Journal of Applied Economics. Vol IX, No. 2 (Nov 2006), 381-402

CENTRAL BANK'S VALUE AT RISK AND FINANCIAL CRISES: AN APPLICATION TO THE 2001 ARGENTINE CRISIS

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Submitted December 2003; accepted May 2005

Blejer and Schumacher (1999) were the first to suggest that Central Bank's Value at Risk (VaR), a widely used composite measure of potential portfolio losses in the corporate sector, could be used as an early warning indicator of financial crises. We extend their research in two aspects. First, we develop an operational model to calculate Central Bank's VaR and illustrate the methodology using data from the recent financial crisis in Argentina. Second, we compare the predictive performance of diverse measures based on the VaR approach to that of another well known early warning system, the signals approach, and several univariate leading indicators. The results reveal a strong relationship between the measures proposed and the crisis. Furthermore, one of the measures provides higher accuracy and announces the probability of a crisis sooner than the competing indicators.

JEL classification codes: E58, F31, G15
Key words: currency crises, Argentina, value at risk

I. Introduction

In recent years, together with the increase in the frequency and the severity of balance of payment crises in emerging markets, there has been a flurry of research aiming at identifying economic weaknesses and ultimately anticipating crises. Two popular approaches in the design of early warning systems (EWS) have been the

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use of probit or logit models (e.g., Frankel and Rose 1996) and the "signals" approach introduced by Kaminsky, Lizondo, and Reinhart (1998).[1]

Blejer and Schumacher (1999) –B&S– suggest a different methodology. They propose that Value at Risk (VaR), a well-known composite measure of potential portfolio losses, could be used to assess the solvency of a representative Central Bank. Further, they suggest that, since speculators react to changes on the ratio of VaR to the Central Bank's portfolio value, this measure could be a good indicator of financial crises.

The VaR approach has two distinct advantages over competing methodologies. First, it provides a theoretical foundation for the use of many of the variables that have been found to be successful to predict crises in previous research (i.e., these variables are important in so far they affect the monetary authority's portfolio). Second, it provides a theoretical base to evaluate the marginal contribution of the variables in the development of financial crises (i.e., the marginal contribution depends on the exposure and response of the Central Bank's portfolio to changes in the variables).

This paper extends B&S's research in two aspects. First, we develop an operational model to calculate Central Bank's VaR and illustrate the methodology using data from the 2001 financial crisis in Argentina. We assume that the Central Bank's risk factors follow stochastic processes designed to incorporate the common mean reversion of interest rates, sovereign risk, and devaluation expectations, and the jump-diffusive pattern usually followed by exchange rates under speculative attacks. Second, we compare the predictive performance of diverse measures based on the VaR approach to that of the "signals" methodology and various univariate leading indicators.

The results reveal that the Central Bank of Argentina showed increasing signs of solvency problems beginning in September 2000. By June 2001 the composite measures proposed here point to the possibility of a high level of speculation, situation that actually occurred and ended with the fixed parity in January 2002. Furthermore, one of the measures provides higher accuracy and announces the probability of a crisis sooner than the signals approach and the univariate indicators.

The paper is organized as follows. Section II gives a brief introduction to VaR models and presents the relation between value at risk and financial crises. Section III introduces the empirical model, including the pricing of Central Bank's assets and liabilities, the stochastic processes of the variables, and the calculation of

[1] For a comprehensive review of the empirical literature on balance of payments crises see Kaminsky et al. (1998).

correlation and volatility parameters. Section IV presents the evolution of value at risk and the portfolio value of the Central Bank of Argentina and discusses some of the factors underlying the increasing vulnerability of the Bank. In section V we evaluate the relative predictive power of the VaR measures, while section VI concludes.

II. Value at risk and financial crises

Jorion (1997) defines value at risk as "the expected maximum portfolio loss over a target horizon within a given confidence interval". We can write this as

$$\Pr\left(dP \geq VaR\right) = 1 - c \ , \tag{1}$$

where dP is the change in the portfolio value over a selected horizon and c is confidence level. The approaches to measure *VaR* from (1) can be divided in two groups: local and full valuation. The variance-covariance method is the best example of the first group. Consider a portfolio with a single asset with normally distributed returns, value P, and volatility σ; then, value at risk is given by

$$VaR = P\left(-\sigma\sqrt{dt}\ a\left(1-c\right)\right), \tag{2}$$

where dt reflects the time horizon and $a\left(1-c\right)$ is the inverse cumulative distribution for the Standardized Normal distribution.

The main advantage of the variance-covariance method is its simplicity. Ease, however, comes at a cost; if the portfolio contains assets with returns that are not normally distributed, such as options and bonds, this method will not provide a good measure of risks. In addition, extreme movements of the assets, such as exchange rate collapses, are not captured by the Gauss distribution. Thus, given the common leptokurtic distribution (the existence of "fat tails") of financial assets, the variance-covariance method tends to underestimate VaR.[2] Full valuation models can overcome those problems. The best example of this group is Monte Carlo simulations, which Jorion (1997) considers as "the most powerful method to compute value at risk".

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[2] See Campbell and Koedijk (1999) and Ho et al. (2000) for discussions on the implications of non-normal returns in periods of financial turmoil and applications of different VaR methods to calculate downside risk of assets in the Asian crisis.

Because of its flexibility and power to account for non-linearities and extreme movements of assets, we selected Monte Carlo simulation to develop the empirical estimation of the Central Bank's VaR. With Monte Carlo we use simulations for the random behavior of the assets to generate a probability distribution of the changes in portfolio values. Particularly, VaR is measured using the following algorithm: 1. Value the portfolio today using current market values; 2. Choose a stochastic model and parameters for the behavior of asset prices and simulate the changes in prices over the target horizon; 3. Revalue the portfolio using the changes in prices given by the stochastic processes; 4. Subtract the current value of the portfolio from the value calculated in step three; 5. Perform many simulations of steps two to four to build up a probability distribution of the changes in prices; 6. Calculate the VaR as the appropriate percentile of the probability distribution developed in step five.

How is the value at risk measure related to financial crises? B&S propose: "Our claim is that solvency is a critical factor in sustaining a nominal regime; therefore the suggested indicator (VaR) ... is highly relevant for economic agents, who would make direct use of it as a yardstick to assess a Central Bank's ability to keep its commitments".[3] As we shall demonstrate, the effects of fiscal and monetary policies that are inconsistent with a nominal peg, which are central to first generation models of currency crises (e.g., Krugman 1979), and the existence of self-fulfilling devaluation expectations, associated with second generation models (e.g., Obstfeld 1994) are incorporated into the VaR measure. If one accounts for an explicit or implicit deposit insurance scheme as a contingent liability of the Central Bank, VaR should also be able to capture the relationship between banking and currency crises, which is central to the latest line of financial crises literature.[4] Thus, as pointed out by B&S, although the specific utility function of speculators is unknown, it is plausible to assume that the level of speculation, Π_t, is positively related to the ratio of Central Bank's value at risk to portfolio value, P,

$$\Pi_t = f\left(\frac{VaR_t}{P_t}\right). \tag{3}$$

[3] Borer and Weder (2001) suggest that the use of VaR methods by private banks can itself be a cause of a financial crisis.

[4] See Hattori (2001) and Lai (2002) for current surveys on financial crises.

In the next section we present the necessary ingredients to calculate (3) using a Monte Carlo methodology.

III. Empirical model

A. Central bank portfolio

We follow an approach similar to that of B&S to value the portfolio of a representative Central Bank. Long positions consist of international reserves, assumed to be invested in US treasury bills earning the risk-free interest rate, loans to the financial sector earning the domestic interest rate, and loans to the government. Short positions include the monetary base, debt denominated in foreign and domestic currency, and the value of an implicit or explicit deposit insurance.

The Central Bank's portfolio (*P*), in domestic currency, can be represented as:

$$P = (R - D^f)\, Z\, S + (A^d - D^d)\, Z^* + G\Omega - M - I^d - I^f \quad , \tag{4}$$

where R = the gross stock of international reserves; Z = the price of the risk-free international zero coupon bond; S = the exchange rate; A^d= the stock of loans to the private sector; Z^* = the price of a domestic zero coupon bond denominated in domestic currency; G = the stock of loans to the treasury; Ω = the price of the Central Bank's loans to the treasury; M = the monetary base; D^d= the stock of Central Bank's domestic debt; D^f= the stock of Central Bank's foreign debt; I^d= the value of the deposit insurance corresponding to deposits in domestic currency; I^f= the value of deposit insurance corresponding to deposits in foreign currency.

Assuming all assets and liabilities have the same maturity, equal to one year, it will be useful to define the price of the zero coupon bonds as

$$Z = Z\left(i\right) \tag{5}$$

$$Z^* = Z^*\left(i^*\right) = Z^*\left(i, a, E\left(dS\right)\right) \tag{6}$$

where i = the discount factor for the international zero coupon bond with maturity 1; i^* = the discount factor for the domestic zero coupon bond denominated in domestic currency with maturity 1; α = the sovereign risk; $E(dS)$ = the expected rate of devaluation.

Substituting (5) and (6) into (4), the portfolio becomes

$$P = (R - D^f)\,Z(i)\,S + (A^d - D^d)\,Z^*(i, \alpha, E(dS)) + G\Omega - M - I^d - I^f \;. \quad (7)$$

This valuation differs from the one in B&S in four aspects. First, in valuing the zero coupon bonds we do not assume that the domestic and international interest rates are constant through the VaR horizon. Although the valuation becomes more complex, by introducing stochastic interest rates the model is more consistent with the objective of the paper (i.e., if interest rates are constant no risk would arise, but if they are not constant the valuation of zero coupon bonds given in B&S is flawed). Second, we do not include foreign currency forward contracts mainly because of the lack of reliable data on non-spot transactions by the Central Bank of Argentina (BCRA). Third, we do not consolidate the Central Bank's debt with that of the treasury; we assume that the Central Bank is only liable for its obligations and it pays the international interest rate on its foreign debt. We believe that this assumption resembles reality more closely for a fairly independent Central Bank such as the BCRA. Finally, given that Argentinean banks have a large portion of deposits and assets in foreign currency we break up the deposit insurance contingent liability to account for exchange rate risks.

Differentiating totally equation (7) and rearranging we obtain the change in the value of the portfolio

$$\begin{aligned} &(dR - dD^f)\, ZS + (R - D^f)\,(Z_i di\, S + ZdS) + (dA^d - dD^d)Z^* + \\ &+ (Z^*_i di + Z^*_a d\alpha + Z+_{E(dS)} dE\,(dS)\,(A^d - D^d) + dG\Omega + Gd\Omega - dM - dI^d - dI^f, \end{aligned} \quad (8)$$

where dX indicates the change in the value of a variable X and X_Y indicates dX/dY.

We follow some of the simplifying assumptions used by B&S. Given a commitment to maintain a nominal peg, (where we assume that the peg is $S = 1$), the monetary base expands in response to changes in international reserves and in public and private net domestic credit creation (this assumption resembles very close the convertibility law established in Argentina in 1991):

$$dM = dG + dR + dA^d - dD^d. \quad (9)$$

Further, B&S assume that the government does not repay its debt with the Central Bank,

$$\Omega = d\Omega = 0 \tag{10}$$

new reserves are invested at par value,

$$dRS = dR = dRZ, \tag{11}$$

new loans are granted at par value, and new domestic debt is issued at par value,

$$dA^d - dD^d = \left(dA^d - dD^d\right)Z^*. \tag{12}$$

The model developed by B&S, and (8) here, include portfolio exposures to changes in the exchange rate. However, the change in the exchange rate is, by definition, zero under a fixed parity regime. Thus, we incorporate the concept of the "shadow" exchange rate (i.e., the exchange rate that would prevail if the currency were to float), S^*, to provide a meaningful model for an exchange rate that is fixed but can change if there is a successful speculative attack.

Using (9-12) and the concept of the shadow exchange rate, the change in the value of the portfolio becomes,

$$\begin{aligned}&(R - D^f)\,(Z_i di + ZdS^*) + (Z^*_i di + Z^*_\alpha d\alpha + Z^*_{E(dS)} dE\,(dS))(A^d - D^d) -\\&- dD^f Z - dG - dI^d - dI^f.\end{aligned} \tag{13}$$

The relation between (13) and the different "generations" of financial crises models can be readily seen. Policies that are inconsistent with a fixed parity, central to first generation models, should be reflected in changes in loans to the government, the sovereign risk, and in some degree in changes in the Central Bank's foreign and domestic debt. Contagion effects and sudden changes in speculators expectations, which are the most common issues of second generation models, are incorporated in changes in country risk, in the shadow exchange rate, and in devaluation expectations. Finally, the change in the value of deposit insurance (principally the dollar deposit insurance) encompasses the latest line of literature of financial crises, which finds a high degree of correlation between currency and banking crisis. To obtain the Central Bank value at risk using the Monte Carlo methodology we then need to define the stochastic processes for i, α, S^*, $E(dS^*)$, G, D^f, I^d, I^f, and the valuation of the zero coupon bonds and the deposit insurance liabilities.

B. Stochastic processes, zero coupon bonds valuation, and deposit insurance valuation

International interest rate

To represent the mean reverting process followed by the short-term international interest rate, we use the widely known Cox, Ingersoll, and Ross (1985) model

$$di = g\left(f - i\right)dt + \sigma i^{1/2} dX \ , \tag{14}$$

where f is the long run level of i -set equal to 4 percent in the empirical estimation-, g is the mean reversion rate –set at 0.05-, σ is the volatility of the short term interest rate, and $dX = \varepsilon\,(dt)^{1/2}$ indicates a generalized Wiener process where ε is a random drawing from a standardized normal distribution.

Using (14) the analytical solution for a zero coupon bond with maturity of one year is

$$Z = Ae^{-Bi} \tag{15}$$

where $B = \dfrac{2\ (\mathrm{e}^{\Psi}\text{-}1)}{[(\Psi + \mathrm{g})(\mathrm{e}^{\Psi}\text{-}1) + 2\Psi]}$, $A = \left\{\dfrac{2\ \Psi(\mathrm{e}^{(g+\Psi)})}{[(\Psi + \mathrm{g})(\mathrm{e}^{\Psi}\text{-}1) + 2\Psi]}\right\}^{2gf/\sigma^2}$,

and $\Psi = (\mathrm{g}^2 + 2\sigma^2)^{1/2}$.

Shadow exchange rate and expected rate of devaluation

We assume that the shadow exchange rate follows a Brownian motion with drift,

$$dS^* = \upsilon dt + \sigma dX \ , \tag{16}$$

where υ is the expected change in the shadow exchange rate (i.e., $E(dS^*)$), σ its volatility and dX is defined as before.[5] Further, to incorporate the possibility of a jump in S^* we define a process dq as

[5] Since the volatility of the shadow exchange rate is not observable I assume that it is equal to the volatility of changes in the expected rate of devaluation defined later.

$$dq = \begin{cases} 0 \text{ with probability } (1-\lambda)dt \\ 1 \text{ with probability } \lambda dt \end{cases}$$

where λ is the intensity of the jumping process.

Assuming there is no correlation between the Brownian motion and the jumping process, the jump-diffusion model is then given by

$$dS^* = \upsilon dt + \sigma dX + Jdq\,. \tag{17}$$

J is set to 0.4; thus, S^* jumps by 40% randomly and the stochastic process becomes

$$dS^* = \begin{cases} udt + \sigma dX + 0.4 & \text{if } \Phi < \lambda dt \\ udt + \sigma dX & \text{if } \Phi \geq \lambda dt \end{cases}$$

where Φ is drawn from a standardized normal distribution and the intensity of the process is a discontinuous linear function of the growth of reserves net of foreign debt,[6]

$$\lambda = \begin{cases} 0.05479 + 0.8\left[\dfrac{R_t - D_t^f}{R_{t-1} - D_{t-1}^f} \right] \\ 0 \quad \text{if} \left[\dfrac{R_t - D_t^f}{R_{t-1} - D_{t-1}^f} \right] \geq 0 \end{cases}.$$

Since the Central Bank's portfolio is exposed to changes in devaluation expectations a process for υ -$E(dS^*)$- in (17) is needed. We assume that devaluation expectations follow a mean reverting stochastic process

$$dE\left(dS^*\right) = a\left[b - E\left(dS^*\right)\right]dt + \sigma E\left(dS^*\right)^{1/2} dX\,, \tag{18}$$

where σ is the volatility of the expected rate of devaluation and dX is defined as before. The parameter b can be seen as the long run domestic inflation rate.

[6] The numbers for the intensity of the jumping process were selected so that $\lambda = 1$ in January 2002, the month of the government switch to a floating exchange rate regime

Assuming the foreign inflation rate is zero and relative purchasing power parity (rPPP) holds in the long run, *b* is set to zero under the fixed parity regime. However, we allow for short run deviations from rPPP and assume that there is a "pull back effect" of *E(dS*)* towards the inflation rate.[7] Parameter *a* gives the speed of convergence to rPPP and, following the empirical research in the theme, we assume it is very small (it is set equal to 0.005).[8]

Sovereign risk, foreign debt, and loans to the public sector

The sovereign risk, *a*, also follows a mean reverting process

$$da = h(k - a)dt + \sigma a^{1/2} dX \ , \tag{19}$$

where *k* is the long run level of the sovereign risk –set at the average level in periods of no international or domestic financial turmoil-, σ its volatility, *h* the reversion rate –set at 0.05- and *dX* is defined as before.

Using the processes defined by (14), (18) and (19) we extend the Cox, Ingersoll, and Ross(1985) single-factor bond price equation (15) to a three-factor equation[9]. Under the assumption that the Brownian motions driving the international interest rate, devaluation expectations, and sovereign risk are independent, the price of a domestic zero coupon bond issued in domestic currency is

$$Z^* = A_1 A_2 A_3 e^{-\left[B_1 i + B_2 a + B_3 E\left(dS^*\right)\right]}, \tag{20}$$

where *A1* and *B1* are as defined in (15) and *A2, A3, B2, B3* are the same functions but replacing the parameters of the sovereign risk and devaluation expectations of equations (18) and (19) respectively.

Finally, foreign debt and loans to the public sector follow driftless Brownian motions,

$$dD^f = \sigma dX, \tag{21}$$

[7] Since rPPP holds only under the stringent case when the fixed parity has been and remains perfectly credible, so that the shadow exchange rate, the expected rate of devaluation, and their volatility equal zero (i.e, dS=dEdS = 0), it is only an approximation that *b* equals zero.

[8] For a survey on empirical tests of PPP see Giovannetti (1992).

[9] We follow Duffee (1999), who extends the Cox, Ingersoll, and Ross model to incorporate default risk.

$$dG = \sigma dX\,, \tag{22}$$

where σ is the instantaneous volatility of the risk factor and dX is defined as before.

Deposit insurance

Following Merton (1977) we value deposit insurance as an European-style put option, written by the Central Bank, on the value of the banks assets, with strike price equal to the value of the banks' debt. This intuition is the following. If at the time of an audit of a bank –maturity of the option- the value of its debt (*L*) is higher than the value of its assets (*A*) the bank has the right to exercise the put option, by selling its assets to the Central Bank, and obtain in return the value of the insured liabilities, which is used to pay depositors. Assuming assets follow a geometric Brownian motion,

$$dA = uAdt + \sigma AdX, \tag{23}$$

allows us to value deposit insurance as a put option using the Black and Scholes (1973) formula

$$I = L\ e^{-rT} N(-d_2) - A_0 N(-d_1), \tag{24}$$

where

$$d_1 = \sqrt{\frac{\ln\frac{A_0}{L}\left(r+\frac{\sigma^2}{2}\right)(T-t)}{\sigma(T-t)}}\,,\ d_2 = d_1 - \sigma\sqrt{T-t}$$

and N(*x*) is the cumulative probability distribution for a standard normal variable, A_0 is the value of the bank's assets at time zero, *L* is the face value of bank debt, *r* is the continuously compounded risk-free interest rate, and *T* is the time to maturity which is assumed one year.[10]

[10] We assume that *r* is the long run level of the interest rate used in (14).

As pointed out by Laeven (2002), to apply the model, values have to be assigned to two unobservable variables, the bank's assets value and its volatility.[11] In the case of the banking system of Argentina a good approximation for the former is of particular importance given the large exposure of banks to dollar and peso denominated government debt and the large fluctuations that this debt suffers due to default risks. We use a straightforward approximation. We discount the book value of government debt denominated in pesos using (20). Further, since debt denominated in dollars does not have devaluation risk we use (20) to approximate its market value but without the parameters *A3* and *B3*. Finally we assume that the current value of all other assets equals the balance sheet value.

We also take a pragmatic approach to assign the volatility parameter; as in Black and Scholes (1973), we maintain it constant. We set assets' volatility at 12 percent monthly, which is the average volatility during the period of financial turmoil, December 2001 to June 2002. It can be readily seen that this approach suffers from two problems. First, the large volatility will tend to overestimate the value of deposit insurance and the value at risk in "calm" periods. Second, the volatility estimate was measured *ex-post* the period of the value at risk estimates (January 1996 to December 2001). However, since we are trying to estimate the worst expected loss that the Central Bank can suffer, the model should present a fair approximation.

Since we are assuming that assets have a lognormal distribution it is straightforward that the deposit insurance follows the process

$$dI \approx \left[\left(dI/dA\right)uA + 0.5\left(d^2I/dA^2\right)\sigma^2 A^2 + dI/dt\right]dt + dI/dA\,\sigma A dX. \qquad (25)$$

To obtain the stochastic process followed by the put representing the value of the dollar deposit insurance, I^f, but paid in domestic currency we need to make a small adjustment for the possibility of an exchange rate collapse –taking into account that both assets and deposits are in dollars–. It is approximately true that,

$$I_1^f \approx I_0^f dS^* + (1 + dS^*)\left[\left(dI/dA\right)dA + 0.5\left(d^2I/dA^2\right)dA^2 + dI/dt + ...\right], \qquad (26)$$

[11] Although information about the balance sheet historical value of assets is readily available, similar information about market values is inexistent.

where $I_1^{\,f}$ and $I_0^{\,f}$ are the value of the dollar deposit insurance in domestic currency at time one and zero respectively, and, as before, *dA* is the change in the underlying.

C. Correlation and volatility parameters

If variables are uncorrelated we can perform the randomization in the Monte Carlo simulations independently for each of them. However, apart from the assumption that the Brownian motions driving *E(dS*)*, α, and *i* are uncorrelated among them, we allow for correlation among the variables using a Cholesky factorization.

To update volatility estimates, for all variables except the deposit insurance options, we take the pragmatic approach used in J.P.Morgan (1997) Riskmetrics database; we use an exponentially weighted moving average. Then, volatility at time *t* is given by $\sigma_t^2 = \Upsilon\sigma_{t-1}^2 + (1-\Upsilon)R_{t-1}^2$, where Υ is the decay factor and is set equal to 0.97, the recommended rate by J.P.Morgan (1997) for one month VaR calculations, σ_{t-1}^2 is the variance of the variable at time $t - 1$, and R^2_{t-1} is the change in the variable from period *t-2* to *t-1*.

IV. Evolution of the VaR measures

Table 1 presents the BCRA portfolio value calculated from March 1996 to December 2001 using (7), (15), (20), and (24). The table also shows net reserves (reserves minus debt with international institutions), the VaR for 99.9 degrees of confidence, and three alternative measures of vulnerability: the ratio of VaR to portfolio value, the difference between the two, and the ratio of VaR to net reserves. The last two measures (*P–VaR* and *VaR/Net reserves*) are of particular importance to make significant comparisons among the three months when the portfolio value is negative.[12]

The vulnerability measures portrait fairly well the Argentine crisis.[13] Until the third quarter of the year 2000 the measures show signs of distress in several occasions, reflecting the contagion effects of the Tequila, Asian, Brazilian, and

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[12] 10,000 simulations were run for each month.

[13] For an in-depth discussion of the factors that unleashed the Argentine crisis see Mussa (2002).

Table 1. BCRA portfolio values, net reserves, and VaR measures. March 1996-December 2001 (in millions of pesos)

	Portfolio values	Net reserves	$VaR_{99.9}$	$VaR_{99.9}/P$	$P\text{-}VaR_{99.9}$	$VaR_{99.9}$/ Net reserves
Mar-96	3,819	8,116	1,466	0.384	2,352	0.181
Jun-96	3,901	8,858	1,107	0.284	2,794	0.125
Sep-96	3,739	8,388	1,281	0.343	2,457	0.153
Dec-96	2,576	9,302	1,287	0.5	1,289	0.138
Mar-97	6,329	10,938	1,414	0.223	4,914	0.129
Jun-97	7,176	12,399	1,242	0.173	5,934	0.1
Sep-97	7,381	13,310	1,554	0.211	5,827	0.117
Dec-97	6,107	14,602	1,745	0.286	4,363	0.119
Mar-98	7,681	14,677	1,690	0.22	5,991	0.115
Jun-98	9,484	16,172	1,771	0.187	7,712	0.11
Sep-98	11,360	17,744	2,122	0.187	9,238	0.12
Dec-98	10,666	18,382	1,854	0.174	8,812	0.101
Mar-99	17,646	17,880	2,060	0.117	15,586	0.115
Jun-99	11,293	17,598	2,142	0.19	9,151	0.122
Sep-99	12,151	17,365	2,229	0.183	9,922	0.128
Dec-99	9,602	19,125	2,496	0.26	7,106	0.131
Mar-00	14,288	19,999	2,509	0.176	11,779	0.125
Jun-00	13,359	20,393	2,344	0.175	11,015	0.115
Sep-00	12,272	20,370	2,999	0.244	9,274	0.147
Dec-00	9,081	17,730	2,643	0.291	6,438	0.149
Mar-01	10,459	15,482	2,917	0.279	7,541	0.188
Apr-01	8,473	13,761	2,684	0.317	5,789	0.195
May-01	7,588	11,219	2,964	0.391	4,624	0.264
Jun-01	-1,292	11,039	3,084	-2.386	-4,376	0.279
Jul-01	-969	9,703	3,113	-3.214	-4,082	0.321
Aug-01	-2,369	5,867	7,624	-3.217	-9,993	1.299
Sep-01	1,038	2,928	6,089	5.869	-5,052	2.08
Oct-01	3,366	4,090	5,629	1.672	-2,263	1.376
Nov-01	3,499	2,310	8,346	2.386	-4,847	3.613
Dec-01	414	-317	32,083	77.472	-31,669	-101

Source: Based on own calculation using information available at the BCRA web site www.bcra.gov.ar and the Economic Ministry of Argentina web site www.mecon.gov.ar. The value of the deposit insurance was calculated using the Derivagem software (Hull, 2000). All data and programs are available from the author upon request.

Russian crises. Starting in September 2000, however, we observe a steeper deterioration in the Central Bank's position, which can be mainly attributed to increases in the sovereign risk, reducing net domestic assets in the portfolio.

Were these early worries justified? We believe they were. When president De la Rua took office in late 1999 Argentina was already in a period of contraction. Domestic political turmoil, together with external factors such as an appreciating currency due to a strong U.S. dollar tied with domestic deflation and weak commodity prices, exacerbated the recession.[14] Under the optimistic assumption that the government could maintain a constant debt to GDP ratio at least twelve billion Dollars were needed in external funds for the year 2001 (Mussa 2002). The country was now at the mercy of capital markets that had witnessed four major financial crises during the previous five years, in a worse shape than ever before.

In early 2001, interest rates cuts in the U.S. and the approval of an extraordinary augmentation and immediate release of an IMF loan gave some relief to the markets and improved the Central Bank's position. The relief, however, was short lived. In the international front Turkey's exchange rate crisis triggered a contraction in capital inflows to emerging markets. Meanwhile, domestically, investor's confidence was severely hit when the widely respected Central Bank's president was removed from his position and the government announced a change in the convertibility plan to peg the peso to the euro in addition to the U.S. dollar. As a result, increases in the sovereign risk, in the foreign debt (i.e. the recently acquired obligations with the IMF), and in the expected rate of devaluation -through its effect on the net asset position, the deposit insurance liability, and the shadow exchange rate- contributed to a steady deterioration of the Central Bank's situation.

In June we observe a collapse in the portfolio value due to large increases in loans to the government, a fall in reserves, and continuing increases in the expected rate of devaluation and the sovereign risk. Ironically, this situation was concurrent with a large bond swap (Mega-Canje) announced by the government to reduce interest payments. Yet, the negative impact of such policy is not difficult to explain. The swap stipulated interest payments reductions between 2001 and 2005 for around twelve billion dollars at the expense of substantially higher interest and principal payments in later years (around sixty billion dollars). A rough calculation shows that these numbers imply a discount rate of around 15 percent. Obviously, no realistic budget surplus would be sufficient to pay such interest rate. Thus, the swap not only did not dissipate the worries but confirmed them.

[14] By the end of 2000 real GDP had contracted more than ten percent from its peak in 1998.

After June the measures show a very fragile situation of the Central Bank's portfolio. In particular, we observe sizable increases in the value of the dollar deposit insurance –due to higher devaluation expectations-, in the monetization of fiscal deficits, and a fall in net foreign assets –due to a new augmentation of the IMF loan with continual decreases in reserves-.

In summary, the measures proposed seem to capture the increasing vulnerability of the Central Bank. However, although casual observation might provide some guidance, a more thorough analysis is needed to assess the predictive power of the VaR measures. Further, in drawing any policy implications we need to compare the VaR methodology with the existing approaches to see if the former provides an improvement. The next section focuses on these issues.

V. Relative performance of the VaR measures

In this section we compare and contrast the predictive capabilities of the previously proposed measures with a composite index *à la* Kaminsky et. al. (1998) and various univariate leading indicators. The basic idea behind the signals approach (SA) is that certain macroeconomic variables will show signs of frailty before a financial crisis occurs; thus, identifying these signs might serve to forecast an impending crisis. Because the VaR method is based on the same assumption, the two approaches are readily comparable.

A. Methodology

To establish the relative performance of the VaR measures we first construct five sets of conditional probability forecast as follows

$$P_{i,t}\left(C_{t,t+h}\middle|I_T < I_i\right) = \frac{\text{months with } I_T < I_i \text{ and a crisis within h months}}{\text{months with } I_T < I_i}\ . \qquad (27)$$

The probability at time *t* of a crisis in the interval [*t*, *t*+*h*] equals the months that the indicator I_i (*i=VaR/P, P-VaR, VaR/Net reserves, SA composite index, univariate indicators*) is above a predetermined threshold I_T and accurately predicts a crisis (i.e. sends a correct signal), divided by the total number of months within the overall sample period (previous to time *t*) that the indicator is above the threshold. The signaling window *h* is set at 18 months.

The SA composite indicator is defined as the number of signals being issued by twelve variables (which we also use as univariate indicators) that have been proven successful in anticipating crises in previous studies.[15] Table 2 presents the rationale for inclusion of each of them.

For the VaR measures and the univariate indicators the threshold is, alternatively, one and two standard deviations from the mean in the tranquil period (January 1996 – May 2000). For the SA composite index we set the threshold at five and eight signals. Thus, we have a total of ten probability forecasts for the VaR and SA methods and 24 forecasts for the univariate indicators.

Finally, we evaluate the indicators in terms of accuracy. Specifically, we estimate the average closeness of the conditional probabilities and observed realizations, as measured by a zero-one dummy variable, using the quadratic probability score

$$QPS_i = \frac{\sum_{t=1}^{h} 2(P_{i,t} - R_t)^2}{h}, \tag{28}$$

where R_t equals one if a crisis occurs between periods t and $t+h$ and zero otherwise. It is readily seen that the QPS ranges from 0 to 2, with a score of 0 corresponding to perfect accuracy.

B. Results

Table 3 presents the sets of QPS values for the VaR measures, the SA composite index, and each of the univariate indicators. The table also reports the ranking of the indicators in terms of forecasting accuracy.

Among the 34 indicators, the ratio of Value at Risk to net reserves, evaluated when the signal occurs at one standard deviation above the mean, provides the best predictive performance. The difference is also of significant magnitude, with a QPS around 25 percent smaller than the second best performing indicator (stock market index). The other two VaR measures perform similarly to the SA composite index at different threshold levels, although considerably worse than a number of univariate indicators.

The best performers among the univariate indicators are closely linked to the VaR concept. First, as argued before, the interest rate differential –sovereign risk-

[15] Kaminsky (1999) analyses three alternative composite indicators.

Table 2. Leading indicators

Symptoms	Indicator	Critical-shock sign	Rationale for inclusion
Problems current account	Exports	Negative	Most currency crises are preceded by loss of competitiveness. As second generation models of crises predict, policymakers face a trade-off between higher competitiveness and currency stability.
	Imports	Positive	
	Terms of trade	Negative	
	Real exchange rate	Negative	
Problems capital account	Public debt/GDP	Positive	Large amounts of debt, large interest-rate spreads, and capital flight might signal an issue of unsustainability
	Interest rate differential (EMBI spread)	Positive	
	M1/Net reserves	Positive	
	Net reserves	Negative	
Growth slowdown	GDP growth (seasonally adj.)	Negative	Most banking and currency crises occur after important recessions. This reflects the trade-off mentioned above and the increasing vulnerability of banks to loans failures
	Industrial output index (seasonally adj.)	Negative	
	Stock prices (Merval market index)	Negative	
Overborrowing	M1/Monetary base	Positive	Banking and currency crises are linked to rapid credit growth

Table 3. Quadratic probability score and ranking of indicators

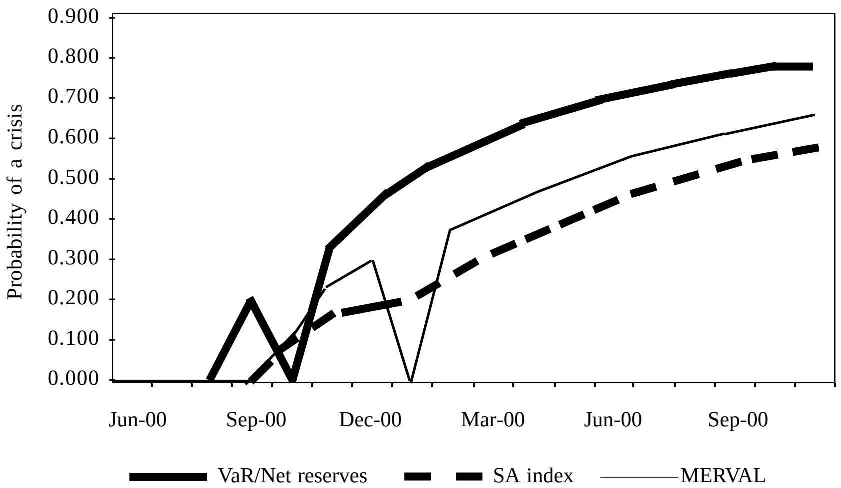
	Signal = one std dev.		Signal = two std. dev.	
VaR/net reserves	0.74	(1)	1.20	(7)
VaR/P	1.45	(13)	1.51	(17)
P-VaR	1.73	(24)	1.33	(10)
SA composite index (≥5)	1.12	(6)	1.56	(18)
SA composite index (≥8)	1.33	(10)	2.00	(28)
Exports	2.00	(28)	2.00	(28)
Imports	1.61	(20)	1.71	(23)
Terms of trade	2.00	(28)	2.00	(28)
Real exchange rate	1.20	(7)	2.00	(28)
Debt/GDP	1.11	(4)	1.11	(4)
Interest rate differential	1.07	(3)	1.28	(9)
M1/net reserves	1.98	(27)	2.00	(28)
Net reserves	1.81	(25)	1.56	(18)
GDP growth	1.51	(16)	1.61	(20)
Industrial output index	1.37	(12)	1.61	(20)
Merval (stock market index)	1.02	(2)	1.45	(13)
M1/monetary base	1.45	(13)	1.92	(26)

Note: Rankings in parenthesis. Source: Based on own calculation using information available at the BCRA web site www.bcra.gov.ar and the Economic Ministry of Argentina web site www.mecon.gov.ar

was an important determinant for the increase in VaR previous to the crisis. Second, the increase in the debt to GDP ratio was closely tied to the Central Bank's vulnerability insofar part of the increase was due to larger liabilities of the Bank. Finally, an important part of the Merval index is composed by domestic corporations and banks which were highly indebted in foreign currency. Fears of bankruptcy due to devaluation and of large bailouts on behalf of the Central Bank probably connect the VaR measures to the stock market index.

The evolution of the conditional probability is also of interest. Figure 1 shows the conditional probability of a crisis for VaR/Net reserves, the Merval Index, and the SA composite index with a threshold of 5 signals. None of the indicators are able to capture any probability of the crisis up to August 2000. Beginning in September and during most of the period the VaR indicator predicts a crisis with higher probability. For example, while the VaR indicator forecasts a crisis with a

Figure 1. Conditional probability of a crisis occurring in the following 18 months



probability of 50 percent in January 2001, the stock market index and the SA composite index reach this value only four and seven months later. We believe that this is an important factor since it implies that the measure can potentially predict a crisis with larger accuracy and sooner.

For better or worse it is important to be cautious about these results. The conditional probability forecasts and thus the relative performance of the indicators depend upon the sample period chosen, the arbitrary thresholds that we selected, the definition of the SA index, as well as the variables that comprise it. Addressing these issues, extending our framework to a multi-country setup, and evaluating the relative performance of the VaR measures with other early warning systems will prove useful in further identifying impending crises.

VI. Conclusion

Many of the crises in the nineties were characterized by sudden reversals in investor's confidence. In contrast, the crisis in Argentina occurred after a gradual deterioration of the economy due to a mixture of poor domestic policies and diverse international factors. In particular, we believe that the crisis can be characterized as a combination of the three generations of financial crises. Weak fiscal policies led to early speculation about a possible default of the sovereign debt and devaluation. Increases in the sovereign risk and the expected rate of devaluation, in turn, weakened the private banking sector that had stockpiles of sovereign debt and cut-off the government from world capital markets leaving no possibility to rollover the mounting debt. The fear of massive bailouts and the failed attempts to reduce the monetization of fiscal deficits originated even more speculation and fed a vicious cycle that ended confirming the original speculative beliefs.

As any other EWS, the VaR measures can neither predict the exact timing of crises nor provide a definite answer about the motives underlying the occurrence of financial crises. In general, crises are shaped by not only economic motives but also by the political scenario, cultural patterns, the legal system, and, in general, the social infrastructure of the country. This line of research, however, allows policymakers to understand the weaknesses of the system, take pre-emptive measures when possible, and recognize the marginal contribution of the variables to the frailty of the economic system. We believe that the methodology presented in this study is an important step in that direction, while the empirical results are encouraging.

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