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**Central Bank Vulnerability and the Credibility of Commitments:  
A Value-at-Risk Approach to Currency Crises**

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**Abstract**

A loss of solvency increases central bank vulnerability, reducing the credibility of commitments to defend a nominal regime, including an exchange rate peg. This paper develops a methodology to assess central bank solvency and exposure to risk. The measure, based on *Value-at-Risk*, is frequently used to evaluate commercial risk.

The paper emphasizes that the ability to sustain nominal commitments cannot be gauged by focusing only on selected accounts (such as reserves), but requires a comprehensive solvency and vulnerability analysis of the monetary authorities' complete portfolio (including off-balance-sheet operations). The suggested measure has powerful reporting value and its disclosure could improve monitoring of sovereign solvency risk.

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## SUMMARY

The currency debacles of the 1990s revitalized the search for early-warning and forward-looking indicators of financial vulnerabilities. This paper proposes an approach to assess central bank solvency and to examine the factors putting it at risk, and refines the concepts relevant for solvency analysis of central bank portfolios. It postulates that a loss of solvency increases central bank financial vulnerability and leads to credibility losses regarding central bank's ability to defend a nominal regime, including exchange rate pegs.

The methodology proposed for appraising central banks' financial vulnerability is based on *Value-at-Risk (VaR)*, a concept developed to assess commercial risk. While central banks cannot commercially fail, they behave equivalently if they forsake their commitment to an announced nominal regime. Since a default in central bank commitments would arise from the increased vulnerability caused by solvency losses, solvency measures, such as VaR, are good forward-looking indicators of possible credibility crises.

The paper analyses risks derived both from traditional central bank operations and from off-balance sheet positions, including foreign exchange forwards and financial sector guarantees.

Methodological and policy implications are derived. Main factors putting central bank solvency at risk are the *volatilities* of the exchange rate, of expected exchange rate changes, of international interest rates, of country risk coefficients, and of the magnitudes of the corresponding positions exposed. Therefore, central banks with positions implying high VaR face difficulties in defending rigorous nominal commitments and should not attempt to peg their currencies. Alternatively, if fixing the rate is deemed essential, the central bank should diminish its portfolio's risk exposure and vulnerability in order to reduce the likelihood of credibility crises.

Available data and technology permit the tracking of central-bank VaR measures along the lines suggested here. This indicator, if disclosed to institutions and investors, can reduce the likelihood of contagion and improve the monitoring of sovereign risk.

## I. INTRODUCTION

The objective of this paper is to develop a methodological approach designed to examine the factors that determine and affect the solvency of a country's monetary authority. It builds on the view that a loss of central bank solvency would tend to increase its vulnerability and, therefore, would lead to a loss of credibility on its ability to uphold a commitment to defend a given nominal regime. Thus, the approach suggested here, by providing a synthetic measure to evaluate central bank solvency and the factors that put it at risk, could contribute to the assessment of the probability that a nominal commitment could be maintained or the likelihood that it would have to be abandoned.

The evaluation of solvency and vulnerability is relevant for the appraisal of central bank credibility regarding all forms of nominal pledges. It could certainly apply to a floating exchange rate system where the central bank undertakes an explicit nominal commitment, such as an inflation target. However, most of the arguments regarding central bank's commitments to defend a nominal regime have referred to the maintenance of a nominal exchange rate peg (such as a fixed rate, a crawling peg, or a nominal band) and to the consequences, in terms of speculative attacks and currency crises, of the loss of public's confidence in the ability of the central bank to keep its pledge. The analysis here will, therefore, refer more specifically to currency crises, although it could be equally applied to the assessment of the capability of the monetary authorities to support any other type of nominal regime.

The modern literature on speculative currency attacks originate with Krugman's (1979) pioneering paper on balance of payment crises. It has become conventional to classify the subsequent models that deal with exchange-rate crises into two categories. For the so-called first generation, or canonical, models, a currency crisis is typically caused by the pursuit of policies that are inconsistent with the indefinite maintenance of the adopted nominal exchange rate regime and, in more concrete terms, it is usually preceded by overly expansive domestic policies.<sup>2</sup> In some cases, however, speculative attacks did not seem to have been directly related to the observed evolution of economic fundamentals, such as credit and monetary expansion, and a second generation of models was developed in order to capture these facts.<sup>3</sup> In these second-generation models,<sup>4</sup> optimizing policymakers are assumed to

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<sup>2</sup>The initial work in this type of model can be attributed to Salant and Henderson (1978) and the classical references are Krugman (1979) and Flood and Garber (1984). For a useful survey of models focussed on Krugman's approach see Garber and Svensson (1994).

<sup>3</sup>The second generation of models are heavily associated with the writings of Obstfeld (1984, 1994). For a survey of first and second generation models, see Flood and Marion (1997).

<sup>4</sup>Buiter, Corsetti, and Pesenti (1997) label the first and second generation models as

(continued...)

have good reasons to adopt and defend a nominal currency regime, but not at any price. They may, therefore, find it optimal to abandon the regime under certain circumstances. Krugman (1997) establishes that, in addition to these two ingredients (i.e., reasons why a government would like to defend a regime and reasons why it may abandon it) a third one should also be present: the cost of defending a nominal regime must itself increase when the public expects that a regime might be abandoned, and act accordingly by staging an attack.<sup>5</sup> This type of models also deal with various alternative scenarios in which crises could be caused by self-fulfilling expectations,<sup>6</sup> rational herd behavior,<sup>7</sup> and contagion.<sup>8</sup>

The view adopted in this paper is consistent with models of both types. By focusing on a *quantitative measure of central bank solvency and vulnerability* we attempt to summarize in a single aggregated indicator both the effects of inconsistent policies, which are relevant to first generation models, and the consequences of contagion as well as the impact of the public's expectations on the sustainability of the nominal regime, factors that are crucial to second generation models. Our claim is that solvency is a critical factor in sustaining a nominal regime; therefore, the suggested indicator (or similar ones belonging to the same family of vulnerability measures, designed to appraise solvency risks) 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.

The approach we adopt to measure vulnerability is based on the concept of *Value-at-Risk* and derives from modern finance methodologies which were developed in order to evaluate the risks of financial failure. Clearly, a central bank cannot fail in a commercial, private sector, sense. Nevertheless, it behaves in an equivalent manner when it abandons its commitment to an (explicitly or implicitly) announced nominal regime. Since a default in central bank commitments is the predictable outcome of a loss of central bank solvency, indicators that point to increasing vulnerability of the central bank's financial position could serve as good predictors of the probability of a devaluation or of other plausible adjustments to a nominal commitment. Moreover, as recently indicated by Dornbusch (1998), the understanding of crises requires to shift the emphasis from analyzing the sustainability of a regime towards assessing its vulnerability. This is precisely what Value-at-Risk methodologies

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<sup>4</sup>(...continued)

“exogenous-policy” and “endogenous-policy” models, respectively.

<sup>5</sup>The 1992 ERM crisis has been characterized as a classic example of the type of models belonging to the second generation. See Eichengreen, Rose, and Wyplosz (1995).

<sup>6</sup>See, for example, Jeanne (1997).

<sup>7</sup>Calvo and Mendoza (1997).

<sup>8</sup>Masson (1997).

do, since by focussing on the maximal potential losses over a given horizon, they highlight the consequences of bad scenarios and reveal the factors that could lead toward negative outcomes.

This approach seems particularly pertinent in light of the recent search for early-warning indicators of currency crises,<sup>9</sup> and of the fact that prevailing speculative attacks appear to have been led by traders, speculators, and other professional operators with substantive resources to invest in high-risk market information. In such cases, the vulnerability of the central bank and its ability to resist a currency attack is more likely to be evaluated by its counterparties using risk models of the type suggested here, which are commonly used in the assessment of commercial and private firm risk.

Another distinctive feature of the framework presented here is that it takes an all-encompassing view of the balance sheet of the monetary authorities. This has two dimensions. First, it attempts to incorporate all implicit and off-balance sheet operations into the analysis. In this manner, it is able to handle, within a unified framework, not only the risk involved in central bank traditional functions, but also the risk arising from derivative transactions, including forwards and foreign exchange swaps. This framework also enables one to assess the balance-sheet implications of contingent central bank liabilities, such as the options embedded in certain features of the financial system, particularly the presence of implicit or explicit deposit insurance.

Second, this approach emphasizes that the ability of the monetary authorities to defend a nominal commitment cannot be assessed properly by focussing on selected central bank accounts (such as reserves) or even on particular ratios (such as reserves to currency). As we show in the following analysis, some central bank commitments are not captured by the monetary base to reserves ratio (e.g., deposit insurance) while in some cases assets other than reserves could be utilized to fulfill central bank commitment. Therefore, what is required is a comprehensive analysis of the solvency position of the monetary authorities' complete portfolio and the related vulnerability of that position.

Clearly, the quantitative results that could be obtained using the suggested methodology might suffer from the same weaknesses that affect many other available risk management techniques. Moreover, central bank portfolios may be too involved to be analyzed and updated with the sufficient frequency required (and information may not be readily available). However, the merit of the Value-at-Risk (VaR) approach proposed here is to focus attention, utilizing a structured methodology, on the concepts of solvency, vulnerability, and risk as they pertain to the monetary authority. As it has been said regarding

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<sup>9</sup>See Frankel and Rose (1996) and Kaminisky, Lizondo, and Reinhart (1998).

the VaR technique, the process of getting to VaR may be as important as the number.<sup>10</sup> This is indeed true in this case because the process of applying the technique advances the risk assessment of comprehensive central bank positions and of specific macroeconomic policies.

The paper is organized as follows. Section II presents an introduction to Value-at-Risk models. Section III develops the relevant portfolio of a central bank on which the solvency and risk analyses are based. Section IV introduces the elements to measure central bank operations in terms of VaR methodologies. Section V discusses practical aspects of the applicability of this methodology, focussing on the relevant considerations for carrying out the calculations of a representative central bank's VaR. Finally, some concluding policy implications are offered in Section VI.

## II. VALUE AT RISK MODELS<sup>11</sup>

Value at Risk models were developed to estimate the exposure of a portfolio to market risk, that is, to changes in prices such as interest rates, foreign exchange rates, commodities, and equity prices.<sup>12</sup> The development of these models was motivated by the growing use of derivatives and the awareness that the world's largest financial losses, such as those that had occurred in Orange County, California, Barings Inc, Daiwa Securities and others, were due to poor monitoring of market risk. Most recently Value at Risk has become somewhat of a revolution<sup>13</sup> and currently both regulators and industry groups are advocating the use of VaR models to measure and manage market risk.<sup>14</sup>

Value-at-Risk methodologies focus on maximal potential losses, and therefore they consider only those changes in prices that can actually produce a loss. Typically, long positions will be affected by price reductions and short positions will be affected by price increases. The VaR of a position can be defined as a measure that "*summarizes the expected*

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<sup>10</sup>Jorion (1997), pg. xv.

<sup>11</sup>Readers familiar with Value-at-Risk models could safely skip this section without losing continuity.

<sup>12</sup>See for example J.P. Morgan (1996) and Jorion (1997). Current methodologies have also extended value at risk models to the estimation of credit risk; for example, J.P. Morgan (1997).

<sup>13</sup>Hotton (1997).

<sup>14</sup>See for example Bank of International Settlements (1996).

*maximum loss (or worst loss) over a target horizon within a given confidence interval,*<sup>15</sup> due to an adverse movement in the relevant price, that is,

$$\text{VaR} = (\text{value of position}) \times (\text{worst move in the relevant price in a period}). \quad (1)$$

For example, a U.S. dollar-based investor holding a long spot position of DM 100,000 is exposed to losses due to the depreciation of the DM vis-a-vis the U.S. dollar. Let's assume that, under specific assumptions about the probability distribution of changes in the exchange rate, the worst movement of the dollar price of the DM in the next 24 hours, at the 95 percent confidence level (i.e., in 95 percent of all possible scenarios), is a 0.03 percent depreciation. If the current exchange rate is DM 1 = \$0.7, the value at risk of holding the DM position is

$$\text{VaR} = 100,000 \times 0.7 \times 0.0003 = \$21. \quad (2)$$

The interpretation of (2) is that, given a DM 100,000 exposure to changes in the dollar price of the DM, the worst loss that the position could experience in 95 percent of all outcomes over the next 24 hours, is equal to \$21. In other words, if the VaR at the 95 percent level of confidence is \$21, there is only 1 chance in 20 that, under normal market conditions, a loss greater than \$21 would occur in the next 24 hours.

How to measure VaR for portfolios with many assets and exposure to different risks of adverse price movements? There are various methods, or approaches, to measure VaR. Differences among these approaches arise from the model applied to the estimation of the expected changes in prices. It is customary to divide the approaches to measure VaR into two categories: local valuation and full valuation. Their applicability depends on a number of conditions, including the availability of information regarding the probability distribution of returns and the presence or absence of nonlinear payoffs.

The best example of the local valuation approach—and the most simple procedure to calculate VaRs—is the so-called *delta-normal method* or *standard variance-covariance model*, that builds on the assumption that all asset-price changes can be modeled as conditionally normally distributed. Under the assumption of normality the portfolio return is a linear combination of normal variables and is also normally distributed. As is well known, in the case of two assets the portfolio standard deviation is:

$$\sigma_p = \left( z^2\sigma_1^2 + (1 - z)^2\sigma_2^2 + 2z(1 - z)\rho_{12}\sigma_1\sigma_2 \right)^{1/2}, \quad (3)$$

where

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<sup>15</sup>Jorion (1997).



$\sigma_1^2$  = the variance of the changes in asset 1 prices;

$\sigma_2^2$  = the variance of the changes in asset 2 prices;

$\rho_{12}$  = the correlation between changes in prices of asset 1 and changes in prices of asset 2;

$z$  = the proportion invested in asset 1; i.e., the exposure to changes in prices of asset 1;

$\sigma_j$  = the standard deviation of the change in asset prices ( $j = 1, 2$ ).

Similarly, using (3), the VaR of the portfolio of two positions can be constructed from the VaRs of each position:

$$VaR_p = [(VaR_1)^2 + (VaR_2)^2 + 2VaR_1VaR_2\rho_{12}]^{1/2} \quad (4)$$

where, as defined in (1),

$$VaR_j = (\text{Exposure}) \times (\text{worst move in price}) \quad (\text{for } j = 1, 2)$$

and the worst move in price is represented by  $k$  standard deviations of the changes in the relevant price, where  $k$  depends on the desired confidence interval. Thus:

$$VaR_j = Z_j k \sigma_j \quad \text{for } j = 1, 2 \quad (1')$$

where  $Z_j$  is the dollar value of position  $j$  and, e.g.,  $k = 1.65$  (95 percent), or  $k = 2.33$  (99 percent). Therefore, the VaR is equivalent to a measure of the standard deviation of the portfolio as defined in equation (3), but only with respect to its downside potential.

The normality assumption greatly simplifies the calculation of VaR since only the mean and the variance-covariance matrix of changes of prices are necessary in order to calculate the worst loss within a chosen confidence interval. Specifically, the worst loss that can be suffered by a portfolio with normally distributed returns, within a 99 percent confidence interval, is found by calculating the adverse change in prices that correspond to 2.33 standard deviations away from the mean, while the worst loss within 95 percent confidence interval corresponds to 1.65 standard deviations away from the mean. In (1') we represent the chosen adverse move in price as equal to  $k\sigma_j$ . In what follows we define  $k\sigma_j$  as the *volatility* of the position  $j$ .

Equation (4) can now be generalized for a portfolio with  $n$  assets. In matrix form, the worst loss of the portfolio on  $n$  assets over a given interval, under the assumption of normality, and with a 99 percent confidence interval would be:

$$VaR_p = \left[ [z_1 2.33\sigma_1 \quad z_2 2.33\sigma_2 \dots z_n 2.33\sigma_n] \begin{bmatrix} 1 & \rho_{12} & \dots & \rho_{1n} \\ \rho_{21} & 1 & \dots & \rho_{2n} \\ \dots & \dots & \dots & \dots \\ \rho_{n1} & \rho_{n2} & \dots & 1 \end{bmatrix} \begin{bmatrix} z_1 2.33\sigma_1 \\ z_2 2.33\sigma_2 \\ \dots \dots \\ z_n 2.33\sigma_n \end{bmatrix} \right]^{1/2} \quad (5)$$

where the VaR of the portfolio is constructed from the VaRs for each of the positions. (Recall that  $z_j 2.33\sigma_j = VaR_j$  for  $j = 1 \dots n$ ).

Within this type of approach, two methods can be used to obtain the  $VaR_p$  as represented by the variance-covariance matrix in (5). It can be measured with price changes derived from historical data (with higher weights for more recent periods, if desired) or, if information is available, implied volatilities can be calculated from data derived from option prices.

While the variance-covariance method is indeed the simplest procedure to obtain measures of VaR, it is subject to a number of constraints. It does not work very well in the presence of derivatives with non-linear returns (such as option payoffs) or when dynamic trading (characterized by constantly change in positions) is present. Moreover, the normality assumption is often not appropriate. In fact, the distribution of changes in asset prices have been found to have thicker tails than predicted by a normal distribution (i.e., extreme movements seem to occur much more frequently than predicted by a normal distribution). This means that the calculation of the probability of a negative outcome may be less reliable precisely where it is most needed, that is, in the tails. In certain circumstances, these reasons make it advisable to model changes in asset prices utilizing other distributional assumptions or relying on the second approach mentioned above, that is, the full valuation approach.

Full valuation is generally implemented in three manners: (i) the historical simulation approach, (ii) the structured Monte Carlo method, and (iii) the stress test approach. In the historical simulation approach one goes back in time and applies current portfolio weights to a time series of historical asset returns. In this way, future changes in prices can be extrapolated from past changes in prices. The fat-tail-bias problem is avoided because this approach does not rely on normality but in actual distributions and it can also incorporate nonlinear positions in a natural way. The problem with historical simulation is that it is very sensitive to the particular data window that is used to calculate changes in prices. It assumes that the past adequately represents the future and, in particular, the probability of more severe losses in the future than the greatest one experienced in the past has a weight of zero.

The Monte Carlo approach is probably the most complete but most expensive method of calculating VaRs. It creates numerical simulations of financial variables and makes possible the choice of a particular distribution to generate the distributions of future prices in each future date. Then the VaR is estimated as the worst loss in the 99th or 95th percentile of the generated distribution.

The third full valuation approach, stress testing, is probably an addition and not an alternative to the other methods. Using simulations, it examines the effect on the portfolio of very large or unusual movements in key financial variables. The use of subjectively specified scenarios responds to the argument that VaR measures market risk for a stable market environment, but when a discrete and major event such as the 1987 stock market collapse occurs, the relationship between historical stock-price movements and future changes breaks down, rendering VaR quite useless (Zangari, 1997). In order to deal with this and other non-normality problems, it has been suggested to use the so-called “extreme-value theory” that will be discussed in more detail in Section V, in the context of proper estimation techniques for calculating the VaR for a central bank.

### III. THE CENTRAL BANK PORTFOLIO

The first task in applying a VaR-like approach to assess the risk to central bank solvency that arises from the exposures that are involved in its operations is to define and make precise the concepts and elements that compose the relevant central bank portfolio. It is important to remark that the central bank portfolio relevant for solvency analysis, while fully based on the accounting notions embedded in the central bank balance sheet, is a distinctively different concept because it measures the *economic*, and not the historical, value of assets and liabilities. In other words, to undertake a solvency risk analysis, historical values should be converted into economic values, that is, all assets and liabilities should be discounted by the relevant interest rates, and all off-balance-sheet items that commit the central bank (explicitly or implicitly) should be priced accordingly. It should be stressed that proper aggregation and evaluation of on- and off-balance-sheet transaction can only be done under an economic valuation approach, as the one suggested here.

A representative central bank typically holds foreign and domestic assets and has “short” positions in the monetary base and in domestic and foreign debt. In our analysis, we consider therefore a central bank holding a stock of gross foreign reserves and of domestic credit (arising from lending to both the public and to the private sector). Specifically, we assume that the central bank holds the entire stock of government foreign assets, extends credit to the public sector by buying government securities, and lends to the private sector through financial sector rediscounts. Liabilities include, in addition to the monetary base (currency and compulsory bank reserves), debt denominated in foreign currency.<sup>16</sup> All measurements are carried out in domestic currency.

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<sup>16</sup>For simplicity we net domestic-currency debt from the gross rediscount position of the financial sector. Also for simplicity we assume that central bank reserves and central bank foreign debt represent the total foreign assets and liabilities of the sovereign, i.e., the country's foreign assets and the public sector (or publically guaranteed) foreign debt. These assumptions can be relaxed without affecting the nature of the results.

In addition to these standard balance-sheet positions, we allow for the possibility that the central bank may also be active in the foreign-currency forward market and perform foreign-exchange swaps.<sup>17</sup> We also account for the role of central banks as guarantors of the stability of the financial sector and for its commitment to prevent systemic banking crises. Since this commitment usually takes the form of an implicit or explicit deposit guarantee, it is possible to represent it as a put option sold by the central bank to the financial sector. Although a typical central bank balance sheet does not explicitly incorporate the positions that arise from the forward, or those arising from the financial put (or from any other central bank commitment created by contingent liabilities), solvency analysis requires that these positions should be explicitly mapped into the relevant central bank portfolio.

To convert the balance-sheet historical values into portfolio concepts, a number of assumptions regarding the application of the stocks are necessary. International reserves are assumed to be composed of gross assets denominated in a foreign currency that earn an interest rate. Without losing generality we can assume that interest earnings (coupons) are fixed (floating rates are also fixed coupons during the repricing period). Consequently, the value of the international reserves is affected by changes in the discount factor, given by the relevant international term structure, and by changes in foreign exchange rates.

Rediscounts are loans to financial institutions and can be seen as long positions in the domestic currency that earn a fixed interest rate and, therefore their economic value is affected by changes in the domestic yield curve. Thus, an increase in the domestic interest rate would reduce the value of outstanding domestic credit to the private sector, as represented by the stock of rediscounts and of loans to the financial sector. Credit to the public sector, in the form of loans and advances to the government, can also be seen as long positions in the domestic currency.

On the liability side, in addition to the monetary base, we assume that the central bank holds the country's official external debt,<sup>18</sup> that is constituted by liabilities that, being denominated in foreign currency, are exposed to foreign exchange risk. The holders of the sovereign debt also receive a fixed coupon and do not bear risk of devaluation but are exposed to credit—or country—risk. Liabilities also include domestic debt that can be issued for funding purposes or for money control through direct intervention and open market operations. All domestic debt is denominated in domestic currency.

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<sup>17</sup>These operations are widespread among emerging-market central banks and are designed to provide hedges to operators when financial markets are incomplete. They have been also utilized, however, to strengthen the credibility of exchange-rate pegs and, as in the recent case in Thailand, have been kept as off-balance-sheet operations.

<sup>18</sup>Strictly, the analysis is applied to the portfolio of the country's monetary authorities, that is, to the consolidation of the central bank with the relevant treasury accounts.

With respect to the foreign currency forward contracts, they will be mapped in the standard manner used in the finance literature, that is, forward transactions are decomposed into two interest-rate positions and one foreign-exchange position. For example, if the central bank commits to sell foreign exchange forward, the transaction is broken down into a short zero-coupon bond in the foreign currency and a long zero-coupon bond in the domestic currency. The maturity of the bonds depend on the expiration date of the forward contract. The zero-coupon bond denominated in the domestic currency risks a loss if there is an increase in the domestic interest rate (for the relevant maturity). The zero-coupon bond denominated in the foreign currency is exposed to the risk of a loss if there is an increase in the foreign interest rate (for the relevant maturity). In addition, the value of the short zero-coupon bond, i.e., the one denominated in the foreign currency, increases if a devaluation occurs. Therefore, the forward transaction as a whole is also exposed to foreign exchange risk.

Foreign exchange swaps are a combination of a spot short (long) transaction with a forward long (short) transaction; for example, a spot sale and a simultaneous forward purchase or a spot purchase and a simultaneous forward sale. Consequently, a foreign exchange swap can be decomposed into a spot short (or long) transaction plus a forward. The spot leg of the transaction is exposed to foreign exchange risk while the forward leg is exposed to both foreign exchange and interest-rate risk in the fashion that was described above for a standard forward contract.

Finally, it is necessary to value the central bank commitment to preserve financial stability and to prevent a run on the banking system. As mentioned above, this contingent liability can be modeled as a put option “sold” by the central bank to commercial banks (and to other relevant financial institutions). Based on Merton (1974), it is possible to represent an explicit or implicit deposit insurance scheme as the equivalent to the banks holding a right to exercise a put option when the value of the banks’ assets (the “underlying asset” of the put) falls below the value of the debt (the exercise price), that is, they fail. In exercising the put, the banks “sell” their assets to the central bank and “get paid” an amount equivalent to their debt (the exercise price) that they use to pay to their creditors. The value of this option depends on the banks’ leverage (the debt to assets ratio), the volatility of banks’ assets, and the interest rate. The more leveraged banks are and the more risk they undertake, the more valuable the put option is. Under the realistic assumption that the duration of bank assets is larger than the duration of bank liabilities, an increase in the interest rate reduces the market value of capital of banks<sup>19</sup> and makes the exercise of the put option with the central bank more likely. In short, the value of the put option, and therefore the liability of the central bank, rises with increases in the banks’ leverage, in the risk of their portfolios and in the interest rate.

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<sup>19</sup>See, e.g., Saunders (1996) Chapter 7, pp. 113-115.

In summary, the value of the central bank portfolio, including all the assets and liabilities described above, is exposed to changes in the exchange rate as well as in domestic and foreign interest rates.

However, interest parity links domestic to foreign rates and, therefore, assuming initially that all assets and liabilities have the same maturity,  $t$ , and that  $t=1$ ,<sup>20</sup> it is possible to represent the value of the central bank portfolio as exposed to the following three prices:

$$\delta^* = e^{-(i^*)}; \quad (6a)$$

$$\delta = e^{-i} \quad (6b)$$

$$\delta^{**} = e^{-(i^{**})} \quad (6c)$$

where

$\delta^*$  = is the price of the international zero coupon bond with maturity 1;

$\delta$  = is the price of a domestic zero coupon bond denominated in domestic currency, with maturity 1;

$\delta^{**}$  = is the price of the country's foreign currency zero-coupon bond with maturity 1;

$i^*$  = is the international yield or discount factor for an international zero coupon bond denominated in foreign currency;

$i$  = is the domestic yield or discount for a domestic zero coupon bond denominated in domestic currency;

$i^{**}$  = is the yield or discount factor for the country's foreign currency zero coupon bond (or its foreign debt).

Imposing uncovered interest rate parity and incorporating sovereign country risk ( $\alpha$ ), the domestic interest rate on domestic-currency denominated debt becomes:

$$i = i^* + E(ds) + \alpha \quad (7)$$

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<sup>20</sup>This assumption could be relaxed in order to allow for changes in value that result from maturity mismatches (see Section IV below).

where  $E(ds)$  = is the expected devaluation within period 1. For the interest rate on the country's foreign-currency denominated debt we have:

$$i^{**} = i^* + \alpha \quad (8)$$

Using now the prices defined in (6a, b, and c) and the rates from (7) and (8), the economic value of the central bank portfolio,  $V$ , can be expressed as:

$$V = \bar{R}\delta^*S + \bar{D}\delta + \gamma G + F_d\delta - H^s - \bar{C}_s\delta^{**}S - F_x\delta^*S - P\left(\delta, \frac{L}{A}, \sigma_A^2\right) \quad (9)$$

where

$\bar{R}$  = the gross stock of international reserves (capital plus interest earnings);

$\bar{D}$  = the net domestic debt denominated in domestic currency (loans to the financial sector, including rediscounts,  $\bar{Y}$ , minus central bank domestic liabilities,  $\bar{B}$ ), that is,  $\bar{D} = \bar{Y} - \bar{B}$ ;  $\bar{D} \geq 0$  or  $\bar{D} \leq 0$  and both  $\bar{Y}$  and  $\bar{B}$  include interest earnings.

$G$  = the stock of loans and advances to the government;

$F_d$  = the long leg of the forward, denominated in domestic currency.;

$H_s$  = the monetary base;

$\bar{C}_s$  = the outstanding stock of foreign debt (capital plus interest earnings);

$F_x$  = the short leg of the forward, denominated in foreign currency;

$P$  = the implicit or explicit financial sector guarantee, expressed as the value of the put option sold to the financial sector, which is a function of the domestic interest rate, the financial system's liabilities to assets ratio or leverage ratio,  $\frac{L}{A}$  and the volatility of financial institutions' assets,  $\sigma_A^2$ ;

$S$  = the spot exchange rate;

$\gamma$  = the price of the government liabilities to the central bank.

Equation (9) depicts the relationships between the economic value of the various central bank assets and liabilities, and can be seen as the marked-to-market value of the central bank equity.<sup>21</sup> The main advantage of the presentation in (9) is that it permits a direct evaluation of the evolution of central bank solvency and of the main determinants of such evolution. This is facilitated by the fact that (9) represents equity in terms of the exposure of the central bank positions to risk factors and, therefore, it allows for a direct estimate of how policy variables and exogenous prices bear directly on the ability of the central bank to preserve its solvency.

#### IV. USING VAR TO ASSESS THE RISK OF CENTRAL BANK DEFAULT

After specifying in equation (9) the net value of the central bank portfolio (or its equity), we can now use the concepts of Section II in order to define the central bank Value at Risk (VaR) as the worst loss that the central bank portfolio can suffer because of changes in the relevant prices and positions, over a determined horizon, with a certain probability.

The idea behind this exercise is that economic agents can, practically on a daily basis, estimate, within some confidence interval, the worst losses that a central bank is exposed to suffer over a certain (short) horizon, given the available information about central-bank current and contingent assets and liabilities, and given some probability distribution of changes in interest rates and exchange rates. Agents would, then, compare these potential losses to the value of the portfolio and, should these losses exhaust the value of the central bank equity (i.e., render the central bank insolvent), agents would conclude that the central bank is vulnerable and that there is a high probability that it cannot fulfill its commitments. This may result in a rise in velocity, a run from domestic-denominated assets, a financial sector panic and/or, if the central bank has committed to maintain a nominal exchange-rate regime, the risk of insolvency would lead to the view that the central bank might be forced to devalue its currency in order to restore solvency and this would foster a speculative attack.<sup>22</sup> While the

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<sup>21</sup>There is an ongoing debate in the literature regarding the concept of “central bank capital” and the need for a central bank to hold net tangible assets that could be realized on short notice to independently finance its operations. See Stella (1997). The concept embodied in (9), i.e., the net economic value of central bank equity, could be regarded as akin to the concept of capital but it encompasses the complete array of central bank current and contingent assets and liabilities, regardless of their liquidity and disponibility, and revalue them continuously using market prices.

<sup>22</sup>This is most likely when the central bank holds a net foreign asset position, since a devaluation, when the value of international reserves is higher than the value of external debt plus the value of the short forward leads to an increase in solvency, that is, in equity, denominated in domestic currency. Of course, as we discuss below, a sudden devaluation may  
(continued...)



precise relationship between increased central bank vulnerability and the probability of default would be a specific function of the degree of risk aversion and of the heterogeneity of agents' utility functions, it is reasonable to maintain that there exist a monotonic function, such as:

$$\pi(\text{default}) = f(\text{VaR}/V) \quad f' > 0,$$

where  $\pi$  is a probability function. Given a specific confidence interval and a degree of risk aversion, the central bank VaR defines the probability of a default taking place. While the exact timing of a default may not be defined by  $f$ , it is certain that  $\pi$  rises with VaR/V and, therefore, a careful analysis of this relationship would shed much light on the factors, the process, and the mechanism that lead to a confidence crisis. Moreover, we postulate here that with existing methodology and available information and technology, agents do have the capacity to calculate and to utilize comprehensive solvency measures of this sort (rather than relying solely on a myriad of possible leading indicators) so as to ascertain the ability of the central bank to maintain its commitment to a nominal regime.

As defined in Section II, VaR estimates can be calculated based on the volatility of the portfolio as measured by its standard deviation. In order to estimate the central bank's VaR, we first totally differentiate (9) with respect to all quantities and prices:<sup>23</sup>

$$dV = [\bar{R}\delta^*dS + \bar{R}Sd\delta^* + S\delta^*d\bar{R}] + [d\bar{D}\delta + \bar{D}d\delta] + [(Gd\gamma + \gamma dG)] + [(F_d d\delta + \delta dF_d)] - dH^s \\ - [\bar{C}^s \delta^{**} dS + \bar{C}^s S d\delta^{**} + d\bar{C}^s S \delta^{**}] - [F_x \delta^* dS + F_x S d\delta^* + S \delta^* dF_x] - \left(\frac{\partial P}{\partial \delta}\right) d\delta \quad (10)$$

To facilitate an illustrative calculation, we can make some simplifying assumptions. Given a nominal exchange rate commitment, monetary base expands in response to changes in international reserves and in public and private sector domestic net credit creation:

$$dH^s = dG + dR + dD. \quad (11)$$

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<sup>22</sup>(...continued)

increase also the Value-at-Risk, among other reasons, by increasing the volatility of expectations and of country risk.

<sup>23</sup>This is different from the more traditional VaR approach that largely focuses on changes in prices. See, for example, J.P. Morgan (1996).

We further assume:<sup>24</sup>

$$\gamma = 0, \text{ i.e. the government is not expected to repay its debt to the central bank}^{25} \quad (12)$$

$$dRS = d\bar{RS}\delta^*, \text{ i.e. new reserves are invested at par value.} \quad (13)$$

$$dD = d\bar{D}\delta, \text{ i.e., new loans to the banks are granted at par value.} \quad (14)$$

$$dF_d\delta = dF_xS\delta^*, \text{ i.e., interest rate parity holds.} \quad (15)$$

Using (11), (12), (13), (14) and (15) and rearranging (10) we obtain:

$$dV = dS[\bar{R}\delta^* - C^s\delta^{**} - F_x\delta^*] + d\delta^*[\bar{RS} - F_xS] + d\delta[\bar{D} + F_d - \frac{\partial P}{\partial \delta}] + d\delta^{**}[-C^sS] - dG - dC^sS\delta^{**} \quad (16)$$

In order to obtain the central bank VaR, we square (16), assume changes are measured with respect to their mean values, and take expectations:<sup>26</sup>

$$VaR_{CB} = \left[ \begin{array}{l} \sigma_S^2[\bar{R}\delta^* - C^s\delta^{**} - F_x\delta^*]^2 + \sigma_{\delta^*}^2[\bar{RS} - F_xS]^2 + \sigma_{\delta}^2[\bar{D} + F_d - \frac{\partial P}{\partial \delta}]^2 + \\ \sigma_{\delta^{**}}^2[-C^sS]^2 - \sigma_G^2 - \sigma_c^2(S\delta^{**})^2 + covariances \end{array} \right]^{1/2} k \quad (17)$$

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<sup>24</sup>Notice that, to avoid overcomplicating the presentation, we do not introduce further behavioral macroeconomic relationships. However, monetary equilibria conditions could be superimposed on equation (11) and the central bank VaR would then also reflect velocity behavior. Balance of payments and inflation equations could also be added without changing the nature of the model. However, these extensions are avoided in this paper in order to confine the analysis to its basic concepts.

<sup>25</sup>This assumption can be easily changed in the, uncommon but possible, cases where the government makes budgetary allowances to reduce its debt with the central bank. There have been, indeed, cases of governments utilizing fiscal surpluses, capital gains and, particularly, privatization revenues to repay its debt to the central bank.

<sup>26</sup>As discussed in Section II, under the assumption of normality, we evaluate  $VaR_{CB}$  at the chosen desired confidence level by using the corresponding factor  $k$ .

Or, in matrix form:

$$VaR_{CB} = \left\{ \begin{bmatrix} \sigma_s E_s & \sigma_{\delta^*} E_{\delta^*} & \sigma_{\delta} E_{\delta} & \sigma_{\delta^{**}} E_{\delta^{**}} & \sigma_G & \sigma_c S \delta^{**} \end{bmatrix} [\text{correlation matrix}] \begin{bmatrix} \sigma_s E_s \\ \sigma_{\delta^*} E_{\delta^*} \\ \sigma_{\delta} E_{\delta} \\ \sigma_{\delta^{**}} E_{\delta^{**}} \\ \sigma_G G \\ \sigma_{C^s} C^s \end{bmatrix} \right\}^{1/2} k \quad (18)$$

where the Es are the exposures in the portfolio, and equal to:

$$\begin{aligned} E_s &= [\bar{R}\delta^* - C^s\delta^{**} - F_x\delta^*] \\ E_{\delta^*} &= [\bar{R}S - F_xS] \\ E_{\delta} &= [\bar{D} + F_d - \frac{dP}{d\delta}] \\ E_{\delta^{**}} &= [-C^sS] \end{aligned}$$

The interpretation of (18) is not, however, straightforward because it represents the central bank VaR as a function of the volatilities of the exchange rate, of the bonds' prices and of the level of the exposures. It is more useful to transform (18) in order to obtain a formulation that allows the direct assessment of the impact of interest rates and their determinants. Using (6a):

$$d\delta^* = e^{-i^*}(-1)di^* \quad (19)$$

From (6b) and (7), we arrive at:

$$d\delta = e^{-i}(-1)[di^* + d\alpha + dE(s)]. \quad (20)$$

And from (6c) and (8), the result is:

$$d\delta^{**} = e^{-i^{**}}(-1)[di^* + d\delta]. \quad (21)$$

Substituting (19), (20), and (21) in (16) and rearranging, we finally obtain the central bank VaR directly as a function of the volatilities of the exchange rate, the international interest rate, expected devaluation, and country risk (and, of course, the level of the exposures):<sup>27</sup>

$$VaR_{CB} = \left[ \begin{array}{l} \sigma_s^2 [\bar{R}\delta^* - C^S\delta^{**} - F_x\delta^*]^2 - \sigma_{Eds}^2 [(e^{-(i^*+Eds+\alpha)})(\bar{D} + F_d - \frac{\partial P}{\partial \delta})]^2 \\ - \sigma_{i^*}^2 [e^{-i^*}(\bar{R}S - F_xS) + e^{-(i^*+Eds+\alpha)}(\bar{D} + F_d - \frac{\partial P}{\partial \delta}) - e^{-(i^*+\alpha)}\bar{C}^sS]^2 \\ - \sigma_\alpha^2 [e^{-(i^*+Eds+\alpha)}(\bar{D} + F_d - \frac{\partial P}{\partial \delta}) + e^{-(i^*+\alpha)}\bar{C}^sS]^2 \\ - \sigma_G^2 - \sigma_c^2\delta^{**}S + covariances \end{array} \right]^{1/2} k \quad (22)$$

In matrix form:

$$VaR_{CB} = \left\{ \left[ \sigma_s E_s \quad \sigma_{i^*} E_{i^*} \quad \sigma_\alpha E_\alpha \quad \sigma_{Eds} E_{Eds} \quad \sigma_G \quad \sigma_c E_c \right] [correlation\ matrix] \begin{bmatrix} \sigma_s E_s \\ \sigma_{i^*} E_{i^*} \\ \sigma_\alpha E_\alpha \\ \sigma_{Eds} E_{Eds} \\ \sigma_G \\ \sigma_c E_c \end{bmatrix} \right\}^{1/2} k \quad (23)$$

where as before, E represents the exposure to each source of risk, or:

$$E_s = \bar{R}\delta^* - C^S\delta^{**} - F_x\delta^*$$

$$E_{Eds} = (e^{-(i^*+Eds+\alpha)})(\bar{D} + F_d - \frac{\partial P}{\partial \delta})$$

$$E_{i^*} = e^{-i^*}(\bar{R}S - F_xS) + e^{-(i^*+Eds+\alpha)}(\bar{D} + F_d - \frac{\partial P}{\partial \delta}) - e^{-(i^*+\alpha)}\bar{C}^sS$$

$$E_\alpha = e^{-(i^*+Eds+\alpha)}(\bar{D} + F_d - \frac{\partial P}{\partial \delta}) + e^{-(i^*+\alpha)}\bar{C}^sS$$

$$E_c = \delta^{**}S$$

<sup>27</sup>Equations (22) and (23) involve a duration approximation since, as it is well known, the relation between bond prices and interest rates is not linear.

The central bank VaR, as represented by equations (22) and (23) can now be directly calculated and used to measure (for a given confidence interval) the potential losses of the central bank arising from its activities, policies, and exogenous prices. The premise here is that as the value of equation (22) approaches  $V$ , the probability of central bank insolvency increases, economic agents will lose confidence in its commitments, and will engage in a speculative attack.

An examination of this equation facilitates the interpretation of the factors that increase VaR (or raise potential losses) and, therefore, increase the risk of central bank insolvency:

- Given non-zero exposures, the higher the *volatilities*<sup>28</sup> of the exchange rate, of expected changes in the exchange rate, of the international interest rate, and of the country risk coefficient, the higher the potential central bank losses for a given confidence level. VaR increases with the standard deviation of changes in these variables because a higher standard deviation implies a more dispersed distribution and, therefore, this is an indication that the most unfavorable change in price that could take place within a given confidence interval is larger. Consequently it can potentially lead to higher losses. VaR also increases with the chosen confidence level ( $k$ ).
- The central bank VaR depends, of course, on the correlation matrix between returns. If the value of all correlations were equal to one, the central bank total VaR would be just the sum of the VaRs of the individual positions. Since, under most scenarios, the value of the correlations are less than one, the total VaR should be *less* than the sum of the individual VaRs.
- Regarding the portfolio exposure to exchange-rate changes, it is evident that the central bank could close its position by equating the value of reserves to the value of the foreign debt plus the short leg of the forward contract. Clearly, the higher is the open position of the central bank, the higher is the risk exposure to  $\sigma_s$ .<sup>29</sup>

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<sup>28</sup>Note again that we have defined volatility as  $k\sigma$  where  $\sigma$  is the standard deviation of the variable discussed and  $k$  is the multiplicative factor that depends on the chosen confidence interval.

<sup>29</sup>These considerations apply to both floating rates and to exchange regimes that allow fluctuation within given parameters. When the central bank does not hedge its position and holds, say, a net positive exposure—that is, if the economic value of its international reserves, net of the short leg of its forward position, is higher than the economic value of the foreign debt, a negative change in the spot exchange rate (an appreciation of the domestic currency) leads to a portfolio loss.

- Reducing the risk of losses arising from *expected* exchange-rate volatility would be more difficult because it would require the central bank to hedge its domestic exposure. From equation (22) we see that the impact of  $\sigma_{Eds}$  depends on the relation between net domestic debt (loans to the financial sector minus central bank domestic liabilities) and the long leg of the forward plus the put option implied by the deposit guarantee. If  $\bar{D} > 0$  the central bank cannot eliminate the risk arising from the volatility of exchange-rate expectations by hedging its domestic exposure. Clearly, if the domestic interest rate rise in response to higher expectations of exchange rate devaluation, the central bank's VaR increases due to the higher potential losses on its net outstanding loans to the financial sector, on the long leg of the forward operation and, probably more important, on the value of its put with the financial sector (the value of the put is bound to increase with a higher domestic interest rate because of the likely deterioration in the solvency of the financial sector). Only by increasing its money market intervention could the monetary authority reduce its exposure on this account.
- International interest rate volatility increases the risk of central bank losses though its exposure to foreign as well as to domestic positions. To reduce the potential losses from rate increases, the central bank would have to maintain a net foreign asset position larger than its domestic exposure (and vice versa for reductions in the rate).
- Country credit risk affects both the domestic interest rates and the international interest rate paid by the country. Thus, the solvency of the central bank would suffer more, for higher extreme values of country risk, the higher is its domestic net exposure compared with its foreign debt. If its net domestic positions (including the financial sector put option) exceed the foreign debt, the central bank is more exposed to an increase in country risk (and vice versa).
- For purposes of simplicity, equation (22) considers the central bank exposure to only one point in the term structure of the three interest rates. Actually, the central bank is exposed to changes in different maturities for the three term structures. For example, assuming that the central bank has assets with long maturities and liabilities with short maturities (both earning fixed coupons), an equal increase in the volatility of all interest rates will have a lower impact on the value of the liabilities, since they can be rolled over in the short term at the new higher interest rate, while the value of assets will fall since they will still earn a lower interest rate.<sup>30</sup>
- When the central bank engages in forward operations to defend the value of the domestic currency, it increases its risk to incur losses because it is more exposed to

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<sup>30</sup>As Dornbush (1998) points out, a large VaR may be signaling this mismatching that, under extreme circumstances, could turn into a funding crisis (for example, the case of Korea in late 1997).

volatility in the prices mentioned above. In particular, increases in the domestic interest rate due to changes in country risk or expected devaluation will decrease the value of the long forward denominated in domestic currency (a potential asset) without affecting the value of the long forward denominated in foreign currency (a potential liability).

- For obvious reasons, the risk to central bank solvency increases with the instability of public sector financing needs (as measured by the standard deviation of  $G$ ). But it should be noticed that this result arises from the fact that we assumed that the price of government debt held by the central bank is zero. Similarly, the volatility of changes in central bank rediscounts does not affect central bank solvency since we assumed that these loans were issued at par and consequently changes in central bank liabilities are matched with changes in central bank assets. This highlights the fact that when increases in monetary liabilities are fully matched by increases in equally valuable assets (not only by increases in reserves), central bank solvency is not affected.

## V. CALCULATING A CENTRAL BANK'S VaR

The actual calculation of the VaR for a central bank involves a number of initial decisions, including the desired confidence interval, the time horizon, and whether a diversified or a nondiversified VaR (i.e., whether or not correlations are assumed to be equal to unity) should be calculated.

With respect to the confidence interval, it should be noticed that agents facing the probability of central bank insolvency would most likely be interested in the ability of the central bank to keep its commitments in scenarios involving fairly large changes in international interest rates and in country credit risk, or for significant acceleration in expected devaluation. This means that it may be of interest to estimate a VaR with a large  $k$ , i.e., a high confidence interval.

Regarding the time horizon, we favor short ones. Although the central bank does not hold a trading portfolio in a commercial sense, the ability of the central bank to take measures that can improve its financial conditions and avoid insolvency would be viewed by economic agents as the ability to undo its risky positions over a short time interval and, therefore, it may be correct to assume that the relevant holding period is 24 or 48 hours.

Although the calculation of the VaR with partial correlations can make economic sense in a stable scenario, it should be considered that in scenarios of crises or contagion, most correlations would tend to be close to unity. Consequently it may be safer, in turbulent times, to estimate a nondiversified VaR, that assumes that correlations are indeed unity.

Finally, the methodology to estimate potential changes in exchanges rates, interest rates, country risk, and expected devaluation should be chosen among the different

approaches described in Section II. While the variance-covariance approach, which assumes normality of the returns distribution, is the easiest to implement, the application of this approach to stress situations, may require reliance on the ongoing research on the use of extreme-value theory.<sup>31</sup> This approach proposes a methodology for the calculation VaR that combines historical simulation for the interior of the portfolio return distribution with a parametric estimation of the “fat tails” mentioned in Section II. The proposal is based on the fact that all heavy tail distributions have tail shapes that, to a first order approximation, are identical to the tail shape of a Pareto distribution. If that is the case, the probability of a large loss depends on two parameters that can be estimated using extreme-value theory. This approach is particularly interesting because it does not require to know a priori the specific distribution of returns and it is also helpful to estimate the so-called “beyond VaR” scenarios. Those are scenarios that deal with worst-case outcomes, or “event risk,” and refer to the question: if a loss beyond VaR is indeed incurred, how far do we expect the excess to go?<sup>32</sup>

Data for these calculations do not impose undue complications. While central bank precise positions may require additional disclosures, data on prices, including changes in the exchange rate, international interest rates and country risk are readily available. The volatility of changes in devaluation expectations can be obtained from survey data, such as *The Financial Times Currency Forecaster*.<sup>33</sup>

## VI. SOME CONCLUDING POLICY IMPLICATIONS

From the analysis above it is evident that if, as specified here, the ability to maintain a nominal commitment depends on the solvency of the central bank and on the economic agents’ risk assessment regarding such solvency, a central bank with positions that imply high Values at Risk would face difficulties in defending rigorous nominal commitments and should not attempt to peg its currency. Alternatively, if a nominal regime is a policy objective, the central bank should diminish the risk exposure and the vulnerability of its portfolio. Thus, for example, under scenarios of high global and exogenous determined volatility, the central bank should strive to avoid, as much as possible, broadly open positions. This would preclude vast increases in the VaR estimates and would thus reduce the risk of credibility crises.

Unless it issues significant amount of domestic debt, the central bank cannot hedge its domestic exposure. Therefore, central banks that operate within highly volatile environments

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<sup>31</sup>For applications of extreme-value theory to VaR calculations, see Danielson, Hartmann, and de Vries (1998) and Danielsson and de Vries (1997).

<sup>32</sup>See, in this context, Embrechts, Resnick and Samorodnitsky (1998).

<sup>33</sup>See, e.g., Goldfajn and Valdes (1997).



should aim at avoiding, as much as possible, large increases in such exposure.<sup>34</sup> It is usually accepted that the rediscount function and, particularly, the protection granted by central banks to the financial sector through implicit or explicit deposit insurance promotes financial stability. But since it exposes the central bank to losses, and the risk perception of economic agents regarding the size of such losses is magnified in situations of high volatility, increases in this type of domestic exposure disrupt stability by raising the vulnerability of the central bank and by eroding its credibility.

While it is generally acknowledged that the sustainability of a currency peg, or of other nominal commitments, depends on solid fiscal positions and on a low level of foreign debt, our analysis emphasizes that the perception of risk is not only affected by the levels of these variables but also by their volatilities. Higher fiscal instability, when there is a widespread perception that deficits will be funded with non-valuable assets, would increase central bank vulnerability. This applies to the issuance of any other monetary liability that is funded with assets with less than par value.

Although probably fulfilling a positive function in incomplete markets, central bank engagement in forward operations (as well as in other derivatives operations) raises, in all likelihood, the perception of risk. As the central bank enters in a forward contract, it gets exposed to losses should the domestic interest rate rise. Moreover, the risk of high losses increases with the volatility of  $i^*$  and  $\alpha$  and as exchange rate expectations become less certain. Thus, forward transactions should only be undertaken in conditions of stable international environment and only if they can indeed convince speculators about the central bank commitment to defend the exchange rate. But if agents still bet against the fixed exchange rate and certainty is not restored, this would lead to higher and more variable domestic interest rates. In such case the forward transaction impacts on the solvency of the central bank by increasing the Value at Risk of its portfolio and, therefore, raises the probability of a currency crisis by affecting the solvency of the central bank.<sup>35</sup>

Available data and technology permit the construction and tracking of central-bank VaR measures. We provide here some pointers for the practical implementation of this methodology. The principal merit of this approach is to focus attention on the concept of solvency of the monetary authority, and to advance the systematic and comprehensive risk

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<sup>34</sup>Sterilized intervention reduces this exposure since, as sterilized intervention accelerates,  $D$  in equation (22) becomes negative. Another possible way in which the central bank could hedge its domestic positions is by increasing compulsory reserve requirements, a liability on the central bank portfolio, that will fall in value if interest rates go up. These types of interventions give rise, of course, to other distortions.

<sup>35</sup>Clearly, if forward transactions can indeed convince speculators about the central bank commitment to defend the exchange rate, this will translate in a lower variance for expected devaluation, thus decreasing VaR.

assessment of central-bank portfolio positions and of specific macroeconomic policies. Attention should also be drawn on the powerful reporting value of the suggested indicator that, if disclosed by countries to investors and to international organizations, could reduce the likelihood of contagion and improve the monitoring of sovereign solvency risk.<sup>36</sup>

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<sup>36</sup>Dornbusch (1998) suggests that members of the IMF should be required to put in place some sort of VaR analysis “for the entire country” and that they should be monitored by the Fund, disqualifying for financial support those countries that are found deficient.

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