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Proposed model for the identification and prediction of weak banks, in the context of the Basel Committee on Banking Supervision

Modelo propuesto para la identificación y predicción de bancos en dificultades, según el contexto del Comité de Supervisión Bancaria de Basilea

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Abstract

This paper proposes and describes an empirical research whose objective is to determine a model for the identification (which forms part of the BCBS guidelines of 2002 and 2015[1]) and the prediction of weak banks, since detection of the identification or the prediction is a property desirable of any alarm system (Labatut, et al., 2009). The model is based on the application of discriminant analysis to nine Mexican banks in 1999, a year that was key to the stability and certainty of the Mexican financial system with the publication of the LPAB[2] and the creation of IPAB[3]. The financial indicators considered have been used by Beaver, Altman and Ayala, and furthermore the context of this indicators is currently included into

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[2] Ley para la Protección al Ahorro Bancario (Bank Savings Protection Law)
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the framework of Basel II and III[4]. With the discriminant function obtained from proposed model and with base on study of the case, the model was proved with nine Mexican banks, who were involved in the Mexican banking crisis, resulting a 100% in the identification of their respective financial situation. In addition, this situation was predicted to four Mexican banks in the period 2000-2008 and a bank from the United States, affected by the sub-prime crisis, for the period 2000 2010; the prediction based on the empirical results agrees, in general, with the annual reports of the IPAB and with the opinions of presidents of the American bank. It is concluded that the proposed model can be used, in addition to the institutional early warning models, to predict if a bank is weak or not, considering, additionally to the effect on own resources the allowance for loan losses. It should be emphasized that, given the mathematical complexity of the discriminant analysis and the hypotheses involved, we implemented statistical techniques and algorithms for their development.

JEL code: G01, G21, C52
Keywords: Weak banks; Discriminant analysis, Financial ratios

Resumen

Este trabajo propone, y describe, una investigación empírica cuyo objetivo es determinar un modelo para la identificación (la cual forma parte de las orientaciones del BCBS de 2002 y de 2015[1]) y la predicción de bancos en dificultades, ya que la detección de una de ellas es una de las propiedades deseables de cualquier sistema de alarma (Labatut, et. al., 2009). El modelo se basa en la aplicación del análisis discriminante a nueve bancos mexicanos en 1999, año que fue clave para la estabilidad y certidumbre del sistema financiero mexicano con la publicación de la LPAB[2] y la creación del IPAB[3]. Los indicadores financieros considerados han sido utilizados por Beaver, Altman y Ayala, y el contexto de estos indicadores está incluido actualmente dentro de los marcos de Basilea II y III[4]. Con la función discriminante obtenida del modelo propuesto y con base en el estudio del caso, el modelo se probó con nueve bancos mexicanos, que estuvieron en la crisis bancaria mexicana, lo cual dio un resultado del 100% en la identificación de su respectiva situación financiera. Además, se predijo esta situación para cuatro bancos mexicanos en el periodo 2000-2008 y un banco de los Estados Unidos, afectado por la crisis sub-prime, para el periodo 2000 2010; la predicción basada en los resultados empíricos concuerda, en general, con los informes anuales del IPAB y con las opiniones de los presidentes del banco estadounidense. Se concluye que el modelo propuesto puede utilizarse, adicionalmente a los modelos de alerta temprana institucionales, para predecir si un banco está o no en dificultades considerando, además de los recursos propios, la provisión para pérdidas crediticias. Es necesario señalar que, dada la complejidad matemática del análisis discriminante y a las hipótesis involucradas, se implementaron técnicas estadísticas y algoritmos para su desarrollo.

[4] Conjunto integral de reformas elaborado por el BCBS para fortalecer la regulación, supervisión y gestión de riesgos del sector bancario.

Código JEL: G01, G21, C52
Palabras clave: Bancos en dificultades, Análisis discriminante, Indicadores financieros

Introduction

In recent decades, financial and, in particular, banking crises have become more frequent, both in developing and industrialized countries, which translate into a severe shrinkage in production and heavy tax and financial losses (Morón, 2003; Redondo and Rodríguez, 2014). In developing countries, an example of this is the crisis towards the end of 1994 that hit the Mexican banking sector, following its reprivatization four years before in 1991-1992, due to the high NPL ratios caused by high interest rates, the shrinking supply of loanable funds, the decrease in the level of financial intermediation and the economic slowdown, which brought the intervention of the State in the capitalization of said sector. For their part, industrialized countries have also suffered through such situations, as exemplified by the worst financial crises in recent memory, which began in August 2007 and was linked to problems in the real-estate sector of the United States and, particularly, with the subprime mortgages. In the current global economy, no country is exempt from contagion in the event of a crisis as deep as the American financial crisis, since it not only affects mortgage credit but rather the entire financial system as a whole (Saavedra, 2008).

In order to avoid systemic banking crises, the Financial Stability Forum (FSB), substituted by the Financial Stability Board (FSB) in 2009, delegated the development of international financial supervisory guidelines applicable to weak banks to the BCBS in 2001, which were updated in 2015 in response to the 2007-2009 financial crisis. These guidelines stablish that, in order to identify weak banks, supervisors can employ methods based mainly on quantitative financial information that include an analysis of the financial statements and early warning systems (BCBS, 2001; Redondo and Rodríguez, 2014). The term "*weak banks*" refers to the report, issued by the Work Group in 2002, where it established that "*a weak bank is that in which its liquidity or solvency is or will be affected, unless an improvement occurs in its financial resources, risk profile, strategic direction of the company, risk management capacity, or quality management*".

For its part, the Institute for the Protection of Banking Savings, based on the analysis of the financial information of the Mexican banking institutions, carried out activities at the national level allowing to preemptively detect whether a bank is in difficulties. Such is the case of the "Early Warning System" that sends a warning regarding a deteriorating situation that could lead to possible insolvency or bank failure (IPAB, Annual report 2002).

In the last decade, the market instability that began in mid-2007 highlighted once more the importance of *liquidity* in the functioning of the financial markets and the banking sector. The

change in the market conditions revealed the speed with which liquidity can be depleted, and exemplified that the lack thereof can be prolonged for a long time; thus, laying the foundation for its *liquidity* framework, the bcbs144 was published (see Table 5). Basel III (bcbs188, see Table 5) emerged in response to this international financial crisis, since Basel I and II focused on the reserve levels that banks must maintain for bank losses.

One of the reasons why the economic and financial crisis that erupted in 2007 was so severe is that the banking sectors of numerous countries had accumulated an excessive amount of *leverage* in and out of balance (bcbs189, see Table 5).This was in addition to the gradual erosion of the level and quality of its capital base. At the same time, numerous banks maintained insufficient levels of liquidity. Due to all of that, the banking system was not able to absorb the systemic losses suffered by the trading and credit portfolios. The crisis was aggravated by a *procyclical displacement* process and by the interconnexions between systemic institutions through complex operations. At the peak of the crisis, the market stopped trusting in the *solvency* and *liquidity* of numerous banking institutions. The deficiencies in the banking sector were quickly transmitted to the rest of the financial system and the real economy, causing a *generalized shrinkage of the liquidity and credit* available. Finally, the public sector had to intervene with unprecedented liquidity injections and with the provision of capital and guarantees (bcbs189).

Due to the aforementioned, the BCBS has currently established strong regulations at the international level to prevent the severity of the economic and financial crisis. The Early Warning indicators, among others, are considered measurement instruments within these regulations (bcbs144, see Table 5). Similarly, the Financial System Stability Council (CESF for its acronym in Spanish, Annual report, 2011) has been created in our country for the same purpose.

Thus, and given the fact that weak banks can drive or worsen financial crises, the need for early identification of said banks, through prediction methodologies, is evident (Redondo & Rodríguez, 2014). This would allow to take corrective measures to restore their solidity and limit their potential loses. Therefore, this work proposes a model that allows identifying and predicting a weak banks, considering that even when most explanations of such difficulties are of the macroeconomic type, there are also works that relate them to the indicators of the bank itself, that is, explanations of the microeconomic type (Hernández and López, 2001).

Chronological description of the financial situation of Mexican Banks and factors that have influenced it during the 1982-2009 period

The Mexican banking system was nationalized in 1982 and its operations were controlled until 1988; it was in that year that the financial liberation began, culminating with the repri-

vatization of the banking system and the introduction of foreign competition in 1994 (López and Snowden, 2000). Similarly, due to different factors—among which was the fact that the *total non-performing portfolio* of the banks exceeded their total equity—on December 1994 a devaluation of almost 100% occurred which, in addition to high interest rates at the beginning of 1995, generated an exchange rate and credit imbalance in bank operations and some of these went from technical bankruptcy to full bankruptcy (Correa, 1999).

During the period of 1995-1998, actions were taken to face the Mexican banking crisis (Turrent, 2003; Murillo, 2005). The first of these was to solve the liquidity problems, followed by solving the solvency problems. In the case of liquidity, the *Banco de Mexico* (BANXICO) established a dollar credit window to prevent banks from defaulting on the payment of foreign currency liabilities; and in the case of solvency, four programs were implemented:

1) Temporary Capitalization Program (PROCAPTE for its acronym in Spanish)
2) Intervention of the banks that were in a more critical situation to ensure their recovery; which allowed the institutions to enter the Reorganization Program
3) A second Capitalization and Portfolio Purchase Program (PCCC for its acronym in Spanish)
4) Support programs for bank debtors. These programs, destined to strengthen the Mexican banking sector, were carried out through the Banking Fund for the Protection of Savings (FOBAPROA for its acronym in Spanish) (Hernández and López, 2001).

The aforementioned banking crisis evidenced the protection mechanism of the resources of the depositors, since it was not enough and required the support of the Federal Government (Hazera *et al*., 2015) to prevent the collapse of the financial and payment systems. Thus, on January 19, 1999, the LPAB was published giving rise to the IPAB on May 21, 1999, which absorbed practically all of the liabilities of the FOBAPROA. This legal framework made possible a greater regulation of the protection of savings and the need to act in coordination with all other financial authorities in the execution of the necessary actions to procure the solidity of full-service banks. Additionally, the IPAB made possible the acquisition or merger of one bank with another with greater solvency, as well as the disappearance or capitalization of some banking institutions. It should be mentioned that with these measures—combined with the sale of non-strategic assets, the increase of the reserves, and the reorganization of the total non-performing portfolio —the generation of profits allowed to improve the bank capitalization indices in 1999, which, based on the Basel Accords (Hernández and López, 2001), exceeded the 8% minimum required by the authorities by a wide margin. It is therefore reasonable to consider the year 1999 as ideal to represent the sample space and, according to Mora, 1994 seems ideal to select a sample with data corresponding to the same period.

With the conclusion of the New Program in 2005, the IPAB exchanged instruments issued

by the FOBAPROA for new securities and led to the replacement of the PCCC in which some of the banks analyzed in this work participated and survived the financial crisis.

In 2007, a segment of the international financial system fell into an intense crisis caused by an increase, in the United States, of the past due loans indices of the lower quality mortgage loans known as "subprime" (BANXICO, Annual Report, 2007) which, in turn, led to the bankruptcy of Lehman Brothers in September 2008 and, consequently, the intensification of the international financial crisis and the propagation of its effects to emerging economies. Thus, the cost of interbank credit rose abruptly, and the liquidity of the financial markets dropped even more, complicating the situation as a result of the feedback links between the financial and the real sectors. Therefore, in addition to the liquidity crisis, the financial markets faced a solvency problem that led to the risk of collapse of the international financial system. In this context, the cash flows of emerging economies contracted significantly, affecting the exchange rates and equity and bond markets of many of these countries. These facts affected Mexican banking; consequently, in coordination with the Secretariat of Finance and Public Credit (SHCP for its acronym in Spanish), BANXICO implemented different actions directed to maintaining the good functioning of the domestic financial markets (BANXICO, Annual Report, 2008). This helped Mexican banks continue generating profits and be well-capitalized, with sufficient credit reserves to face the rise of the past due loans indices in 2008 (BANXICO, Financial System Report, 2009).

Classification of the nine Mexican Banks analyzed

To apply the discriminant analysis, it is necessary to classify the individuals into alternative groups, for this purpose Table 1 shows a few of the IPAB guidelines that helped classify *weak banks* and *nonweak banks*.

Table 1

Description of some IPAB guidelines and the respective measures taken

DESCRIPTION AND MEASURES TAKEN
Type of program: (2) Reorganization (IPAB, Annual Report, 1999). *Insolvent banks* with shareholders who did not have the capability to provide the necessary resources to capitalize them. The FOBAPROA provided capital, took the share control of the society, and carried out reorganization operations that made it possible for them to be acquired by a financial entity or, otherwise, to proceed with the liquidation of their assets. The National Banking and Securities Commission (CNBV for its acronym in Spanish) has previously intervened with these institutions in two ways: one of a managerial nature and the other of a de facto or administrative nature (Murillo, 2005). Subsequently, the IPAB made the resources from the recovery of goods available for the conclusion of the Reorganization Programs and Liquidation of the FOBAPROA Programs. Thus, according to section I, these banks are defined in this work as "*weak banks*".

Type of program: (3) PCCC (IPAB, Annual Report, 1999). Insolvent banks in which the CNBV sought to get more money from shareholders themselves or new partners through the SCCP; their insolvency was due to deficient management, insufficient capital, or serious problems in the recovery of loans granted. These banks affected, in trust, the flows derived from a part of their loan portfolio, providing in exchange promissory notes with a maturity of 10 years subscribed by the FOBAPROA; obliging them to share the losses resulting from the unrecovered portfolio with the FOBAPROA (shared-loss agreement). Additionally, an incentive scheme was concluded with the FOBAPROA whereby the banks covered their reserves deficiencies in the trusts. The FOBAPROA Technical Committee determined that there were insufficient reserves and that the banks should gradually cover the deficiency with their own resources based on the results obtained in the collection of loans. Annex 4 of the 2000-2005 Accountability Report presents the balances that were the basis for the preparation of the annual financial statements audited by the IPAB based on the financial information of the trusts. Thus, in accordance with section I, these banks are defined in this work as "nonweak banks".

(IPAB, Annual Report, 2000). In June 1999, in compliance with the Fifth Transitional Article of the LPAB, the IPAB issued the General Rules of the new program for the exchange of promissory notes issued by the FOBAPROA under the PCCC. In October of the same year, the institutions that requested the Institute to adhere to the new program, submitting their financial consolidation plans, an annual portfolio collection plan, and compliance with capitalization levels were: Banamex, Bancomer, Banorte, Bital, and BBV. Thus, the CNBV issued a favorable opinion on these submitted plans. In December 1999, the Congress of the Union granted the IPAB the power to issue loans or securities for the purpose of exchanging or refinancing its obligations, meeting its payment obligations, providing liquidity to its securities and, in general, improving the terms and conditions of its financial obligations.

(IPAB, Annual Report, 2000). During the year 2000, the main banks operating in Mexico focused their efforts on strengthening their financial soundness by accelerating their capitalization processes, creating larger reserves, reducing their total non-performing portfolio, and complying in advance with capitalization requirements, which will later become effective in 2003.

(CNBV, Statistical Bulletin, December 2004). As of 2004, the CNBV analyzes the financial information of banks to determine their financial stability or solvency. This process is carried out through a classification of categories (I to V) of early warnings, based on the Capitalization Index (ICAP) published by BANXICO ("Law of Credit Institutions" and "General Dispositions Applicable to Credit Institutions", published in the Official Journal of the Federation on July 18, 1990, and December 2, 2005, respectively).

Source: Own elaboration.

In relation to Table 1, it is indicated that according to the IPAB (Annual Report, 2002) and the regulating criteria (BANXICO, Financial System Report, 2006), the solvency of a bank is detected through the "early warning" mechanism by calculating the Capitalization Index (ICAP). Nevertheless, the solvency of a bank also depends on its capacity to generate profits and the coverage index of its total non-performing portfolio with allowance for loan losses. Considering what is set out in Table 1 and the actions taken by the banks shown in Tables 2

and 3, the latter present the classification of the analyzed banks as *weak banks* and *nonweak banks*, respectively. It is necessary to note that Altman *et al*. (2014) consider a classification of *weak banks* and those *nonweak banks* very similar to that found in this work, and Marín *et al*. (2011) note those institutions that were intervened by the FOBAPROA as a business failure.

Table 2
Classification of weak banks (Program 2) and their respective actions taken

Banca Serfin, S. A. (1)*. Financial Reorganization Program: Administrative Intervention
June/1999. The IPAB capitalized *Banca Serfin*, so that it could return to profitability, by acquiring ownership of the shares representing the share capital (IPAB, Annual Report, 1999).
July/1999. The IPAB took control of *Banca Serfin* without removing its administrative group (Murillo, 2005).
October/06/1999. The call for the assignment of the administration and the commercial, industrial, and mortgage portfolio of Banca Serfin was published, with an approximate value of 25,000 million pesos (IPAB, Annual Report, 1999).
October/27/1999. Banorte was named the winning participant (IPAB, Annual Report, 1999).
February/28/2000. Banorte signed the management contract (IPAB, Annual Report, 1999).
December/02/1999. In parallel with the reorganization process, the IPAB began the sale process of the shares of *Grupo Financiero Serfin* and published the call for the acquisition of up to 100 percent of the shares representing the share capital of the institution (IPAB, Annual Report, 2000).
May/2000. *Grupo Financiero Santander Mexicano* won the bidding process (IPAB, Annual Report, 2000).
Bancen (2). Financial Reorganization Program: Management Intervention
June/1995. Bancen received intervention (Murillo, 2005).
March/1996. Banorte manages Bancen (Murillo, 2005).
June/1997. FOBAPROA transfers the shares of Bancen in favor of Banorte (Murillo, 2005).
Banca Quadrum (3). Financial Reorganization Program: Intervention in Management and Liquidation
August/2001. It received intervention in a managerial capacity (Murillo, 2005).
June/11/2001. Due to the request made by Quadrum with regard to financial aid, the IPAB hired a specialized third-party to carry out a technical study (IPAB, Annual Report, 2001).
August/29/2001. The SHCP considered that Quadrum was in the process of revoking the authorization granted by the Ministry to organize itself and operate as a full-service bank, since it was incurring losses that affected its minimum capital. The SHCP asked that institution to state what was in its best interests and granted it a period of sixty working days from the date mentioned for that institution to capitalize, since it had solvency problems. The deadline was extended to March 11, 2002 (IPAB, Annual Report 2001).
February/28/2002. Since Quadrum failed to capitalize within the time period granted by the SHCP, this authority revoked its authorization to organize and operate as a full-service bank, and it went into liquidation (IPAB, Annual Report, 2002).

March/04/2002. Quadrum delivery-receipt acts were carried out between the managing auditor of the CNBV and the Institute, and between the latter and the liquidator (IPAB, Annual Report, 2002).
2003. Documents were prepared to initiate the selection of the legal firm in charge of the legal audit to the management of the official intervention of the Bank in Liquidation, and the development of the legal audits of the management intervention of the Banca Quadrum was followed up (IPAB, Annual Report 2003).
Banpaís (4). Financial Reorganization Program: Management Intervention
March/1995. It received intervention in a managerial capacity (Murillo, 2005).
April/1997. Banorte's purchase proposal is accepted (Murillo, 2005).
December/1997. The purchase agreement is celebrated. From then on, the intervention was lifted, and the administration is taken over by Banorte (Murillo, 2005).
Banco Santander Mexicano, S. A. (5). Financial Reorganization Program: Sale of Administration and Loan Portfolio Collection
November/1999. The call for tender for the acquisition of administration and collection rights of the loan portfolio of Banco Santander Mexicano, S. A. was published. In this case, the transaction was a sale and not a transfer under administration. The operation includes the bidding of 5 commercial and industrial credit packages, most of which are due and have an approximate value of $7,104 million pesos (IPAB, Annual Report, 1999).
March/2000. A portfolio of approximately 19,972 commercial and industrial loans of Banco Santander Mexicano was auctioned, with a principal value of 6,943 million pesos (IPAB, Annual Report 2000).

*() Bank number

Source: Own elaboration

Table 3

Classification of the nonweak banks (Program 3) and their respective actions taken

Banorte (6)*
2000. Continues under the original board of directors (Murillo, 2005).
Bancomer (7)
August/2000. Bancomer merged with Grupo Financiero BBV-Probursa because, even though it had an adequate level of capitalization, it required additional investments to be able to compete in the new industry environment. This merger was an agreement between banks in which FOBAPROA did not participate (Murillo, 2005).
Banamex (8)
August/2001. It merged with Citibank because, even though it had an adequate level of capitalization, it required additional investments in order to compete in the new industry environment. This merger was an agreement between banks in which FOBAPROA did not participate (Murillo, 2005).
HSBC; formerly BITAL (9)
2000. Continues under the original board of directors (Murillo, 2005).

*() Bank number

Source: Own elaboration

Discriminant Analysis Model

It should be noted that, even when it was formulated by Altman in 1968, discriminant analysis is still used today to classify entities into alternative groups as can be observed in the works of Crespo, 2011, and of Redondo and Rodríguez, 2014. Discriminant analysis seems to have predominated in studies on the difficulties of financial entities from an empirical point of view and has not lost its prominence, perhaps because it is a well-studied technique and, above all, due to the good results it has produced (Redondo and Rodríguez, 2014). This analysis is used to *classify* different individuals into alternative groups based on the values of a set of variables of those to be classified. Thus, each individual may belong to a single group and their belonging is introduced into the analysis by means of a *categorical* (dependent) variable that takes as many values as there are groups. For their part, the variables used for the classification of the individuals are called *classifying* (independent) variables and their information is summarized in functions called *discriminant functions*. The discriminant analysis can be implemented for *explanatory* and *predictive* purposes; in the former (see section V), the aim is to determine the contribution of each *classifying* variable to the correct classification of each individual, while in the latter (see section VI), the aim is to determine the group to which an individual belongs and for which the values of the *classifying* variables are known (Uriel and Aldás, 2005; Carvallo, 2007). The statistical hypotheses of this analysis are the homoscedasticity and multivariate normality of the groups (Hair *et al*., 2005), which are shown in sections V.1 and V.2, respectively.

Explanatory application of the Discriminant Analysis to the nine Mexican Banks

The discriminant analysis was applied to the nine Mexican Banks presented in Tables 2 and 3 for the period of 1999. Thus, the *categorical* (dependent) variable is defined as "*Weak banks*" (Group 1) or "*Nonweak banks*" (Group 2).

Regarding the *classifying* (independent) variables used in this work, it is indicated that they are thirteen of some of the financial indicators that have been used in Beaver's univariate analysis (1966), in the Altman's multiple discriminant analysis (1968), and in Ayala's early warning models for financial crises (1999), with a context currently considered in the Basel Accords II and III of the BCBS. The selection of these indicators was made in accordance with what was proposed by different authors who have worked on the prediction of a business or banking crisis; their specific comments are:

(X_1).- In 1968, Altman used this financial indicator, mentioning that it is frequently found in studies of companies with financial problems and, of the three liquidity indicators that he evaluated, he considered it the most valuable. Similarly, in 1966, Beaver considered it to be

the second best for prediction and Alfaro, Gámez and García (2008) used it to predict the business failure of 1180 companies (commercial and industrial). Likewise, Lifschutz (2010), Alkhatib and Eqab (2011), and Naresh and Sree (2014) have published works that indicate the good prediction of bankruptcy by means of Altman's model and, thus, the use of this indicator.

(X_2) Return on assets.- In 1968, Beaver examined a large number of failed companies for which there had never been a prediction of failure. Through this examination he concluded that this indicator had good predictive power. A more recent study (Cools and van Toor, 2015) used this indicator, among others, to make a comparison between weak and strong banks. Similarly, Gamlath and Rathiranee (2014) used this indicator to carry out a regression analysis of a sample of seven commercial banks in Sri Lanka over the period of 2007-2011 to determine the relation between working capital management and profitability. El-Ansary and Hafez (2015), in their empirical study of Egyptian banks, related the Capital Adequacy Ratio as a dependent variable with the Return on Assets to analyze Profitability between other independent variables, concluding that they are significantly correlated during the 2003-2013 period. Labatut *et al*. (2009) consider this indicator to be very efficient in detecting company insolvency. It should be noted that the work of Labatut was done for small and micro enterprises, but the author himself mentions that his study can be extrapolated to other contexts where similar situations occur, which is the case of banking. For their part, Chávez and Córdova (2017) considered this indicator in the study of the financial situation of Ecuadorian companies using discriminant analysis.

(X_3) Productivity (Altman).- In 1968, Altman used this indicator to measure the real productivity of the company assets and, given that its definitive existence is based on the power of its asset earnings, it seems appropriate for studies related to business failures and outperforms other measures of profitability. In 1999, Carrasco indicated that, according to Altman (1968), *Productivity* is fundamental, given that the existence of an entity is determined by the power of profitability of its assets. For their part, Alfaro, Gámez and García (2008) used this indicator, which was very important in their discriminant model, and mentioned that companies with greater economic profitability have more options to remain active, thus *Productivity* is lower for failed banks (Laffarga, Martín and Vázquez, 1987). Similarly, Lifschutz (2010), Alkhatib and Eqab (2011), and Naresh and Sree (2014) have published works that indicate good bankruptcy prediction using Altman's model. Labatut *et al*. (2009) also used this indicator.

(X_4) Solvency.- In 1999, Carrasco indicated that, according to Altman (1968), the financial indicator *market value of shares/book value of total debts* is an effective predictor of bankruptcy. However, since it is difficult to obtain this type of information, the financial indicator *Internal Leverage* was used as predictor instead. It has also been used by Millán de la Lastra *et al*. (2013), especially in the appearance of losses and particularly in the loan portfolio, which has a significant impact on the deterioration of its assets. Therefore, the accumulation of leverage

of the banks must be avoided. Furthermore, Gutiérrez and Abad (2014) show in the results that the equity structure of the entities, defined as financial autonomy (own funds/liabilities), is one of the two variables with the greatest predictive capacity. Labatut *et al*. (2009) also used this indicator. Chávez and Córdova (2017) applied the inverse of this indicator.

(X_5) Liquidity (MACRO).- This indicator belongs to the Liquidity Risk category in the MACRO acronym (to the Liquidity category of CAMEL). Given that banks are financial intermediaries with liabilities that are short-term deposits and their assets are long-term loans, the imbalance between assets and liabilities is a natural consequence of the financial activity that, if not properly managed, can lead to solvency problems (Ayala, 1999). For their part, Laffarga, Martín and Vázquez (1991) used it as one of the fifteen indicators that they selected for their bankruptcy prediction analysis of Spanish Banks, while in 2008, Alfaro, Gámez and García also used this financial indicator. In 2010, Gamlath and Rathiranee used this indicator in the regression analysis of seven commercial banks in Sri Lanka for the 2007-2011 period. Labatut *et al*. (2009) and Chávez and Córdova (2017) also applied this indicator.

(X_6) Past due loans.- This indicator belongs to the Asset quality category within MACRO (Asset quality of CAMEL). Hernández and López (2001) suggest that this indicator is statistically significant to explain the banking crises and it reflects credit risk. The higher this relation is, the lower the probability of survival of the bank. Banks with this situation must contribute with a considerable portion of assets due to losses, which leads to a decrease in earnings and, consequently, of capital.

The increase of past due loans in the 2007-2012 period had two serious consequences in the Spanish financial system leading to the disappearance of Savings Banks, which represented 50% of the Spanish credit system (Climent, 2017).

(X_7) Provision coverage.- This indicator belongs to the Asset quality category within MACRO. Carrasco (1999) indicates that Whalen and Thomson (1988) used this indicator in models to predict the deterioration in the bank's situation through changes in the CAMEL valuation. Similarly, in this sense, Climent (2017) did a study to predict the performance of the provisions for the impairment of Spanish credit institutions at different stages of the economic cycles they have gone through and thus obtain more real information on the needs of these provisions for loan impairment provisions.

(X_8) Credit risk.- This indicator belongs to the Capital adequacy within MACRO (CAMEL Capital). Carrasco (1999) mentions that the results of the models built by Whalen and Thomson (1988), using only this indicator, are as good as those obtained by other more complex models and that this variable seems to be a substitute for the qualification of assets in the CAMEL valuation. For his part, Ayala (1999) indicates that the variations in the exchange rate can have significant effects on the financial situation of a bank; the risk of this exchange rate can become a credit risk if the profitability of the debtors does not correctly incorporate the expected devaluation.

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(X_9) Return on interest-earning assets.- This financial indicator belongs to the Operative Results category within MACRO (CAMEL Earnings), it is used to measure the risk inherent to the deadline transformation process and can degenerate into crisis when the return on assets falls systematically below the one paid for the liabilities (Ayala, 1999; Ballester *et al*., 2009).

(X_{10}) Implied liability rate.- This financial indicator belongs to the Liquidity Risk category within MACRO (CAMEL Liquidity). As with the *Liquidity* financial indicator, the *Implicit Liability Rate* measures the liquidity risk allowing the evaluation of the volatility risk of the liabilities that fund the assets (Ayala, 1999). Anastasi, Burdisso, Grubisic and Lencioni (1998) mention that a greater rate reflects a greater difficulty in finding depositors in the market. Therefore, this indicator is associated with a greater implicit risk of the entity.

(X_{11}) Efficiency.- This indicator belongs to the Handling (Management) category within MACRO (CAMEL Management). Arango and Botero (2001) indicate that, for Aristóbulo de Juan, an efficient management can help solve macroeconomic disturbances, whereas a deficient management leads banks to insolvency. The results of Ríos and Gómez in 2015 indicate that banks with greater profit margins and with the lowest levels of technical efficiency are the ones that contribute more to the stability of the banking sector.

(X_{12}) Productivity and (X_{13}) Resource management.- These indicators belong to the Handling (Management) category of MACRO and were used to calculate the MACRO qualification index (Ayala, 1999).

Table 4 shows the thirteen classifying variables (X_1-X_{13}) considered in this work.

Table 4

Classifying variables and their respective calculation

(Variable) Financial Indicator		Calculation
Liquidity (Altman)		
(X_1)		Working capital / Total assets
Profitability		
(X_2)	*Return on assets*	Net income / Total assets
(X_3)	*Productivity (Altman)*	Earnings before interest and taxes / Total assets
Leverage		
(X_4)	*Solvency*	Total stockholder's equity / Total liabilities
Liquidity Risk		
(X_5)	*Liquidity (MACRO)*	Current assets / Current liabilities
Asset Quality		
(X_6)	*Past due loans*	Total non-performing portfolio / Total loan portfolio
(X_7)	*Provision coverage*	Allowance for loan losses / Total non-performing portfolio

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Capital Adequacy		
(X_8)	*Credit risk*	Total non-performing portfolio / Total stockholder's equity
Operating Results		
(X_9)	*Return on interest-earning assets*	Net interest income / Average interest-earning assets
Liquidity Risk		
(X_{10})	*Implied liability rate*	Interest expense / Average current liabilities
Management		
(X_{11})	*Efficiency*	Operating expenses / Net interest income
(X_{12})	*Productivity*	Operating expenses / Average interest-earning assets
(X_{13})	*Resource management*	Interest-earning assets / Current liabilities

Source: Own elaboration

Additionally, Table 5 shows how the context of these indicators is currently considered within the Basel Accords II and III, as a result of the instability of 2007.

Table 5
Regulations of the BCBS according to the Basel Accords II and III

Document	Context summary	Related Financial Indicator
(bcbs128)*. International Convergence of Capital Measurement and Capital Standards June 2006	This document sets out the minimum standards to be achieved, which the BCBS presents to determine whether the bank has sufficient capital to cover the various risks and whether it meets the established capital adequacy objectives. The BCBS considers that the essential (core) component of capital on which the greatest emphasis should be placed will be share capital and declared reserves. Regulatory capital shall include or deduct the difference between provisions (whether specific, generic or general for a given portfolio) and expected losses.	(X_4), (X_6), (X_7), (X_8), (X_9), (X_{10}), (X_{11}) and (X_{12})
(bcbs144)*. Principles for Sound Liquidity Risk Management and Supervision. September 2008	Liquidity risk management is extremely important because the lack of *liquidity* of a single institution can have a system-wide impact. Early warning indicators should identify any negative trends or increases in risk associated with a given output line, such as increasing *delinquencies*. Even if *capital* is not the solution to insufficient *liquidity*, or a long-term solution to the inefficiency of risk management processes, banks must operate with higher levels of *capital* because its position may influence their ability to obtain *liquidity*, especially during a crisis.	(X_1), (X_4), (X_5), (X_6), (X_9), (X_{10}), (X_{12}) and (X_{13})

(bcbs188)*. Basel III: International framework for liquidity risk measurement, standards and monitoring. December 2010	The BCBS has reinforced its framework on liquidity, introducing two minimum standards for funding liquidity: Liquidity Coverage Ratio (LCR) and Net Stable Funding Ratio (NSFR). The former is defined as the Fund of High Quality Liquid Assets / Total Net Cash Outflows during the subsequent 30 calendar days. It entered into force on January 1st, 2015. As for the latter, it is defined as the amount of Available Stable Financing (ASF) / amount of Required Stable Funding (RSF), which shall become the minimum standard as of January 1st, 2018.	(X_1), (X_4), (X_5), (X_9), (X_{10}), (X_{12}) and (X_{13})
(bcbs189)*. Basel III: A global regulatory framework for more resilient banks and banking systems. December 2010 (rev. June 2011)	To raise the resistance of the banking sector, the BCBS has reinforced the framework of the regulating capital based on the three pillars of the Basel II framework, increasing both the quality and quantity of the base regulating capital and improving the risk coverage of the capital framework. In addition to this, there is a leverage ratio that acts as a backup of the risk-based capital measures, designed to prevent excess leverage in the banking system and provide greater protection against risk models and measurement errors. One of the main destabilizing factors during the crisis was the inability to correctly capture the major risks on and off the balance sheet, as well as the derivative-related exchanges. It should be mentioned that the *provisioning* initiatives focus on reinforcing the banking system against <u>expected losses</u>, whereas the *capital* measures are geared towards <u>unexpected losses</u>.	(X_4), (X_6), (X_7), (X_8), (X_9), (X_{12}) and (X_{13})
(bcbs238)*. Basel III: The Liquidity Coverage Ratio (LCR) and liquidity risk monitoring tools. January 2013	To achieve a more resistant banking sector, the LCR guarantees that banks will have an adequate fund of High Quality Liquid Assets (HQLA), free of charge, that can easily and immediately be turned into cash in private markets.	(X_1), (X_5) and (X_{10})
<u>(bcbs258)</u>*. The Regulatory framework: balancing risk sensitivity, simplicity and comparability. July 2013	The BCBS argues that a risk-based capital regimen must continue to be the basis for the regulating framework of the banks, which in turn must be backed up by *liquidity* and *financing* measures, among others, such as the *leverage ratio*. A *leverage ratio* provides the measure in which an asset portfolio is backed up with capital but is not risk-sensitive.	(X_4), (X_6), (X_7), (X_8), (X_9), (X_{12}) and (X_{13})
(d295)*. Basel III: The Net Stable Funding Ratio (NSFR) October 2014	The NFSR is one of the essential reforms of the BCBS to promote a more resilient banking sector. The NSFR will require banks to maintain a stable financing profile in relation with the composition of their assets and of the balance sheet actions.	$X_1)$, (X_4), (X_5), (X_9), (X_{12}) and (X_{13})

(d311)*. Guidelines on accounting for expected credit losses February 2015	Establishes the supervisory requirements for credit risk practices associated with the continuous application and implementation of accounting models for expected credit losses (ECL). One of the ruling principles of these requirements is that banks must have adequate policies and processes for an early identification and management of doubtful assets and for the adequate maintenance of provisions and reserves.	(X_6), (X_7) and (X_8)
(d350)*. Guidelines on credit risk and accounting for expected credit losses December 2015	The Board agrees with the International Financial Reporting Standard (IFRS) 9, Financial Instruments, in which delinquency is a delayed indicator of a significant increase in credit risk. Banks should have credit risk assessment and management processes in place to ensure that credit risk increases are detected well ahead of exposures becoming past due or delinquent.	(X_6), (X_7) and (X_8)
(d365)*. Revisions to the Basel III leverage ratio framework. April 2016 (rev. April 25, 2016)	A fundamental cause of the world financial crisis was the accumulation of excessive *leverage* in the banking system, both on and off the balance sheet. In many cases, banks were over-leveraged while appearing to have solid risk-based capital ratios. At the height of the crisis, financial markets forced the banking sector to reduce its *leverage* in such a way as to accentuate downward pressure on asset prices.	(X_6) (X_7) (X_8) (X_9) (X_{12}) (X_{13})
(d368)*. Standars: Interest rate risk in the banking book April 2016	The interest rate risk in the banking book (IRRBB) refers to the current or future risk for the capital or earnings of the bank from adverse interest rate fluctuations that affect the positions of its banking book. Interest rate variations also affect bank earnings by altering its income and sensible expenses, affecting its net interest income (NII). Excessive IRRBB can pose a significant threat to the current base capital of the bank and/or its future earnings if it is not adequately managed.	(X_2) (X_3) (X_4) (X_9) (X_{10}) (X_{11})

* (Document number)

Source: Own elaboration

Table 6 shows the accounting analysis; part of which was done according to Marín and Martínez (2002).

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Table 6

Values of the independent variables considered for the discriminant analysis (Year 1999)

VARIABLE	BANK CLASSIFICATION								
	WEAK BANKS (Group 1)					NONWEAK BANKS (Group 2)			
	1	2	3	4	5	6	7	8	9
	$X_{1,1}$ (*)	$X_{2,1}$	$X_{3,1}$	$X_{4,1}$	$X_{5,1}$	$X_{1,2}$	$X_{2,2}$	$X_{3,2}$	$X_{4,2}$
X_1	-0.210	-0.131	-0.121	-0.222	-0.061	0.049	-0.191	-0.120	-0.092
X_2	-0.023	0.010	-0.035	0.006	0.010	0.012	0.010	0.024	0.004
X_3	-0.068	0.011	-0.046	0.007	0.017	0.010	0.006	0.025	0.006
X_4	0.054	0.077	0.112	0.046	0.091	0.091	0.105	0.142	0.059
X_5	0.531	0.503	0.581	0.429	0.796	1.121	0.520	0.712	0.840
X_6	0.064	0.048	0.175	0.040	0.013	0.087	0.103	0.117	0.115
X_7	-1.564	-1.447	-0.521	-1.157	-1.859	-0.751	-0.800	-0.992	-0.849
X_8	0.982	0.584	1.116	0.743	0.113	0.458	0.767	0.618	0.984
X_9	0.027	0.059	0.002	0.074	0.058	0.084	0.078	0.094	0.086
X_{10}	0.527	0.852	0.429	0.497	0.773	0.390	0.418	0.350	0.417
X_{11}	1.734	0.866	36.475	1.037	0.927	0.864	0.859	0.638	1.052
X_{12}	0.046	0.051	0.078	0.077	0.054	0.072	0.067	0.060	0.091
X_{13}	2.175	3.644	2.418	2.474	3.175	2.102	2.121	2.115	1.573

(*) Observation Vectors. This column corresponds to the observation vector of element 1 of Group 1.

Source: Own elaboration

With the values shown in Table 6 and using equations 1(a)-1(c), the *Observation*, *Group Means*, and *Total Means* vectors were obtained, respectively. In said equations, $x_{i,g,k}$ (see Table 6) is the observation of variable k of element i of group g; G is the number of groups; n_g is the number of elements of group g; K is the number of classifying variables; and $n = n_1 + n_2 + ... + n_g$ is the size of the sample. In our case, $G = 2, n_1 = 4, n_2 = 5, n = n_1 + n_2 = 9$, and $K = 13$.

$$X_{i,g} = \begin{Bmatrix} x_{i,g,1} \\ \vdots \\ x_{i,g,K} \end{Bmatrix} \; i = 1,2,\ldots,n_g \cdot g = 1,2,\ldots,G \quad \bar{X}_{\bullet g} = \begin{Bmatrix} \dfrac{\sum_{i=1}^{n_g} x_{i,g,1}}{n_g} \\ \vdots \\ \dfrac{\sum_{i=1}^{n_g} x_{i,g,K}}{n_g} \end{Bmatrix} \quad \bar{X} = \begin{Bmatrix} \dfrac{\sum_{g=1}^{G}\sum_{i=1}^{n_g} x_{i,g,1}}{n} \\ \vdots \\ \dfrac{\sum_{g=1}^{G}\sum_{i=1}^{n_g} x_{i,g,K}}{n} \end{Bmatrix} \quad 1)$$

(a) (b) (c)

Table 7 shows the *Group Means* vectors and the *Total Means* vector.

Table 7

Group Means vectors and Total Means vector

Group Means		Total Means
X_1	X_2	$\overline{X}$
-1.489×10^{-1}	-8.848×10^{-2}	-1.221×10^{-1}
-6.219×10^{-3}	1.253×10^{-2}	2.113×10^{-3}
-1.582×10^{-2}	1.194×10^{-2}	-3.486×10^{-3}
7.617×10^{-2}	9.938×10^{-2}	8.648×10^{-2}
5.683×10^{-1}	7.985×10^{-1}	6.706×10^{-1}
6.804×10^{-2}	1.056×10^{-1}	8.475×10^{-2}
-1.310×10^{0}	-8.480×10^{-1}	-1.104×10^{0}
7.076×10^{-1}	7.068×10^{-1}	7.073×10^{-1}
4.390×10^{-2}	8.544×10^{-2}	6.236×10^{-2}
6.159×10^{-1}	3.940×10^{-1}	5.172×10^{-1}
8.208×10^{0}	8.531×10^{-1}	4.939×10^{0}
6.111×10^{-2}	7.247×10^{-2}	6.616×10^{-2}
2.777×10^{0}	1.978×10^{0}	2.422×10^{0}

Source: Own elaboration

Homoscedasticity Hypothesis

The null hypothesis is that the covariate matrices of the two groups are equal, whereas the alternative hypothesis is that said matrices are not equal. Thus, to verify the null hypothesis Van Valen's test was used, which requires Student's *t*-distribution and certain values dependent on the standardization of the data given by (Acuña, 2000):

$$d_{i,g} = \sqrt{\sum_{k=1}^{K} \left(xs_{i,g,k} - M_{g,k} \right)^2} \qquad (2)$$

Where $xs_{i,g,k}$ are the standardized observations, and $M_{g,k}$ is the Median of the k-th standardized variable in the g-th Group (Acuña, 2000). The results obtained are shown in Table 8, where it can be observed that the p-value (0.10) is greater than 0.05, indicating that the equality hypothesis of the covariance matrices is accepted.

Table 8
Van Valen's test results

Value	n_g	Mean	Standard Deviation	Standard Error of the Mean	Mean Difference	95% Confidence Interval	g. l.	*t*-value	*p*-value
$d_{i,1}$	5	3.592	1.465	0.655	1.457	(-0.459, 3.374)	4	2.111	0.10
$d_{i,2}$	4	2.135	0.434	0.217					

Source: Own elaboration.

Hypothesis of Multivariate Normality of the groups

The null hypothesis is $H_0 : x_g \approx N(\mu_g, \sigma_g)$, and the alternative is $H_1 : x_g \; No \approx N(\mu_g, \sigma_g)$.

Due to the complexity of the normality analysis in the multivariate case, the variable to variable normality test was used to contrast the hypothesis of the two groups (Uriel and Aldás, 2005). Thus, given that the samples are small, the Shapiro & Wilk test (González, 2006) was used, which consists in comparing the statistic:

$$W_{cal} = \frac{b^2}{\sum_{i=1}^{n} (X_i - \bar{X})^2} \tag{3}$$

with a W_{tab} value. If W_{cal} is greater than W_{tab} for a particular level of significance, the data normality hypothesis is accepted. Based on this, Table 9 shows the results obtained for the thirteen independent variables and it can be observed that only four variables do not comply with this hypothesis. However, Mora (1994) mentions that different authors demonstrate that it is not absolutely necessary to fulfill the normality condition to obtain good results. Similarly, Redondo and Rodríguez (2014) indicate that the difficulty in practice to comply with the restrictive assumptions underlying the discriminatory analysis may not be as serious an inconvenience as it might seem at first glance, given its relative robustness in the face of non-compliance.

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Table 9

Shapiro & Wilk test for data normality

Variable	W_{cal}	W_{cal}		Is the normality hypothesis accepted?
		Level of significance		
		0.01	0.05	
X_1	0.924			Accepted
X_2	0.820			Not accepted
X_3	0.743			Not accepted
X_4	0.960			Accepted
X_5	0.898			Accepted
X_6	0.974			Accepted
X_7	0.950	0.764	0.829	Accepted
X_8	0.956			Accepted
X_9	0.877			Accepted
X_{10}	0.808			Not accepted
X_{11}	0.411			Not accepted
X_{12}	0.964			Accepted
X_{13}	0.887			Accepted

Source: Own elaboration.

Decomposition of the Covariance Matrix

With the *Observation*, *Group Means* and *Total Means* vectors, the variation matrix between groups can be obtained through the *sums of squares and cross products* (SSCP) matrix. Thus,

$$[F] = \sum_{g=1}^{G} n_g \left\{\bar{X}_{\bullet g} - \bar{X}\right\}\left\{\bar{X}_{\bullet g} - \bar{X}\right\}^T \tag{4}$$

For its part, the intra-group variation matrix, defined as the *sums of squares and residual cross products* (SSRCP), is:

$$[W] = \sum_{g=1}^{G} \sum_{i=1}^{n_g} \left\{X_{i,g} - \bar{X}_{\bullet g}\right\}\left\{X_{i,g} - \bar{X}_{\bullet g}\right\}^T \tag{5}$$

The sum of the two matrices mentioned above provides the *sums of squares and total cross products* (SSTCP). Thus,

$$[T] = [F] + [W] \tag{6}$$

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Discriminant Variable Selection

The selection of the variables that contributed the most to the discrimination of the groups was done using the *step by step forward* (Ferrán, 2001) method and the *Wilks' Lambda* criterion to measure the discriminant power gain/loss when introducing/removing a variable from the set. In each step, a classifying variable can enter if its corresponding statistic, *F-to-enter*, is greater than a prefixed minimum *F* value (*F-min-entry*) or it can leave if its corresponding statistic, *F-to-leave*, is lower than a prefixed maximum *F* value (*F-max-leave*). The *F* statistic is:

$$F = \frac{n-G-q}{G-1}\left(\frac{\Lambda_q}{\Lambda_{q+1}}-1\right) \text{ with } n-G-q \text{ and } G-1 \text{ degrees of freedom} \quad (7)$$

Where $\Lambda_q = \frac{|W_q|}{|T_q|}$ is Wilks' Lambda based on the first q variables selected.

For our case, a *F-min-entry* of 2.58 and a *F-max-leave* of 2.43 were specified. Table 10 shows the selected classifying variables, in order of appearance and following the *step by step forward* method and *Wilks' Lambda* criterion. Even when the results are not shown, none of the selected variables were removed from the discriminant set.

Table 10

Selected classifying variables

Step	Variable	Financial Indicator	Wilks' Lambda	*F*	gl_1	gl_2	Sig.
0	X_9	Return on interest-earning assets	0.478	7.655	1	7	0.028
1	X_6	Past due loans	0.139	14.553	1	6	0.009
2	X_{11}	Efficiency	0.092	2.589	1	5	0.169
3	X_5	Liquidity (*MACRO*)	0.048	3.723	1	4	0.126

Source: Own elaboration.

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Canonical Discriminant Function

Canonical discriminant functions are defined as (Pérez, 2005):

$$D_i = u_{i,1}X_1 + u_{i,2}X_2 + \text{L} + u_{i,q}X_q + c_i \tag{8}$$

Where $i = \min(G\text{-}1, q)$, with q being the number of classifying variables selected. In our case $i = \min(1,4) = 1$, meaning there is only one discriminant function. Thus:

$$D_1 = \{u\}_1^T \{X\} \qquad \text{Where} \quad \{u\}_1 = \begin{Bmatrix} u_{1,9} \\ u_{1,6} \\ u_{1,11} \\ u_{1,5} \end{Bmatrix} \quad \text{and} \quad \{X\} = \begin{Bmatrix} X_9 \\ X_6 \\ X_{11} \\ X_5 \end{Bmatrix} \tag{9}$$

Considering matrices $[F]$, $[W]$, and $[T]$ of the multiple variance analysis, vector $\{u\}_1$ is obtained maximizing λ_1, given by:

$$\lambda_1 = \frac{\text{Variability between groups}}{\text{Intra - group variability}} = \frac{\{u\}_1^T [F] \{u\}_1}{\{u\}_1^T [W] \{u\}_1} \tag{10}$$

The maximization of λ_1 leads to the following characteristic values problem:

$$[W]^{-1}[F]\{u\}_1 = \lambda_1 \{u\}_1 \quad \Rightarrow \quad \left([W]^{-1}[F] - \lambda_1 [I]\right)\{u\}_1 = \{0\} \tag{11}$$

Where, with the selected classifying variables, matrices $[F]$ and $[W]$ are:

$$[F] = \begin{bmatrix} 0.004 & 0.003 & -0.679 & 0.021 \\ 0.003 & 0.003 & -0.615 & 0.019 \\ -0.679 & -0.615 & 120.194 & -3.763 \\ 0.021 & 0.019 & -3.763 & 0.118 \end{bmatrix} \text{ and } [W] = \begin{bmatrix} 0.004 & -0.006 & -1.497 & -0.001 \\ -0.006 & 0.016 & 3.791 & -0.011 \\ -1.497 & 3.791 & 999.354 & 0.455 \\ -0.001 & -0.011 & 0.455 & 0.268 \end{bmatrix}$$

Equation 11 was solved using Cholesky decomposition of matrix $[W]$ and power iteration algorithm (Burden and Faires, 1985). Thus, the result of the characteristic λ_1 value was equal to 20.0173 and the characteristic vector was:

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$$\{u\}_1 = \begin{Bmatrix} 28.0289 \\ 42.1010 \\ -0.1223 \\ 2.4827 \end{Bmatrix}$$

Normalizing vector $\{u\}_1$ so that with $\{u\}_1^T [W] \{u\}_1 = 1$ we obtain vector $\{v\}_1$ Thus,

$$\{v\}_1 = \begin{Bmatrix} 19.9415 \\ 29.9533 \\ -0.0870 \\ 1.7663 \end{Bmatrix}$$

For its part, the standardized coefficients vector of the canonical discriminant function $\{u_e\}_1$ is obtained with:

$$\{u_e\}_1 = [S] \{v\}_1 \tag{12}$$

Where matrix [*S*] is a diagonal matrix with elements that are the square roots of the elements of the main diagonal of matrix [*W*]. Thus,

$$\{u_e\}_1 = \begin{Bmatrix} 1.1809 \\ 3.8127 \\ -2.7507 \\ 0.9138 \end{Bmatrix}$$

The structure vector, which contains the combined intra-group correlations among the standardized canonical discriminant variables, is:

$$[S]^{-1} [W] \{v\}_1 = \begin{Bmatrix} 0.2337 \\ 0.0984 \\ -0.0775 \\ 0.1483 \end{Bmatrix}$$

For its part, the non-standardized coefficients vector of the canonical discriminant function is:

$$\{u_{ne}\}_1 = (n-G)^{1/2} \{v\}_1 = (9-2)^{1/2} \begin{Bmatrix} 19.9415 \\ 29.9533 \\ -0.0870 \\ 1.7663 \end{Bmatrix} = \begin{Bmatrix} 52.7603 \\ 79.2489 \\ -0.2302 \\ 4.6733 \end{Bmatrix}$$

http://dx.doi.org/10.22201/fca.24488410e.2018.1770

The constant c_1 of the canonical discriminant function (Equation 8) with non-standardized coefficients is obtained through the following expression:

$$c_1 = \left\{\overline{X}\right\}^T \left\{u_{ne}\right\}_1 \tag{13}$$

Where $\left\{\overline{X}\right\}^T$ is the transposed vector of total means of the selected classifying variables. Thus, c_1 = -12.0032 and the canonical discriminant function with non-standardized coefficients is:

$$D_i = 52.7603\,X_9 + 79.2489\,X_6 - 0.2302\,X_{11} + 4.6733\,X_5 - 12.0032 \tag{14}$$

For its part, the *i-th* canonical correlation has a value of

$$CR_i = \sqrt{\frac{\lambda_i}{1+\lambda_i}} = \sqrt{\frac{20.0173}{1+20.0173}} = 0.976$$

To know whether a discriminant function is significant, we will contrast the null hypothesis below in the (*k*+1)-*th* step (the process begins with $k = 0$):

$$\mathrm{H}_0 : \lambda_{k+1} = \lambda_{0+1} = \lambda_1 = 0 \tag{15}$$

through the contrast statistic (Salvador, 2000):

$$T = \left(n - 1 - \frac{q+G}{2}\right) \sum_{j=k+1}^{\min(G-1,q)} \ln(1+\lambda_j) \tag{16}$$

Which is distributed as a χ^2 with (*q-k*)(*G-k*-1) degrees of freedom if H_0 is true.
For its part, the *T* statistic corresponds to a Wilks' Lambda given by equation 17.

$$\Lambda = \frac{|W|}{|T|} \tag{17}$$

The *p*-value associated to the contrast is given by:

$$P\left[\chi^2_{(q-k)(G-k-1)} \geq T_{\text{obs.}}\right] \tag{18}$$

Where T_{obs} is the observed value of T. Thus, substituting the corresponding values, the following is obtained:

$$\Lambda = 0.048,\ T_{\text{obs.}} = \left(9 - 1 - \frac{4+2}{2}\right)\sum_{j=1}^{1}\ln(1+\lambda_j) = (5)\ln(1+20.0173) = 15.227$$

$$P\left[\chi^2_{(4-0)(2-0-1)} \geq T_{\text{obs.}}\right] = P\left[\chi^2_4 \geq 15.227\right] = 0.004$$

With the canonical correlation (0.976) and the *p*-value (0.004), it is concluded that the obtained function has a high discriminant power and is significant. Additionally, the square of the canonical correlation (0.953) leads to the conclusion that 95.3% of the variance of the dependent variable can be explained by this model, which includes four independent variables (X_9, X_6, X_{11}, and X_5).

Linear Discriminant Analysis

This function can be obtained for each of the groups by using:

$$b_{i,j} = (n-G)\sum_{l=1}^{q} w^*_{i,l}\bar{X}_{l,j} \qquad j = 1,2,\ldots,G \text{ and } i = 1,2,\ldots,q \qquad \text{for the coefficients} \tag{19}$$

$$\text{and } a_j = \ln(\pi_j) - \frac{1}{2}\sum_{i=1}^{q} b_{i,j}\bar{X}_{i,j} \qquad j = 1,2,\ldots,G \qquad \text{for the constants} \tag{20}$$

In equations 19 and 20, $w^*_{i,l}$ are elements of matrix $[W]^{-1}$, $\bar{X}_{l,j}$ are the elements of vector $\bar{X}_{\bullet j}$ that correspond to the selected classifying variables; and π_j are the probabilities *a priori*. Thus, for this case study, we have:

Group 1

$$\begin{Bmatrix} X_{1,1} \\ X_{2,1} \\ X_{3,1} \\ X_{4,1} \end{Bmatrix} = \begin{Bmatrix} 4.390 \times 10^{-2} \\ 6.804 \times 10^{-2} \\ 8.208 \times 10^{0} \\ 5.683 \times 10^{-1} \end{Bmatrix} \text{ and } \pi_1 = 0.5$$

Group 2

$$\begin{Bmatrix} X_{1,2} \\ X_{2,2} \\ X_{3,2} \\ X_{4,2} \end{Bmatrix} = \begin{Bmatrix} 8.544 \times 10^{-2} \\ 1.056 \times 10^{-1} \\ 8.531 \times 10^{-1} \\ 7.985 \times 10^{-1} \end{Bmatrix} \text{ and } \pi_2 = 0.5$$

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Group 1 Group 2

$$\text{Therefore} \Rightarrow \begin{Bmatrix} b_{1,1} \\ b_{2,1} \\ b_{3,1} \\ b_{4,1} \end{Bmatrix} = \begin{Bmatrix} 556.7703 \\ 613.3457 \\ -1.4557 \\ 45.1338 \end{Bmatrix} \text{ and } a_1 = -40.6282 \quad \Rightarrow \quad \begin{Bmatrix} b_{1,2} \\ b_{2,2} \\ b_{3,2} \\ b_{4,2} \end{Bmatrix} = \begin{Bmatrix} 975.7229 \\ 1242.6354 \\ -3.2838 \\ 82.2430 \end{Bmatrix} \text{ and } a_2 = -139.4446$$

Thus, Fisher's Linear Discriminant Analysis for Groups 1 and 2, respectively, are:

$$F_1 = 556.770 X_9 + 613.346 X_6 - 1.456 X_{11} + 45.134 X_5 - 40.628 \quad \text{and}$$

$$F_2 = 975.723 X_9 + 1242.635 X_6 - 3.284 X_{11} + 82.243 X_5 - 139.445$$

For both groups, the coefficients and constant are:

$$\begin{Bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{Bmatrix} = \begin{Bmatrix} b_{1,2} \\ b_{2,2} \\ b_{3,2} \\ b_{4,2} \end{Bmatrix} - \begin{Bmatrix} b_{1,1} \\ b_{2,1} \\ b_{3,1} \\ b_{4,1} \end{Bmatrix} = \begin{Bmatrix} 418.953 \\ 629.290 \\ -1.828 \\ 37.109 \end{Bmatrix} \text{ and } \quad a = a_2 - a_1 = -98.816$$

Thus, for both groups, Fisher's Linear Discriminant Classification Analysis is:

$$D - C = 418.953 X_9 + 629.290 X_6 - 1.828 X_{11} + 37.109 X_5 - 98.816 \qquad (21)$$

Using the function above, Table 11 shows the classification of the banks under study.

Table 11

Classification of the banks under study using Fisher's Linear Discriminant Analysis

Bank	Peer Group	Return on interest-earning assets	Past due loans	Efficiency	Liquidity (MACRO)	Discriminant Score	Classification
1	1	0.027	0.064	1.734	0.531	-30.558	1
2	1	0.059	0.048	0.866	0.503	-26.936	1
3	1	0.002	0.175	36.475	0.581	-32.991	1
4	1	0.074	0.040	1.037	0.429	-28.778	1
5	1	0.058	0.013	0.927	0.796	-38.373	1
6	2	0.084	0.087	0.864	1.121	31.376	2
7	2	0.078	0.103	0.859	0.520	16.027	2
8	2	0.094	0.117	0.638	0.712	39.437	2
9	2	0.086	0.115	1.052	0.840	39.269	2

Source: Own elaboration.

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The probabilities of belonging to the groups were obtained with:

$$\text{Prob}(g / D) = \frac{\pi_g \, e^{F_g}}{\pi_1 \, e^{F_1} + \pi_2 \, e^{F_2}} \qquad g = 1,2 \tag{22}$$

Where $\boldsymbol{\pi}_g$ and F_g are the probability *a priori* and Fisher's Linear Discriminant Analysis, respectively, of the *g-th* group.

Table 12 shows the probabilities of belonging to Groups 1 and 2 according to Fisher's Linear Discriminant Analyses and the probabilities *a priori*.

Table 12

Probabilities of Belonging to the groups of Weak banks and Nonweak banks

Bank	Return on interest-earning assets	Past due loans	Efficiency	Liquidity (MACRO)	F_1	F_2	Prob(2/D)	Prob(1/D)
1	0.027	0.064	1.734	0.531	35.174	4.616	0.0000	1.0000
2	0.059	0.048	0.866	0.503	42.925	15.989	0.0000	1.0000
3	0.002	0.175	36.475	0.581	40.951	7.960	0.0000	1.0000
4	0.074	0.040	1.037	0.429	42.842	14.064	0.0000	1.0000
5	0.058	0.013	0.927	0.796	34.317	-4.055	0.0000	1.0000
6	0.084	0.087	0.864	1.121	109.046	140.421	1.0000	0.0000
7	0.078	0.103	0.859	0.520	87.797	103.823	1.0000	0.0000
8	0.094	0.117	0.638	0.712	114.628	154.065	1.0000	0.0000
9	0.086	0.115	1.052	0.840	114.654	153.924	1.0000	0.0000

Source: Own elaboration.

As can be observed in Tables 11 and 12, the proposed model perfectly identifies the classification of the nine Mexican banks that were part of the Mexican banking crisis.

Predictive Application of the Financial Situation of Four Mexican Banks and One American Bank

Using Fisher's Linear Discriminant Classification Analysis (ec. 21) the situation of the Mexican banks 1, 5, 6 and 7 was predicted, shown in Table 13. The empirical results of the prediction are generally consistent with the analyses reported by the IPAB 1999-2005 (see Table 1) and BANXICO in its annual reports for the 2007-2008 period. The recovery of the banks in 2008, which is consistent with what is set forth in section II, should be noted. The same prediction was done for an American bank, the results of which are shown in Table 14. As can be observed, the predicted result is not consistent with the annual reports provided by the presidents of said bank for the 2000-2006 period but are consistent for the 2007-2010

period. For this last period, it should be mentioned that the proposed model has a recovery for 2009 and 2010, which is reflected by the tendency for positive values of the aforementioned function. This coincides with the fact that this bank adhered to the Trouble Asset Relief Program (TARP), which was approved by the U.S. Congress in October 2008 for the restoration of price formation mechanisms in the markets through the purchase of assets with valuation problems by the country's Treasury Department (Calvo and Martín de Vidales, 2014). It should be noted that Cools and van Toor (2010) considered Bank of America as a week bank during the 2002-2006 period.

Table 13

Prediction of four banks in order to know whether they are weak banks or nonweak banks

Year	Serfin		Santander Mexicano		Banorte		BBVA Bancomer(***)	
2000	-57.232	Weak	-36.679	Weak	-30.195	Weak	-3.694	Weak
2001	-40.947	Weak	-23.286	Weak	-29.856	Weak	-16.414	Weak
2002	-45.756	Weak	-52.683	Weak	-43.455	Weak	-25.149	Weak
2003	-29.311	Weak	-32.917	Weak	-49.125	Weak	-33.464	Weak
2004	-36.993	Weak	-24.717	Weak	-42.474	Weak	-38.618	Weak
2005	-19.201(**)	Weak	-20.500(**)	Weak	-34.014	Weak	-38.136	Weak
2006	-31.153(*)	Weak	-31.153(*)	Weak	-36.168	Weak	-29.894	Weak
2007	-21.343(*)	Weak	-21.343(*)	Weak	-42.058	Weak	-32.134	Weak
2008	24.052(*)	Nonweak	24.052(*)	Nonweak	6.197	Nonweak	-2.744	Weak

(*) Banca Serfin merged with Banco Santander Mexicano as of December 2004

(**) In 2005 it had different average values

(***) Bancomer merged with BBVA – Probursa as of August 2000

Source: Own elaboration

Table 14

Prediction of an American bank to know whether it is weak bank or nonweak bank

Year	Bank of America	
2000	-67.917	Weak
2001	-63.764	Weak
2002	-63.788	Weak
2003	-68.365	Weak
2004	-67.829	Weak
2005	-70.852	Weak
2006	-73.656	Weak
2007	-73.820	Weak
2008	-63.542	Weak
2009	-46.257	Weak
2010	-48.772	Weak

Source: Own elaboration

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Based on the aforementioned, it is possible to indicate the goodness of the proposed model with regard to prediction. Additionally, even when the IPAB determined that the institutions analyzed here—in relation to capitalization levels—comply with the requirements in the New Program of the PCCC in the 2000-2003 period and, according to the CNBV, were classified in category I from 2004 to 2008, it should be noted that the international financial crisis raised various questions regarding capitalization rules in line with the recommendations of the BCBS. Specifically, the goodness of the capitalization index as a banking solvency indicator has come into doubt (BANXICO, Financial System Report, 2009). On the other hand, the total provisions—calculated as a proportion of the total non-performing portfolio of the Banorte, Banamex, Santander, BBVA Bancomer, and HSBC banks—remained stable in 2006. However, in 2007 these banks reduced their profits due to lower intermediation revenue and higher provisioning expenses. Subsequently, in 2008, provisions were affected by a substantial increase in full-service bank credit ratings below "A" due to an increase in delinquency (BANXICO; Financial System Report, 2009). In this manner, it can be observed that, although capital insufficiency is prevented by considering the capitalization index, the insufficiency of preventive reserves is determined using the level of banks loans.

Even though financial crises are not the only source of economic slowdown, quantified by the Gross Domestic Product (GDP), the turbulence of the international financial markets significantly affected the performance of the world economy during and after 2008 (BANXICO, Annual Report, 2008). In particular, given that the financial situation of four Mexican and one American banks are analyzed in a predictive manner in this work, Table 15 shows the annual variation of the GDP (as a percentage) of Mexico and the U.S. for the 2006-2010 period. As can be observed in the aforementioned table, the growth of the economy was very low in said period, which coincides with the predictions presented in Tables 13 and 14.

Table 15

Annual variation of the Gross Domestic Product (GDP) as a percentage(*)

Country	2006	2007	2008	2009	2010
Mexico	4.9	3.3	1.5	-6.5	5.5
United States	2.7	2.1	0.4	-2.4	2.9

(*) Source: BANXICO, Annual Report, 2009 and 2010

Source: Own elaboration.

Conclusions

We have presented a discriminant analysis model to identify and predict the financial situation of full-service banking institutions through a combination of financial indicators belonging to different methodologies that show an eminently predictive approach. As far as identification is concerned, it is observed that this analysis has a verified *explicative application* as demonstrated by the discriminant function obtained, which is significant having a high discriminant power since the canonical correlation value was of 0.976 and, for its part, the probabilities of belonging to one or another group (Table 11) were 1. Regarding prediction, it was also shown that the *predictive application* to the four Mexican banks analyzed in the 2000-2008 period, and to the one American bank analyzed in the 2000-2010 period, is reliable since it generally coincides with the analysis issued by the IPAB, BANXICO, and the presidents of the Bank of America. Both applications were done based on the classifying variables resulting from the *step by step* method such as *Return on interest-earning assets*, *Past due loans*, *Efficiency* and *Liquidity (MACRO)*, which are closely related to the national and world financial crisis. In the case of *Return on interest-earning assets*, which contemplates operations with derivative financial instruments, it can be said that, even when it was selected with data from 1999 through the proposed model, it still plays an important role in financial crises as evidenced by the Dodd-Frank Wall Street Reform in the United States (González and Marqués, 2010) and the European Market Infrastructure Regulation (EMIR) in Europe (Regulation of the European Parliament and of the Council, 2012), where it is stated that the common denominator of these initiatives is that they mainly focus on the derivatives, which contributed to the destabilization of the markets (Asobancaria, 2013). On the other hand, the cited financial products, in addition to the structuring and proliferation of other low-quality loans and, in general, the incidence of economic policy within the real economy (2004-2011 period) and on their performance, can be cited for the case of Spain, where their immediate consequence was the deterioration of liquidity and financing leading it to a recession toward the end of 2008 (Marín *et al*., 2015). In relation to the gross financial margin, it is influenced by variations in the exchange rate that directly affect the cash and revenue streams of banking entities (Ballester *et al*., 2009).

Regarding delinquency, Ana Fernández-Sainz and Felipe Llaugel, emphasized in 2011 that some variables relative to the banking sector helped explain the possibility of problems, although not the time of the crisis. Among the specific variables considered were: the risk-adjusted capital ratio, the total non-performing portfolio as a proportion of the total loan portfolio, and the credit concentration as a proportion of the total loan portfolio.

Previous authors also state that numerous studies have demonstrated that the individual analysis of the indicators can be tricky, especially when the aim is to determine a threshold

within which each indicator must be located and that, when it exceeds said threshold, an alert signal is generated. Thus, this entails the development of a methodology that does not individually analyze the indicators, but rather the pattern of the set of relevant indicators. Additionally, it can be said that diverse investigations strengthen the hypothesis that it is not the individual indicators that must be analyzed but rather the behavioral pattern that they present. Furthermore, said authors mention that some works (Todorov *et al*., 1999) indicate that the classification function (statistical technique of multivariate analysis) can be created with a relatively reduced number of indicators due to the great correlation that is commonly observed between them.

Regarding the financial indicators used in this research work, it should be mentioned that Altman *et al*. (2014), in their article "Anatomy of Banks in Crisis", contemplate financial indicators belonging to the CAMEL system that are similar or equal to those analyzed here, originating from the *Bankscope* database. There is no general theory that guides the selection process of said indicators (Labatut *et al*., 2009). However, the context of each of the thirteen indicators considered in this work has been or will be contemplated—with lesser or greater relevance—in Basel Accords II and III of the BCBS as of 2008 as shown in Table 5, which highlights the relevance of the selection and effective employment of each of the indicators utilized here.

Without a doubt, the current situation and possible future economic development of a country or world area normally reflects, first of all, on the financial economy and it first shows itself in the financial information of the Banks. For this reason, it is of great interest to have methodologies, verified in the field of praxis that contribute with real and timely information regarding this possible development and that additionally control key variables in banking such as solvency through own resources, as well as adequate records of possible delinquents via credit provisions. Following the bibliographic review carried out, we can confirm that the proposed methodology is in line with the latest trends in ex ante analysis of bank solvency prediction, which are analyzed and supported by the BIS, the Basel Committee, the European Banking Stress Test and the national analysis, among others. This analysis and information would allow developing a national and/or supranational economic and financial policy in due course that will mitigate the effects on the real economy and its incidence in all the key variables for economic development.

Based on the above, it is concluded that the proposed model can be used, in addition to the institutional early warning models, to predict whether a bank is in distress. In that regard, it should be mentioned that said model, even though it does not take the ICAP into account as early warning models do, does consider the provision for credit losses. Additionally, this model can be applied to any bank of any country and for any year after those analyzed in this work, considering that, for its application, the necessary and important updated information in

the banking sector (Gras *et al*., 2015) should be available to calculate the financial indicators proposed in this work.

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