in the crisis year. When the dependent variable crosses the first threshold and early warning of banking distress is turned on. The inclusion of lags of the explanatory variables allows a dynamic analysis of the effect of the variables in financial vulnerability, specially the boom and bust cycle.

The authors also test for the significance of regional effects of macroeconomic variables, and whether the experiences of past crises in the country are significant in the development of new crises. The out-of-sample test of the model for the Asian crises, performs better than most other models (it is able to predict three out of four crises).

Hutchinson and Mc-Dill (1999) estimate a multivariate probit model for banking distress. Banking distress is defined based on the proportion of the portfolio of non-performing loans and limited capital base studied by Glick and Hutchison (1999), identifying 65 episodes of severe banking problems. The study includes two sets of indicators: macroeconomic and institutional variables, and test their potential uses as leading indicators of banking problems.

The only two macroeconomic variables that systematically correlated with the onset of banking distress are declines in output and in equity prices. The other macroeconomic

variables (exchange rate variations, inflation, real interest rate credit growth, Reserves/M2) were not associated, in general, with the onset of banking crises.

The institutional factors tested were: central bank independence, explicit deposit insurance, financial liberalization and moral hazard (interaction term when both, financial liberalization and explicit deposit insurance are present). These factors were significant in explaining increases in the probability of banking crises.

Berg and Pattillo (1999) is quoted in Berg, Andrew, E. Borensztein, G.M. Milesi-Ferretti, and C. Pattillo (1999) as the main reference for the EWS model for currency crises of the Developing Countries Studies Division of the IMF. In the first section, the paper evaluates the signal extraction model contained in Kaminsky, Lizondo and Reinhart (1998), and then proposes a methodology based on probit-estimates of the probability of crises.

Although the KLR model performs better than an un-informative benchmark (random guesses), and is able to predict some crises in-sample, it still misses a large number of crises and most alarms given by the model are false. With respect to the out-of-sample performance, most alarms are false, and the performance for the timing of crisis call correctly is poor. However, the KLR model is successful in ranking the countries by the severity of their crises and the fitted probabilities from the composite indexes are significant predictors of crisis probabilities.

BP proposes a methodology that preserves some elements of the KLR model, but has major departures in the estimation. The dependent variable is a binary variable that takes the value of 1 if there is a crisis in the subsequent 24 months, and zero otherwise "p". They estimate a multivariate probit equation for the probability of "early" signal of crisis.

The advantages of their methodology over the KLR are: "(1) it is possible to test the significance of the threshold concept; (2) the resulting composite index aggregates the explanatory variables taking account of the correlations and marginal contributions of each variable; and it is possible to test for the significance of individual variables and the constancy of coefficients across time and countries.

Threshold Concept. To test of the threshold concept, Kaminsky, Lizondo y Reinhart assumes that the probability of crises in the 24 month-window is a step function of the value of the indicator. Berg and Pattillo test this hypothesis by fitting a bivariate probit equation for the panel of the binary crises variable of the form:

$$p = f\left(\alpha_0 + \alpha_1 b(x) + \alpha_2 I + \alpha_3 I(b(x) - T)\right) \quad (1)$$

where T is the threshold, $b(x)$ is the percentile value of the individual indicator x, and I is the indicator function if there is a signal (if $b(x)>T$). Applying this equation for each indicator, allows to test whether the KLR assumption is justified ($á_1=á_3=0$, and $á_2=1$). The results of BP show that this assumption misses an important part in the variation in the probability of crises as function of the variables.

Multivariate Logits. The Logit approach is not restricted to generate indicators in a variable by variable basis, therefore, Berg and Pattillo (1999) estimate multivariate Logit equations for the probability of crises.

Analytically the model can be represented by:

$$L = \prod_{y_i=0} F(-b'\boldsymbol{X}_i) \prod_{y_i=1} [1 - F(-b'\boldsymbol{X}_i)]$$

The previous model is estimated by using the maximum likelihood methodology:

$$\log L = \sum_{t=1}^{T}\sum_{i=1}^{n}\{Y_{it}\log[F(\beta'\mathbf{X}_{it})]+(1-Y_{it})\log[1-F(\beta'\mathbf{X}_{it})]\}$$

They estimate three models: in the first model the explanatory variables are in binary form (1 if they have cross the threshold, 0 otherwise); in the second model the variable (expressed as a percentile) enter linearly to the probit specification; and the last estimation is piecewise-linear model, a multivariate generalization of equation (1).

The ranking among the three Logit models is ambiguous. However, all the models outperform the KLR model both for in-sample and out-sample estimation. The out-of-sample tests also show that the linear model tends to out-perform the piecewise-linear model. This suggests that the threshold and indicator approach of Kaminsky, Lizondo and Reinhart add little explanatory power to the estimation.

3.4. Other approaches

Sachs, Tornell and Velasco (1996) use a simple model to identify why, after the Mexican crisis of 1994, some emerging countries faced financial crises while other countries did not. The purpose is to identify whether there are some fundamental variables that can explain the crises or whether the crises episodes were originated by unpredictable contagion of the Mexican crisis.

The dependent variable is an index of exchange rate pressure (measured as an average of percent change in devaluation and loss of reserves). The index is used as the dependent variable in a cross-country regression. Therefore, they do not study a discrete event (crisis, no crisis). The idea is to predict which countries should face the greatest pressure in the index in the period of international financial turbulence generated by the Mexican crisis.

The authors present a simple static multiple equilibria theoretical models. The exchange rate peg is maintained if the level of reserves can finance a capital outflow. Additionally, in the event of a nominal devaluation, the devaluation policy depends on the health of the banking system (weaken by a previous lending boom, since it would reduce the quality of the bank portfolio). It is a standard model of speculative attacks and multiple equilibria. It provides the theoretical justification for the three variables with sounder empirical results. Using a sample of 20 countries (23 in a second version) their estimate a **cross country** regression for 1995. In the explanatory variables, they include a dummy for weak fundamentals and interact with this dummy and the explanatory variables.

Their model identifies three factors of vulnerability: Real exchange rate appreciation, Low level of reserves (high M2/reserves), and a recent experience of a lending boom (magnitude of increase in credit). While variables, usually considered explanations of the onset of crises, like excessive capital inflows, loose fiscal policies and high current account deficits are not a good explanation of the crises.

Signals and limited dependent variable approaches define crisis as a specific event in time, with the disadvantage of ignoring the transition dynamic involved in the crisis. Considering these limitations Vlaar (1999) develops a new methodology for predicting currency crises and exchange rate distress.[11] The model assumes two different regimes, one for tranquil and one for crises episodes. In the second regime there is a change in the distress of the economy, both in terms of mean and volatility. This methodology allows studying not only the probability and timing of a crisis, but makes a clear distinction

[11] The methodology is presented as a combination of the limited dependent regression (DD) and the cross-country studies (STV).

between different degrees of stress in the system and the severity of the crises.

$$
\begin{aligned}
I_{it} &= X1_{it}\, b_1 + l_{it} J_{it} + e_{it} \\
e_{it} &\sim (1 - l_{it}) \cdot N(-l_{it} J_{it}, h_{it}) + l_{it} N((1 - l_{it}) J_{it}, h_{it} + d_{it}) \\
h_{it} &= X2_{it}\, b_2 \\
l_{it} &= \frac{e^{X3_{it} b_3}}{1 + e^{X3_{it} b_3}} \\
J_{it} &= X4_{it}\, b_4 \\
d_{it} &= X5_{it}\, b_5
\end{aligned}
\tag{2}
$$

The *exchange rate pressure* is based in an index (index of crises, I_{it}) formed as a weighted average of variations in the exchange rate and reserve losses[12]. This index is assumed to have different mean $(-l_{it} J_{it}, J_{it})$ and variance (h_{it}, d_{it}) when the economy is stable or when a crisis hit the system. The model includes six equations for estimation. The two main equations are the equation of the index, and a Logit equation for the probability of regime change. The other two equations estimate the time varying mean and variance under the stable and crisis regime (four equations in total).

It is necessary to define a threshold of variation in the index that defines the crisis episodes (10%). The estimation generates two probabilities, the probability of entering a crisis regime and the probability of a crisis. This distinction is important because the probability of regime change signals the vulnerability due to economic conditions, and it tends to fall after a crisis has hit the economy. On the other hand, the probability of crisis is dominated by current volatility and remains high after a crisis episode.

The estimation uses monthly data for a panel of 31 emerging economies, and includes information on real exchange rates, reserves, inflation, GDP, bank credit and current

[12] In the empirical section, we employ this index to measure the exchange rate pressure as an additional macroeconomic explanatory variable in our banking distress estimations.

account, debt and monetary variables. Since the estimation uses monthly information, it is important to include lags of the variables to be useful as early warning indicators. The results indicate that inflation, overvalued exchange rates and reserve losses have a significant explanatory power both, in the exchange rate pressure and in the probability of switching to the volatile regime. Other important elements that can trigger a crisis are solvency problems (high imports/exports, overvalued currency), and liquidity problems (reserves/M2 and Short term debt/reserves).

4. Bank Failure and Institutional Early Warning Systems

The second strand of the literature concentrates on individual bank failure. The traditional approach to assess financial vulnerabilities in individual banks is closely related with the work of supervisors of the banking system and rating agencies. In this approach, indicators of bank strength are summarized by some key variables originally evaluated during on-site examinations by the supervisory agencies. The most known rating systems is known as CAMEL the acronym for the criteria: capital adequacy, assets quality, management, earnings and liquidity.[13] Frequently, the score of individual performance for each institution is computed relative to all the other institutions, generating a unique rating index. However, recently there has been an increasing recognition of the limits of this approach. Although the supervisory reports include an overall assessment of the macro-legal environment in which the banks operate, the CAMEL systems, and related methodologies, are design to assess the condition of an institution in a point in time, and their are highly responsive to changes in the economic conditions and the bank

[13] The CAMEL system was the first uniform rating system for financial institutions. It was originally design for on-site

performance. Also the links between the macro and micro dimensions of financial vulnerability of the banks is not well explored. Gonzalez-Hermosillo (1999) proposes a methodology to study the effect of both dimensions that can help to predict crises and time their occurrence. Some authors have also questioned the relevance of the CAMEL indicators to assess vulnerabilities in emerging and underdeveloped economies (Rojas Suarez (2001)).

In this section we start by surveying some systems used by official supervisors to assess the risk of individual banks and the prediction of banking distress. Later in the section, we review other recent research in individual bank failure and early warning systems.

4.1. Institutional Supervisors

Institutional supervisors use a wide range of practices for assessing financial vulnerability of individual banks. Sahajwala and Van den Berg (2000) propose a classification of the different systems used by supervisory institutions of G-10 countries: supervisory bank rating, financial ratio and peer group analysis, comprehensive bank risk assessment, and statistical models. Using this classification we briefly summarize the different methodologies of institutional supervisors.

4.1.1. Supervisory bank rating systems

This system was originally design for assessment on the performance of financial institutions based in on-site examinations. As mention before, the most prominent is the CAMEL system that in 1996 evolved into CAMELS to include an additional component:

assessments in the US in the 1980's.

sensitivity to risk. The system consists on a rating for each individual component using a scale from 1 (best) to 5 (worst) based on an extensive on-site evaluation of qualitative and quantitative information of the financial institution. From the individual component ratings, a composite index is calculated. The supervisor has some discretionary power to weight the ratings of different components into the composite index. The individual ratings and the composite index are then used to decide further supervision or specific action.

There have also been developed off-site systems based on quantitative analysis intended to replicate the on-site ratings. An example of off-site rating is the US Federal Deposit Insurance Corporation (FDIC) CAEL system that uses a rating methodology similar to CAMEL.[14]

The rating systems are effective measures of the current financial condition of banks, and constitute an essential tool for banking supervision. However, these systems have several limitations. They reflect the condition of the bank under study at the time of the examination, and are highly responsible to changes in bank decisions or economic conditions. In addition, the risk assessment generated is an ex-post measure of financial problems. Therefore, the rating results may come too late to take preventive action. Another limitation of this approach is that the different ratings neither provide information about the potential sources and areas of fragility of the bank operation, nor show the contribution of particular decisions taken by banks in the overall fragility of the institution.

[14] Other countries off-site rating systems are the PATROL (Italy), ORAP (France) and a system developed by the Netherlands Bank.

4.1.2. Financial ratio and peer group analysis systems

The financial ratio and peer group analysis systems use ratios of financial variables of the banks to replicate the on-site analysis of a banking institution beyond a rating of performance. The financial ratio analysis defines a threshold for the chosen ratios and signals a warning whenever the ratio exceeds this threshold. The peer group analysis systems group banks on the basis of their size or financial activity, and performs a comparative analysis of the ratios within the current ratios of the peer group and their past.

These approaches have the advantage of providing a systematic assessment of bank activity, can detect trends in the banking industry, point to specific areas of weakness in a bank and filter potentially problematic banks. However, the ratio analysis has limitations to identify the risk taken by the financial institutions. The peer group analysis can detect outlier banks, but fails to detect systemic problems, i.e., when there is a deterioration of the financial conditions of the whole peer group. The uses of these systems for predicting banking distress is limited, but the extensive analysis they allow are a natural complement of an EWS.

4.1.3. Comprehensive bank risk assessment systems

This system is the broader approach undertaken for risk assessment. It provides a complete assessment of qualitative and quantitative risk factors in a banking institution.

The system defines relevant factors of risk profiles to be analyzed, then this aggregates the

bank or banking group into business unites, and assesses the condition for all risk factors, for each business unit. This methodology allows the aggregation of risk assessments at different levels of the institution or group.

Countries that have introduced comprehensive bank risk assessment systems are the UK and the Netherlands. The UK RATE system, for example, evaluates for each business unit, structure and for the whole bank, nine areas of risk CAMEL-B: capital, assets, market risk, earnings and liabilities and business, where the business factor includes the bank's overall business and external environment. In addition to the current condition of the bank's current risk profile, the report includes an assessment of its likely evolution over the next period, using the information available in the comprehensive assessment and the supervisor's forecast of the market.

This approach allows to identify areas of potential vulnerability and to account for the specificity of each institution. It also depicts a complete picture of the banking activity in the whole system. However, its main disadvantage is the resources needed for performing such extensive evaluation in a periodic basis.

4.1.4. Statistical early warning models

The previous methodologies for risk assessment of banking institutions have limitations to signal potential financial distress and bank failure, either because they present the evidence of current conditions of banks, or because it is very costly to perform a comprehensive assessments. During the 1990's several efforts were made by institutional supervisors of developed economies to forecast the future financial condition of banks,

and to constitute early warning models for financial problems in individual banks. In addition the statistical models allow determining causal relationships between economic and financial variables and the financial distress or fragility of the financial intermediaries. The different methodologies could be classified in prediction of crisis, failure and timing of failure, and expected loss models.

Prediction of ratings

This methodology is aimed to forecast the estimate the probable rating that financial institution would have in an on-site examination (CAMELS). Using limited dependent regression techniques the models determine the historical relationship between a set of variables, included in the periodic reports of banks, and the ratings assigned in on-site examinations. The results of the estimated equations are then used for a periodic estimation of the ratings. Although this estimation reflects the current condition of the bank, the possibility of performing this analysis in a more regular basis can show any deterioration in the condition of the bank. Moreover, these models can produce an ex-ante indicator of financial problems, because they allow estimating the likelihood of rating downgrade of a financial institution, and the specific areas responsible for this downgrade. The systems that use this methodology are the US Federal Reserve SEER rating model, and the US FDIC SCOR model.[15]

The SEER model has an indicator function I which take a value 1 when the dependent variable y_j belongs to a predetermined interval and cero otherwise. After defining this threshold they proceed to estimate the following likelihood model:

[15] System for Estimation Examination Rating (SEER), and Statistical CAMELS Off-site Rating (SCOR).

$$L(a,b)=\prod_{i=1}^{n}\prod_{j=1}^{m}\left[F(a_{j+1}-b'\mathbf{x}_i)-F(a_j-b'\mathbf{x}_i)\right]^{I_{ij}}$$

$$\log L(a,b)=\sum_{i=1}^{n}\sum_{j=1}^{m}I_{ij}\log[F(a_{j+1}-b'\mathbf{x}_i)-F(a_j-b'\mathbf{x}_i)]$$

The last equation must be estimated by maximum likelihood to obtain the vector of parameters a and b'.

Failure and timing of failure

Another sets of models of institutional supervisors aim to estimate failure and its timing. This estimation must be performed over a sample of failed banks, and therefore it requires historical data of such events. In the absence of such events, it is possible to define a weak or distressed bank and perform the estimation for such events.

The SEER model of the FRS has a risk rank model that predicts the probability of failure over a two-year time horizon. Since there have been few events of failure in the US during the 1990's, the model uses pooled cross-section and time series data for the period 1985-1991 and estimates the probability with a probit regression. In addition to the probabilities of failure per bank, the model's output contain a "risk profile analysis" that compares the results of a given bank with its historical evolution and with similar banks that belong to its "peer group". The distribution of rank profiles provides a measure of the overall risk of the banking system.

The US OCC has developed two models using this methodology. The first estimates the probability of failure and the probability that a bank will survive beyond a two-year horizon. The second model (Bank Calculator), under construction, will estimate the probability of failure using a standard logistic regression. The set of explanatory variables

will include not only financial variables from bank reports, but also variables that can account for changes in the "environment" of the banking activity. The variables are classified according with three categories of risk: bank portfolio risk, bank condition risk and bank environment risk.

Expected loss models

These models are an alternative for countries where the incidence of bank failure has not been frequent enough to allow its prediction. The French Banking Commission's Support System for Banking Analysis (SAAB) estimates potential future losses to predict future solvency of a bank. The system estimates the probability of default of individual loans and constructs a potential loss for the next three years. This potential loss is subtracted from the level of reserves of the banks, if the level of remaining reserves goes beyond the legal requirement it flags problems in future solvency. This approach allows an aggregation at any level of the banking activity of a country, however, its clear disadvantage is the intensity and disaggregation of information it requires.

4.2. Indicators

Rojas-Suarez (2001) questions the use of the CAMEL variables to assess risk of financial institutions in developing countries. She argues that the system, designed for developed financial systems, performs poorly in signaling problems in emerging markets because of accounting deficiencies, supervisory framework and the illiquidity in the market for bank shares. She proposes an alternative set of indicators that can provide a better ranking and serve as indicators for early warning of financial problems. The alternative indicators

proposed are: interest rate paid on deposits, interest rate spreads, rate of loan growth and growth of interbank debt.

She tests the performance of these indicators for four episodes of banking crises: Mexico 1994-95, Venezuela 1994, Colombia 1982-86 and Asia 1997, and concludes that the indicators out-perform traditional indicators. The traditional indicators tested include Capitalization (risk-weighted capital-asset ratio) Change in equity prices, Net profits to income, Operating Costs to assets and Liquidity Ratio.

The alternative indicators provide significantly out-perform the traditional indicators in predicting banking problems for all the episodes analyzed.

Ahumada and Budnevich (2001) propose an early warning indicators system for the Chilean banking system. Since in the last 15 years there has not been a relevant history of bank failure, it is not possible to base and EWS for Chile in the estimation of probabilities of failure or survival of banking institutions. The authors adopt an alternative methodology that attempts to estimate two fragility variables: the ratio of non-performing loans-to-loan portfolio, as an indicator of fragility arising from credit risk; and the interest rate spread in the interbank market, as a measure of financial fragility coming from liquidity risk.[16]

The explanatory variables include a set of macroeconomic variables, such as economic activity, interest rate and the real exchange rate; and a set of bank-specific variables regarding the criteria: capital, efficiency, liquidity, earnings, loan growth and market based. For the estimation of non-performing loans, peer group differences in the

[16] The interbank spread is calculated as the difference between the real interest rate charged among banks for short-term daily liquidity loans and the liquidity interest rate for overnight deposits in domestic currency at the central bank. This variable is considered as a market-based indicator of financial fragility.

estimation parameters are allowed by defining three groups: foreign, large domestic and financial companies. For each variable, a reduced form regression is estimated in a panel data set. The model is estimated for different lags, starting at twelve, for each explanatory variable and is represented by:

$$y_{it} = \sum b_i y_{it-j} + g_i X_{it} + e_{it}$$
$$e_{it} = m_i + n_{it}$$

The results of the estimation suggest that while bank-specific variables are important determinants of credit risk fragility, macroeconomic and market variables play a much more important role in explaining liquidity risk. Capital, liquidity and efficiency reduce the percentage of non-performing loans, and the market interest rate and loan growth increase fragility. Higher profit margins may reflect loose credit policy since tends to reduce fragility in the short run, but later on may be a source of increased fragility. The peer group analysis suggests than the impact of explanatory variables on fragility differs among groups. In particular, the financial companies' fragility seems to have completely different determinants than the banks, except for the assets to liabilities ratio, none other variable appear to be significant in explaining their fragility.

This methodology allows studying the bank-specific and macroeconomic determinants of the indicators of bank fragility; however; its use as and EWS is limited. First, it has no definition of what a warning could be, i.e., what is the benchmark that defines whether certain increase in non-performing portfolio or interbank spread is normal or dangerous. Second, the indicators proposed as fragility proxies may allow for fragility differences, for example, it is possible that two banks have the same non-performing loan ratio, but different capital and liquidity reserves. Finally, the model is not forecasting the indicators

over a time window for early warning.

4.3. Failure probability and timing of failure

Gonzalez-Hermosillo (1999) studies the contribution of microeconomic and macroeconomic factors in five episodes of banking crises (Southwest, Northeast, and California for the US, Mexico, and Colombia). This paper is an attempt to marry two strands in the literature on the prediction of banking crises: models that use macroeconomic and aggregate data and models that use bank specific information obtained from the banks' balances. The selection of the explanatory variables for banking distress must account for the sources of risk of the banking activity. The explanatory variables included are proxies for: banking fragility, market risk, credit, risk, liquidity risk, moral hazard, macroeconomic conditions, contagion and herding, and profitability and efficiency.

The paper analyzes individual bank failure estimating the probability of crises and the timing of the crises. The contribution of each explanatory variable is measured by its contribution to the probability and the survival rate of the bank. The probability of time failure is estimated using fixed effects Logit model. The timing of failure is estimated using a non-parametric (time varying) proportional hazard model. The estimation is performed using quarterly panel data information of banks and macroeconomic variables for each episode.[17] Both estimations require the definition of failure or "severe distress" events. There are two alternative definitions used: in the first, failure of a bank is

[17] The sample used in each episode uses a time window that covers from some years before the crises to few quarters after the peak of the crises.

considered the period before government intervention in the bank. For the second definition, a ratio of banking distress is generated,[18] and whenever the index goes beyond certain threshold, an event of severe distress is recorded. Although the distress ratio tends to overstate the number of occurrences of banking problems, it may also provide an earlier warning of problems in the bank under question.

The ratio of non-performing loans to total assets (a fragility variable) is the main indicator of banking problems, although the main increase in this variable is close to the beginning of the bank's crises. The ratio of capital equity to total assets has also a significant explanatory power in all episodes.

The results show the importance of the macro and micro dimensions of financial vulnerability. Even though the models with bank specific variables only perform well, the inclusion of macroeconomic and banking sector variables (contagion) clearly improve the estimation results. For comparison purposes, the author also estimates both models using a standard CAMEL approach. The performance of this model is poor, and improves significantly when the ratio of non-performing loans to total assets and the ratio of capital equity to total assets are included.

The availability of quarterly data improves the use of the limited dependent regression for early warning of financial problems. It is possible to monitor the evolution of the probability and the survival function more closely and take preventive action before actual bank failure. However, its use as early warning requires further elaboration of when the results can be considered a signal of distress.

[18] The distress index is the ratio capital equity and loans reserves minus non-performing loans to total assets. This ratio can take negative values, however, as it approaches zero, the bank resources become insufficient to cover non-performing loans.

Another potential problem is the estimation of the models using a window around banking crisis episodes, because the results are difficult to extrapolate to normal periods. For example, the estimation of bank failure for Mexico uses information from the first quarter of 1992 to the last quarter of 1995; it is clear that by 1992 the banking portfolios already contained high sources of risk.

Using a similar methodology Dabos and Sosa (2000) estimate survival and hazard functions for the Argentinean banking crisis. The financial indicators used to reflect the banks' financial "situation" was selected from the CAMEL approach, and include ratios of net worth/assets, liabilities/assets, liquidity/deposits, structural liquidity, efficiency, non-performing loans, and profitability. The results show that although there is evidence of contagion, the bank failures were significantly explained by economic and financial factors of the institutions. Of all the variables, the liabilities-to-assets ratio had the larger effect in default risk.

4.4. Non parametric EWS

Kolari *et al.* (2000) compare the predictive power of two early warning methodologies for large US bank failures: the limited dependent regression (Logit), and a non-parametric trait recognition model (henceforth TRM). The use of limited dependent regression is the main technique used for EWS. However, the authors identify some drawback of this methodology: (1) it is not possible to determine which variables are the most useful in predicting the event (bank failure), the result only indicates the effectiveness of the variable in discriminating between the two groups (failed and non-failed banks); (2) the

estimation results do not provide information about how each variable affects Type I and Type II errors per se; and (3) these models are not well suited for examining interactions between the variables.

The set of independent variables for early warning only includes financial information of specific banks. The authors conclude that both models perform well in predicting in-sample failure, using information one year before the crises. However, the TRM outperforms the Logit regression when the information is two years before the crises and also for out-sample tests. Another advantage of the TRM is that it is much more stable to the sample. We briefly describe this new methodology below.

The TRM is a non-parametric recognition technique that attempts systematic patterns in the data.[19] In a similar fashion to the signal extraction approach, this methodology identifies a set of variables that exhibit abnormal behavior preceding bank failure. The financial variables of failed banks will tend to be located in one of the tails of the distribution of the variables. For each variable two cut-off points are selected, defining three regions.[20] The value of each variable is coded according with their position in the three regions: Low (00), Middle (01) and up (11). A binary code XY has four classifications: X=0 (ML), X=1 (U), Y=0 (L) and Y=1 (MU).

To identify patterns and allow the interaction of different variables, the methodology proceeds to form strings of indicators, for example, a three variable string is given by $X_1Y_1X_2Y_2X_3Y_3$. The interaction between the different variables is explored by forming a

[19] "The TRM is closely associated with neural network models in that it seeks to exploit information contained in complex interactions of the independent variable set" Jagtiani et al. (2000) pag. 8.

[20] The criteria for the thresholds can be statistical ($\pm x$ standard deviations from the mean) or based on discretionary judgment.

trait matrix from these strings. The trait matrix considers all the possible combinations of single codes for all the variables. A three variable-three trait indicator, for example, is formed by *pqrPQR*, where case letters point the position (from 1 to 6) in the string, and capital letters indicate the respective value (0 or 1).[21]

The trait matrix is then used to identify the traits of failed and non-failed banks. A safe feature is trait frequently present in non-failed banks, and vice versa for an unsafe feature. The classification of safe and unsafe features requires defining certain occurrence of the score in episodes of failure and non-failure (e.g., a trait is an unsafe feature if it occurred at least z% of the cases of bank failure). The entire trait that cannot be classified as safe or unsafe features, as well as those that reveal no new information, are drooped. Each bank is then voted, counting the number of safe and unsafe features. The banks are classified using a voting matrix, with the number of safe votes as rows, and the number unsafe votes as columns. The last decision is to define the signal emitted by each cell of this matrix.

In a similar paper Jagtiani *et al.* (2000) estimate a logit model and a TRM to predict inadequate capitalization of banks as a proxy for incipient financial distress. The dependent variable used in this study is the capital-to-assets ratio.[22] This estimation can serve as an EWS and flag those banks that would require closer supervision before the financial distress builds up. This application is particularly useful for banking systems with limited episodes of bank failure. Another advantage of this methodology is that "the

[21] For example, *pqr*=111 has a value $PQR=X_1X_1X_1$, and only shows the difference between up and middle low of the first variable. The trait *pqr*=126 has a value $PQR=X_1Y_1Y_3$ and interact all the information contained in the first variable with having a low or middle up level of the third.

[22] The cut-off point of the variable is defined as 5.5%. The estimation uses year-end data for 1988, 1989 and 1990 to obtain sufficient number of troubled banks.

financial distress event is not biased by regulatory actions that typically take place prior to bank closure or technical insolvency".

The TRM methodology has the disadvantage of requiring a lot of discretionary judgment. The selection of independent variables, the definition of the thresholds for the variables, the classification of features, and the decision of signals in the voting matrix are arbitrary. The results are sensible to all these decisions, and they may even introduce a bias in the estimation.

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