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Evaluation of Default Risk for the Brazilian Banking Sector

Marcelo Y. Takami*
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Abstract

This paper employs new methods to measure and monitor risk in the Brazilian banking sector. We prove that the option-based risk measure is negatively sensitive to interest rates. As this is an important issue for emerging market economies, the risk measures are built as deviations from mean. Additionally, the option-based indicator is compared with market-based financial fragility indicators. Results show that these indicators are useful for risk managers and regulators, especially during crisis. Furthermore, option-based methods are preferable to classify banks in periods of high distress, such as the banking crises that occurred in the early nineties in Brazil.

JEL Classification: G21.
Keywords: financial institutions; distance to default; systemic risk; financial stability.

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1. Introduction

The past two decades have witnessed many banking crises around the world. These crises have important implications for the economy as a whole. Hoggarth *et al.* (2002) studied the costs of banking system instability and found that the cumulative output losses incurred during crises are 15-20% of annual GDP, on average.

The increase in financial fragility around the globe in the 1990s led to the development of financial indicators that are used in early warning systems. Recent literature has suggested indicators that employ market data such as data on equity prices and options and accounting information to unveil the risk in the banking system (Vassalou and Xing, 2004).

This paper contributes to the literature by adapting market and option-based financial stability indexes for an emerging market economy. We have calculated banking vulnerability indicators based on equity prices and balance sheets for individual banks and showed that these indicators have forecasting power and may be used to assess financial fragility. We innovate by calculating relative risk indexes (section 6), because within this approach the comparison of risk levels of different banks is straightforward. If specific banks have a high-risk profile compared to their peers, then they may be seen as high-risk banks, although their absolute risk level may not be large. In this sense, we argue that these indicators should also be sensitive to the interest rate, especially for emerging market countries, where crises have often been accompanied by high interest rate volatility. We underpin our argument by:

a) the calculation of the derivative of the risk measure on interest rate (section 3);

b) simulations (section 3);

c) empirical analysis of the Brazilian experience (section 6).

The Brazilian experience represents an interesting case study due to its relevance in Latin America and because its financial system has been through structural changes in the past decades, with large increases in banking productivity (privatization, merges and acquisitions), but also with changes in the complexity of its financial operations, in an environment of, until recent years, substantial macroeconomic volatility. Specifically, the Brazilian banking system suffered a banking crisis in 1994-1996, when the introduction of the Real and the subsequent defeat of inflation deprived banks of substantial float income. Hoggarth *et al.* (2002) estimate that the fiscal and quasi-fiscal costs of the Brazilian banking crises of 1994-1996 was within 5-10% of annual GDP, while the ratio of non-performing loans over total loans peaked at 15%.

We aim to contribute to the literature in three ways. First, we present an important limitation of the option-based methodology, especially when applied to emerging markets. Second, we employ recently developed methodologies to estimate bank default risk and compare these methodologies in the context of emerging markets (Vassalou and Xing, 2002 and Lehar, 2005). Finally, we show that these financial fragility indicators may prove useful for regulators and risk managers. Our empirical results suggest that option-based methods may prove useful in classifying financially embarrassed banks, especially in periods of financial distress.

The remainder of the paper is structured as follows: Section 2 provides a brief literature review; Section 3 discusses the limitation of the option-based method; Section 4 presents the methodology, while Section 5 gives a brief overview of the Brazilian banking industry and of the Brazilian banking system restructuring program (PROER); section 6 discusses the empirical results and Section 7 concludes the paper.

2. Literature Review

When financial systems stop working, the cost in terms of social welfare can be substantial, as bank crises are associated with the slow down of economic activity, high inflation, tax increases and currency depreciation (Hoggarth *et al.* 2002). The health of the banking system is, therefore, one of the main concerns of supervisory authorities.

The need for monitoring banking risk has led to the search of indicators of economic disequilibrium to complement direct supervision. In particular, the market value of stocks and bonds of banks has the potential of revealing information regarding the economic-financial equilibrium of a bank, under the hypothesis that markets price risk correctly. A clear advantage of the use of market prices as opposed to direct supervision is that the market information is available on a high-frequency basis (Jobert *et al* (2004)).

The literature is divided into two main lines of research. Part of the literature suggests that fundamentals of banks and firms can be captured by accounting information and can be used for monitoring bank risk. This literature suggests that accounting variables can capture bankruptcy risk (Altman, 1968; Altman *et al.*, 1977; Lau, 1987). However, another strand of the literature has used market data, such as stock and option prices, to build financial stability indicators (Clare and Priestley, 2002; Tabak and Staub, 2006). However, recent literature has employed both market data and accounting information to extract information regarding the implied default probability of firms and banks (Vassalou and Xing, 2004; Lehar, 2005; Bystrom *et al.*, 2006).

Using market data, Clare and Priestley (2002) calculated the probability of bankruptcy in the Norwegian banking sector before and after banking crises in Norway. They found empirical evidence that showed an increase of systemic risk starting in 1984, right after the deregulation of this sector, and a decrease beginning in 1992. The details of the methodology for estimation of our market-based risk measure are described in section 4.1.

Vassalou and Xing (2004) used the option-pricing model of Merton (1974) to calculate indicators of bankruptcy probability for individual North American firms using data from the stock market. These authors investigated how bankruptcy risk affects stock returns and found evidence that balance sheets contain information related to the bankruptcy of firms and that bankruptcy risk represents a systemic risk. In subsection 4.2, we describe their methodology to calculate distance-to-default.

Lehar (2005) proposed a new method to measure and monitor systemic risk in the financial system. The innovation was about incorporating the interdependence between banks into Merton's (1974) framework in order to estimate risk measures. The author concluded that high correlation between bank assets implied a higher probability of multiple bankruptcies and that larger and most profitable banks presented lower systemic risk. The distances-to-default of our paper are derived from Lehar's methodology, which is detailed in subsection 4.2.

On approaches to emerging market economies, Bystrom *et al* (2005) applied the Merton model (1974) to 50 firms listed in a stock index of Thailand and verified a significant rise of the probability of default around a crisis and a slow reversion to pre-crisis levels as well as a negative relationship between firm size and the probability of default of the corresponding company only during crises.

The literature on the Brazilian banking system is scant, despite its relative importance in Latin America. Moreover, the approaches do not employ option-based methodologies to extract information regarding bank system vulnerabilities. Tabak and Staub (2006) have built a financial stability index for Brazilian banks and suggested that macroeconomic stability has helped the stability of the domestic banking system. Tannuri and Sales (2005) suggested that the Brazilian banking system-restructuring program (PROER) had an effect on the reduction of bankruptcy probability in Brazil in the late 1990s.

This paper contributes to the literature by adapting market and option-based models to derive financial stability indexes for an emerging market banking sector.

3. Limitations of the option-based approach

We discuss now a few limitations of this methodology. According to Merton (1974) the value of the asset of the firm, V_t, is assumed to follow a geometric Brownian motion:

$$\frac{\mathrm{d}V_t}{V_t} = \mu dt + \sigma dZ_t, \tag{1}$$

where μ is the drift, σ^2 is the variance of the underlying asset, and Z_t is a standard Wiener process.

In this model, credit risk arises from the potential default, which is assumed to occur only at maturity of debt. The value of the firm's equity is given by[1]

$$E_t = V_t N(d_1) - Xe^{-r(\tau)} N(d_2), \tag{2}$$

with

$$d_1 = \frac{\ln(V_t/X) + (r + \sigma^2/2)(\tau)}{\sigma\sqrt{\tau}},$$

and

[1] Lehar (2005) and Ronn and Verma (1986) did not include the risk free interest rate explicitly in the equations, because the value of the debt is already adjusted for present value.

$$d_2 = d_1 - \sigma\sqrt{\tau} \, ,$$

where τ is the length of time until maturity, r is the risk-free interest rate and X is the strike price of the option (face value of debt from the balance sheet). In our empirical exercise we fix debt maturity to one year[2]. Equity prices E_t are used in order to solve equation (2) for the bank´s asset value (V_t).

The default distance (dd_t) is calculated according to the following formula:[3]

$$dd_t = \frac{\ln(V_t / X_t) + (\mu - \sigma^2/2)\tau}{\sigma\sqrt{\tau}} \; . \tag{3}$$

As for the calibration process, we verify that: i) in the iterative method of Vassalou and Xing (2004), the convergence of the algorithm depends on the initial bid of the market value of asset V_t, and ii) in the methodology of Lehar (2005), the resulting parameters of calibration (σ and V_t) are highly sensitive to the scale of entry variables (E_t and X_t), especially at the period prior to the introduction of the Real.

Furthermore, it is observed that the distance to default is significantly sensitive to the interest rate. For the same calibration methodology, the higher the interest rate, the lower the present value of the debt (as indicated by the term $Xe^{-r(\tau)}$ in equation 2). According to equation 2, the market value of the assets should be lower for a given value of E_t. Thus, the chance of the market value of the assets covering the value of the debt will be lower and, therefore, the distance to default (dd_t) will be smaller and the default risk will be higher. Analytically, it is expected that $\frac{\partial dd}{\partial r} < 0$. Therefore, taking the derivatives of (2) and (3) with respect to the interest rate *r*, we have:

$$0 = \frac{\partial V}{\partial r} N(d_1) + VN'(d_1)\frac{\partial d_1}{\partial r} - Xe^{-r\tau} N'(d_2)\frac{\partial d_2}{\partial r} + Xe^{-r\tau} N(d_2)\tau \tag{4}$$

---

[2] We also allow for shorter debt maturity and compare results. However, qualitative results remain unchanged.

[3] See deduction in Vassalou and Xing (2004)

$$\frac{\partial dd}{\partial r} = \frac{\partial V / \partial r}{V \sigma \sqrt{\tau}} \tag{5}$$

We know that:

$$d_2 = d_1 - \sigma\sqrt{\tau} \tag{6}$$

implies

$$d_2^2 = d_1^2 - 2d_1\sigma\sqrt{\tau} + \sigma^2\tau =$$

$$= d_1^2 - 2\left[\ln\left(V / X\right) + (r + \sigma^2 / 2)\tau\right] + \sigma^2\tau = d_1^2 - 2\ln\left(Ve^{r\tau} / X\right) \tag{7}$$

We also know that:

$$N(d) = \int_{-\infty}^{d} \frac{1}{\sqrt{2\pi}} e^{-t^2/2} dt \Rightarrow N'(d_2) = \frac{1}{\sqrt{2\pi}} e^{-d_2^2/2} \tag{8}$$

Therefore, we have

$$N'(d_2) = \frac{Ve^{r\tau}}{X} \frac{1}{\sqrt{2\pi}} e^{-d_1^2/2} \Rightarrow Xe^{-r\tau} N'(d_2) = VN'(d_1) \tag{9}$$

Knowing that from (6), we have $\frac{\partial d_2}{\partial r} = \frac{\partial d_1}{\partial r}$ and replacing this and (9) in (4), we obtain:

$$\frac{\partial V}{\partial r} = -\frac{Xe^{-r\tau} N(d_2)\tau}{N(d_1)} < 0 \tag{10}$$

Replacing (10) in (5) we arrive at:

$$\frac{\partial dd}{\partial r} = -\frac{Xe^{-r\tau} N(d_2)\sqrt{\tau}}{VN(d_1)\sigma} < 0 \tag{11}$$

Alternatively, we evaluate the sensibility of *dd* to the interest rate, calculating firstly the market value of assets (V_t) corresponding to real interest rates between 0 and 100%, according to equation 1 and maintaining the other variables (E_t/X_t e σ) at a fixed value (their averages for each bank was adopted as a reference). Then, we replaced each V_t in equation 2, obtaining different values of distance to default. Figure 1 shows that the distances to default of banks B, E and F, which presented lower E_t/X_t ratio, are more sensitive to interest rates.

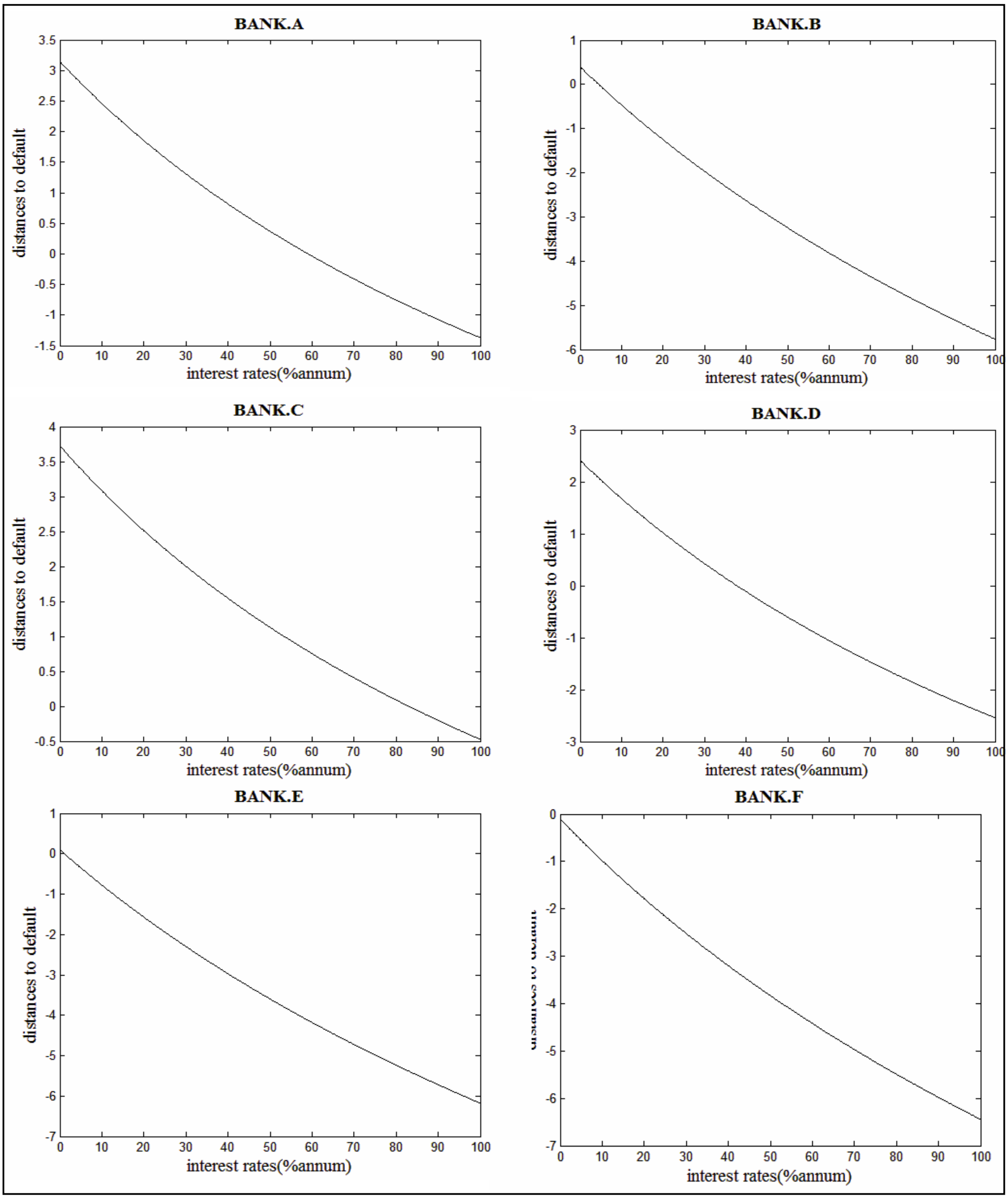

Figure 1 – Distances to default x interest rates

For each bank we present how sensitive the distance to default is to the variation of its cost of opportunity. As we can notice, banks E and F are significantly more sensitive than banks A and C.

Due to this limitation, we estimate deviations of the distance to default from a reference value (average distance to default of the 6 banks weighted by the total debt) for each bank and for each month. The results are in section 6.

4. Methodology

4.1. Market-based methodology

We estimate a market-based default measure by using the methodology described in Clare and Priestley (2002). Through a conditional version of CAPM (Capital Asset Pricing Model), a measure of variability is derived using market data.

According to the CAPM, for an individual stock *i* and for an instant of time *t*, we have: $\mathrm{E}(\tilde{\mathrm{R}}_{\mathrm{it}}) = \beta_{\mathrm{it}}\mathrm{E}(\tilde{\mathrm{R}}_{\mathrm{St}})$, where $\mathrm{E}(\tilde{\mathrm{R}}_{\mathrm{it}})$ is the expected excess return of stock *i* and $\mathrm{E}(\tilde{\mathrm{R}}_{\mathrm{St}})$ is the expected excess return of the market portfolio. If the expected returns are correct on average, we have:

$$\tilde{\mathrm{R}}_{\mathrm{it}} = \beta_{\mathrm{it}}\mathrm{E}(\tilde{R}_{St}) + e_{it}, \tag{12}$$

where e_{it} is the residual term.

Finally, we obtain the market-based risk measure just by calculating the inverse of the standard deviation of the residual term: $1/\sigma_{e_{it}}$. Clare and Priestley (2002) derive this statistic by dividing the market value of equity by its standard deviation, i.e., this statistic represents the number of standard deviations that a company is distant from default point[4]. The smaller this value, the closer the company will be to default and the higher its default risk will be. We calculated $1/\sigma_{e_{it}}$ on a monthly basis with a moving window of *m* business days, applying a regression (OLS) to the data of this moving window, according to the following single factor model:

$$R_{it} = \beta_0 + \beta_1 R_{St} + \mathrm{e}_{\mathrm{it}}, \tag{13}$$

[4] Clare and Priestley (2002) obtain estimates e_{it} using an AGARCH-M (*Asymmetric Generalised Autoregressive Conditional Heteroskedasticity in Mean*) model, which considers asymmetry of price in the conditional variance.

where R_{it} is the return of bank i and R_{St} is the banking sector return.[5,6]

The choice of the banking sector as the portfolio of reference, instead of a broader market portfolio, is due to the difference in financial performance of the Brazilian banking sector as opposed to other industries, mainly before the introduction of the Real.

4.2. Option based methodology

The calculation of the option-based risk measure was based on two papers: Vassalou and Xing (2004) and Lehar (2005). They only differ in the methodology used to calibrate the instantaneous volatility (σ). Vassalou and Xing (2004) use the following algorithm: first of all, an initial value σ^0 (0-iteration) is attributed to σ. This initial value $\sigma^0=\sigma_E$ is simply the standard deviation[7] of the continuous return on equity prices E_t for the corresponding moving window of m business days[8]. Then, they replace $\sigma^{(k-1)}$ (or $\sigma^{(k-1)}=\sigma^0$ if the algorithm is in its 0-iteration) in equation 2 to calculate V_t for each day along the corresponding window of m business days. Of course, we also have to use the given values of E_t, X_t and r_t in equation 2 for each day. Then, taking all those m values of V_t, we calculate σ^k by simply computing the standard deviation of V_t. While $\sigma^k - \sigma^{k-1}$ > tolerance interval, σ^k is replaced in equation 2 for a new calculation of the m values of V_t's. This loop iterates until σ^k converges within an arbitrarily tiny tolerance interval (1e-06 in our case).

On the other hand, Lehar (2005) estimates (μ,σ) through maximization of the following log-likelihood function[9]:

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[5] We tested several CAPM specifications, with different proxies for interest rates, and the estimated default risk for each bank was practically equal.

[6] For banks A, C and D, we take the PN shares (preferred), while for the banks B, E, and F, we take the ON (ordinary) shares. The choice of the type of stock was made depending on the availability of data.

[7] $\sigma_E = \sqrt{\dfrac{\sum_{t=2}^{m}\left[\ln\left(\dfrac{E_t}{E_{t-1}}\right)-\mu_E\right]^2}{m-2}}$, $\mu_E = \dfrac{\sum_{t=2}^{m}\ln\left(\dfrac{E_t}{E_{t-1}}\right)}{m-1}$ and $m \cong 255$.

[8] m = number of business days in the corresponding moving window of 12 months $\cong$ 255.

[9] The author proceeds in this way alleging that asset volatility is difficult to estimate, because it is not linear in the equity volatility. In this sense, this procedure overcomes such problem.

$$L(E,\mu,\sigma) = -\frac{m-1}{2}\ln(2\pi) - \frac{m-1}{2}\ln\sigma^2 - \sum_{t=2}^{m}\ln\hat{V}_t(\sigma) - \sum_{t=2}^{m}\ln N(\hat{d}_{1,t})$$

$$-\frac{1}{2\sigma^2}\sum_{t=2}^{m}\left[\ln\left(\frac{\hat{V}_t(\sigma)}{\hat{V}_{t-1}(\sigma)}\right) - \mu\right]^2 . \qquad (14)$$

The solution of this maximization problem was found by using the quadratic hill-climbing algorithm of Goldfeld *et al.* (1966). Notice that $\hat{V}_t(\sigma)$ is an implicit function of σ according to equation 2. Our paper employs both methodologies and compares the results.

For both calibration methodologies, μ is given by $\mu = \sum_{t=2}^{m}\ln\left(\frac{\hat{V}_t(\sigma)}{\hat{V}_{t-1}(\sigma)}\right) \Big/ (m-1)$, and the default distance (dd_t) is calculated on a monthly basis according to equation 3.

The default distance consists of the number of standard deviations that the firm is away from the default point. This measure is a proxy for a firm's default risk. The more positive the dd_t, the lower the probability that the firm will default on its debt.

4.3. Data Sample

The daily values of equities of 6 large Brazilian banks with traded stocks at the Sao Paulo Stock Exchange (Bovespa) were obtained from the Economática database and the monthly values of debt were collected from the Central Bank of Brazil. Daily Brazilian interest rates (DI-OVER) were collected from Bloomberg and the consumer price index (CPI) from the www.ipeadata.gov.br[10] site. The CPI was used to deflate market and debt values. We collected daily data of financial time series and monthly observations for accounting information, covering the period from March 1988 to February 2005.

[10] The DI-OVER series was chosen because it presents data from October 1986, while the series of swap PRE-DI, for example, presents data only from January 1995.

5. An Overview of the Brazilian Banking System

The Brazilian banking system is the largest in Latin America and also the most sophisticated in terms of technology. Many changes have taken place in the past two decades, with a substantial increase in bank productivity, as well as a rise in merges and acquisitions, which resulted in a higher concentration of the banking system (Nakane and Weintraub, 2005; Beck *et al.*, 2005).

One of the main changes in the Brazilian banking system was the consolidation of the defeat of inflation in early 1994 with the introduction of the Real. Before the Real, a large part of the profit of Brazilian banks was based on gains from non-interest-bearing liabilities, such as cash deposits and resources in transit. From 1988 to 1994, the number of banks increased from 102 to 244 banks. After the introduction of the Real, some banks could not manage to promote the necessary adjustments for their survival in this new economic environment and ended up bankrupt. From 1995 to 2005, 55 financial institutions were liquidated, causing high financial and social costs. After the distress of the Banco Econômico (the 22nd bank under intervention/liquidation since the introduction of the Real, which at the time was the 15th largest by assets) and to avoid a potential systemic crisis, the PROER was introduced on November 3, 1995, which kept mergers and acquisitions of banks under the ruling of the Central Bank. This program was aimed to provide credit and fiscal benefits to institutions interested in buying distressed banks[11]. As a result of the introduction of PROER and the inflation-free environment, the banking sector shrunk to 184 banks in 2005.

Therefore, the period from 1988 to 2005 may be viewed as a period of large transformations in the Brazilian banking system. Consequently, it is an interesting period to study the evolution of financial fragility indicators and whether they can help forecast bank failures.

[11] See Nakane and Weintraub (2006) and Tannuri and Sales (2005).

6. Empirical Results

Six large Brazilian banks (of which two – banks E and F – were liquidated in the second semester of 1996) were analyzed and the individual measures of default risk (distance to default – *dd* – and $1/\sigma_{e_{it}}$) were calculated on a monthly basis from May 1989 to February 2005 using a moving window of *m* business days (m ≅ 255). All banks are private, except bank B, which is state-owned.

We chose to compare the default distances and the deviations of these distances to the weighted mean, instead of default probabilities, due to its ordinal nature that is similar to a rating. According to Altman *et al.* (1977), this measure is not necessarily associated to a pre-defined value of default probability, as different types of distribution lead to different probability values.

Regarding the option-based risk measures, based on Merton (1974), the magnitude of the distance to default (*dd*) according to Vassalou and Xing (2002) and Lehar (2005) are very similar through time for each bank and the correlations of these risk measures are high (close to 100% for banks A, B, C and D and to 92% for banks E and F).

Therefore, we focus on the methodology described in Lehar (2005) as the estimation by the maximum likelihood function is considered more suitable. This suitability refers to the hypothesis that the value of the asset of the firm, V_t, is assumed to follow a geometric Brownian motion (see Duan (1994, 2000)).

We observe a similarity among the evolution of banks until July 1995. This similarity concerns the option and market data-based methodologies as shown in Table 1. This Table presents correlations of distance to default measures for banks, and then show a pair-wise similarity regarding risk dynamics[12].

[12] The F statistics of Granger´s causality test were significant between banks A and C and between C and D at 10% of significance and were not significant between banks E and F.

Table 1 – Correlation of each risk measure (*dd* and $1/\sigma_{e_{it}}$) for each pair of banks before July 1995*

	A-C	C-D	A-D	A-E	A-F	C-E	C-F	D-E	D-F	E-F
dd	96%	92%	85%	82%	81%	85%	83%	96%	94%	100%
$1/\sigma_{e_{it}}$	82%	60%	71%	25%	56%	43%	64%	45%	81%	74%

* We do not compute pair-wise correlations using Bank B because its time series starts only in December 1994.

In each column we present correlations between different banks for each risk measure. The table shows that there may have been some sector-like or pervasive economic factor in operation.

The high positive pair-wise correlations (Table 1) indicate that the dynamics of individual risk measures were related to some sector-like or pervasive economic factor. We used the parameters estimated for the calculation of the measure based on the one factor model, and observed the prevalence of the systematic component ($\beta^2\sigma_m^2$) over the idiosyncratic component ($\sigma_{e_{it}}^2$) for banks A and C (Table 2).[13]

Table 2 – Measures of systematic and idiosyncratic risk in relation to the total risk

	Bank A	Bank B	Bank C	Bank D	Bank E	Bank F
$\beta^2\sigma_m^2/\sigma_i^2$	71%	46%	58%	13%	0,07%	0,35%
$\sigma_{e_{it}}^2/\sigma_i^2$	29%	54%	42%	87%	99,93%	99,65%
Average β	1,28	1,05	1,01	0,55	0,02	0,04

In each column we present the breakdown of the total risk, according to the one factor model. The first and second lines present the proportion in total risk of systemic and idiosyncratic risks, while the last line presents average systemic risk. These measures are an average of the measures obtained on a monthly basis from May 89 to July 95.

Besides, the larger share of idiosyncratic risk of the distressed banks (banks E and F), as shown in Table 2, is a clear indication of a distinct performance of these banks as opposed to the surviving banks as a whole. For the distressed banks, we obtained low values for β, which explains their low share of systematic risk. The relative measures *dd* and $1/\sigma_{e_{it}}$ capture this difference in performance and then, are helpful for assessing financial fragility in the banking system.

[13] The ADF and KPSS tests were applied to the series of stock returns for each bank before estimating the β's by OLS regressions and stationarity was achieved.

Therefore, considering the ordinal nature of our risk measures and in an attempt to identify genuine idiosyncratic risk variations, we estimate the deviation of the distance to default from a reference value (average distance to default of the 6 banks weighted by the total debt) for each bank and for each month. Note that classifying banks in this way is more convenient than, for example, having to arbitrarily define a critical value below which a bank would be considered highly risky. This would have been the case, if the analysis had been developed using absolute values of distance to default measures (*dd* or $1/\sigma_{e_{it}}$). In this sense, we calculate deviations from mean and check whether it is possible to identify the relatively worse performance of distressed banks. This relative distance to default is shown in Figure 2 (negative deviations suggest that banks are underperforming in terms of default risk compared to the sector benchmark and vice-versa):

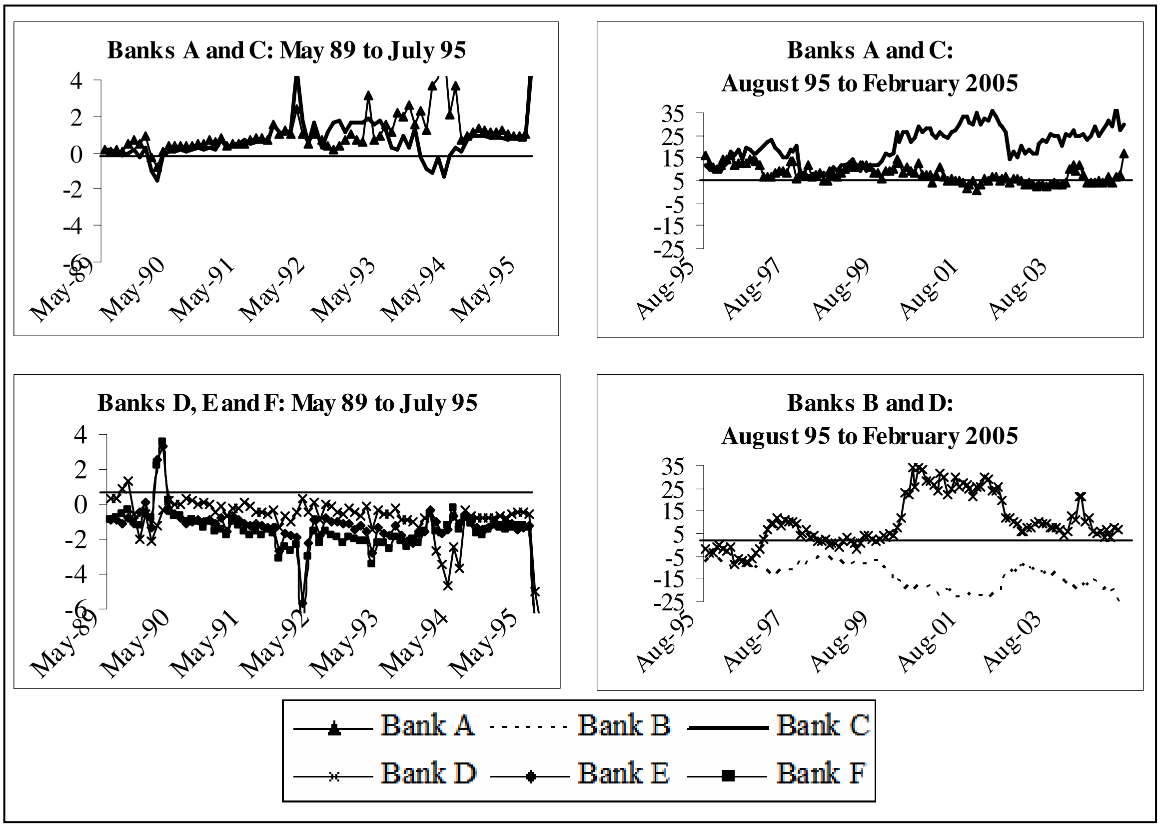

Figure 2 – Relative distance to default (*dd*)

For each bank we present relative risk measures for different periods. Banks E and F failed in this period, and their relative risk measures were below average for most of the sample, while A and C were above average (non failing institutions).

Figure 2 suggests that *dd* fairly succeeds in correctly capturing the relative risk of each bank. The visual analysis of this figure suggests that the risk level of banks A and C were below average (higher relative default distances) during most of the period in analysis. Moreover, banks E and F, which suffered a government intervention in the second semester of 1995 and were liquidated a year later, presented the highest risk levels among the 5 banks in 84% of the months from May 1989 to July 1995. As for bank D, its risk levels remained above average (lower relative default distances) during the period prior to July 1995, but since that date, the default distances increased, reaching values above those of bank A for several months.

Next, we test whether interest rates paid to depositors by banks show evidence of increasing risk (market discipline). If a bank's funding rates show bank's risk then we would expect that banks with higher risk pay higher interest rates on their deposits (CDB rates)[14]. The Granger causality test results with 12 lags are presented in Table 3.

[14] The same analysis was made with the weighted mean of the CDB rate for the 6 banks and the results are equivalent.

Table 3 – F statistics of the Granger causality test between weighted *dd* x average CDB (interest rates paid by banks on time deposits) and $1/\sigma_{e_{it}}$ weighted x average CDB[15]

	H_1	H_2	H_3	H_4
Before July/95	4,52*	4,21*	0,511	1,17
After July/95	4,74***	0,53	5,97***	0,599

H_1: weighted *dd* does not cause average CDB,
H_2: average CDB does not cause weighted *dd*,
H_3: weighted $1/\sigma_{e_{it}}$ does not cause average CDB,
H_4: average CDB does not cause weighted $1/\sigma_{e_{it}}$

***, ** and * stand for significance at the 1%, 5% and 10% level, respectively.

This Table shows whether risk measures anticipate changes in interest rates paid by banks on time deposits, and whether the opposite holds true.

We verify an increase in market discipline as indicated by highly significant F-statistics under the columns H_1 and H_2 after July 95 (Table 3). It is also important to notice that in the recent period (after July 1995), our risk measures anticipate changes in banking funding rates. Therefore, it is worthwhile estimating such measures and monitoring them as they anticipate changes in banking funding rates, which may be a sign of problems in the banking system.

Moreover, the explanatory power of both risk measures was compared, applying the following GMM regression: average $CDB_t = \alpha_0 + \alpha_1 * mr_t + \varepsilon_t$, where $mr_t = \{$weighted *dd*, weighted $1/\sigma_{e_{it}}$ $\}$ and ε_t is the residual term, assumed to be independent and identically distributed with zero mean and variance σ^2_ε. We employ mr_{t-1} as an instrumental variable. The results are presented in Table 4.

Table 4 – GMM regressions of the variables at aggregate levels

Explanatory variable	**Before July/95**		**After July/95**	
	α_0	α_1	α_0	α_1
Weighted *dd*	0,333** (2,181)	-0,306*** (-4,367)	0,101*** (13,798)	-0,002*** (-4,528)

[15] Since the rejection to the non-stationality of the variables was not very strong, Granger´s causality test was also applied for the first difference between the variables. The results do not change qualitatively.

Weighted $1/\sigma_{e_{it}}$	1,234 (0,027)	-0,008 (-0,006)	0,124*** (5,744)	-0,0009** (-2,345)

T-statistics are provided in parentheses. ***, ** and * stand for significance at the 1%, 5% and 10% level, respectively.

Average $CDB_t = \alpha_0 + \alpha_1 * mr_t + \varepsilon_t$,

where mr_t = {weighted *dd*, weighted $1/\sigma_{e_{it}}$ } and $\varepsilon_t \sim IID(0,\sigma^2_\varepsilon)$.

mr_{t-1} was used as an instrumental variable. mr_{t-1} seems to be a valid instrument because it is not expected to be correlated with the residual in the above regression. The residual in this regression captures other aspects of the decision on interest rates paid on deposits that are not related to risk, such as business policy and others.

Together, the results of Tables 3 and 4 show evidence of market discipline for aggregate level after July 1995. The α_1 coefficients, as shown in Table 4, are strongly significant and with the expected sign for weighted *dd* (an increase in the funding rate (CDB) must be related with an increase of risk measures and vice-versa).[16]

We apply the same GMM regression for banks A, C, E and F with relative average CDB_i (average CDB_i) as a dependent variable. It is expected that the α_1 coefficients are significant and with a positive sign. When this coefficient is positive then if banks are paying lower than average funding rates they must also be incurring in less relative risk.[17] It is important to notice that it is very difficult to assess whether options or market-based measures have a better performance, as is shown in Tables 5-7.

[16] We employ Flemming (1998) to estimate these regressions.
[17] average CDB_i = average CDB – CDB of the bank i.

Table 5 – GMM regressions for bank A

Explanatory variable	Before July/95		After July/95	
	α_0	α_1	α_0	α_1
dd A	-0,022 (-0,640)	0,025 (0,845)	-0,003 (-2,139)	0,0006*** (4,068)
$1/\sigma_{e_{it}}$ bank A	0,076 (1,393)	-0,004 (-1,388)	0,004 (1,486)	-7,14e-05 (-0,601)

T-statistics are provided in parentheses. ***, ** and * stand for significance at the 1%, 5% and 10% level, respectively.

Average $CDB_t = \alpha_0 + \alpha_1 * mr_t + \varepsilon_t$,

where mr_t = {weighted *dd*, weighted $1/\sigma_{e_{it}}$ } and $\varepsilon_t \sim IID(0,\sigma^2_\varepsilon)$.

mr_{t-1} was used as an instrumental variable. mr_{t-1} seems to be a valid instrument because it is not expected to be correlated with the residual in the above regression. The residual in this regression captures other aspects of the decision on interest rates paid on deposits that are not related to risk, such as business policy and others.

Table 6 – GMM regressions for bank C

Explanatory variable	Before July/95		After July/95	
	α_0	α_1	α_0	α_1
dd C	0,008 (0,573)	-0,001 (-0,145)	0,0117** (2,165)	-0,0002 (-0,744)
$1/\sigma_{e_{it}}$ bank C	0,017 (1,128)	-0,002 (-1,139)	0,007*** (2,890)	-2,81e-05 (0,207)

T-statistics are provided in parentheses. ***, ** and * stand for significance at the 1%, 5% and 10% level, respectively.

Average $CDB_t = \alpha_0 + \alpha_1 * mr_t + \varepsilon_t$,

where mr_t = {weighted *dd*, weighted $1/\sigma_{e_{it}}$ } and $\varepsilon_t \sim IID(0,\sigma^2_\varepsilon)$.

mr_{t-1} was used as an instrumental variable. mr_{t-1} seems to be a valid instrument because it is not expected to be correlated with the residual in the above regression. The residual in this regression captures other aspects of the decision on interest rates paid on deposits that are not related to risk, such as business policy and others.

Table 7 – GMM regressions for banks E and F from February/92 to July/95

Explanatory variable	Bank E		Bank F	
	α_0	α_1	α_0	α_1
dd	-0,007 (-0,709)	0,003 (0,508)	0,028 (1,002)	0,009 (1,024)
$1/\sigma_{e_{it}}$	0,008 (0,703)	0,001** (2,035)	0,047 (1,305)	0,006 (1,507)

T-statistics are provided in parentheses. ***, ** and * stand for significance at the 1%, 5% and 10% level, respectively.

Average $CDB_t = \alpha_0 + \alpha_1 * mr_t + \varepsilon_t$,

where mr_t = {weighted *dd*, weighted $1/\sigma_{e_{it}}$} and $\varepsilon_t \sim IID(0,\sigma^2_\varepsilon)$.

mr_{t-1} was used as an instrumental variable. mr_{t-1} seems to be a valid instrument because it is not expected to be correlated with the residual in the above regression. The residual in this regression captures other aspects of the decision on interest rates paid on deposits that are not related to risk, such as business policy and others.

As we can see, although we obtain evidence of market discipline at an aggregate level (Tables 3 and 4), we didn't obtain any evidence for individual banks (Tables 5-7). The deviations of the risk measures are slightly correlated with the deviations of the funding rate CDB_i (average CDB_i) and when α_1's are significant (only for two cases), they are low.[18] The CDB rate could be an inadequate proxy for the vulnerability variation of each bank, due to the lack of market discipline before 1995, as Table 8 indicates.

Table 8 – Dynamic relative risk position of each bank in the 1993-1995 period.

	A	B	C	D	E	F
CDB deviations	20%	0%	40%	8%	76%	72%
***dd* deviations**	0%	100%	24%	100%	100%	100%
$1/\sigma_{e_{it}}$ **deviations**	0%	100%	16%	100%	100%	80%

In the first line we present how often (% of months) banks paid interest rates above average for their time deposits, what should indicate risk above average, prevailing strong market discipline. In the second and third lines we present the proportion of months that these banks had their risk measures above average.

Results of Table 8 suggest that for the period prior to 1995 market discipline was low, as distressed banks – banks E and F – were paying lower interest rates on their deposits than other banks in at least 24% of the months (we expected percentage values close to 0%, i.e., risk position close to 100%). One possible explanation is the effect of hyperinflation in the period, which could have inhibited market discipline. Not only by generating considerable gains in bank's float but also for reducing the transparency of

[18] The correlations between the risk measures and the deviation of CDB for each bank are low. Only bank A presented relatively high correlation (54%) between the *dd* deviation and the CDB deviation for the period after July 1995.

the term structure of interest rates. Therefore, this evidence suggests that our vulnerability indicators may add value in monitoring and assessing banking vulnerabilities

7. Conclusions

We present an important limitation for the option-based approach: it is negatively sensitive to interest rates. This sensitiveness seems to be crucial when applying that approach to emerging market banking sectors. Therefore, in order to assess default risks, we calculate deviations from mean.

This paper compares two methodologies to assess banking risk and finds that option and market-based banking vulnerability indicators are important for monitoring banking risks. We have shown that these measures are helpful in assessing the likelihood of bank failures and have presented evidence of such for the Brazilian 1994-1995 banking crisis.

Overall, the option-based measure presented a risk classification closer to what one should expect than the market-based methodology. Therefore, empirical results suggest that models that incorporate both accounting information and market valuation may have performed better than models that rely solely on market information.

We test whether risk measures are related to interest rates paid on time deposits, as the latter would be important indicators of bank's financial conditions if market discipline is exerted in the banking system. However, empirical results suggest that market discipline was low in 1989-1995. Therefore, risk measures based on market and options data may be an important tool for assessing banking vulnerabilities.

A few caveats apply to this study. Although large banks have traded stocks and debt in secondary markets in Brazil, many medium-sized, but still important banks do not. Therefore, we evaluate only a sample of the banking system. Measures that induce banks to open their capital and issue stocks could be seen as a way to increase transparency and help promote market discipline. Additional research could also focus on studying models which incorporate interest rate risk.

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