Contingent Reserves Management: An Applied Framework

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One of the most serious problems that a central bank in an emerging market economy can face is the sudden reversal of capital inflows (or sudden stops). Hoarding international reserves can be used to smooth the impact of such reversals (see, for example, Lee, 2004), but these reserves are seldom sufficient and always expensive to hold.

In Caballero and Panageas (2005), we derive and estimate a quantitative model to assess the (noncontingent) reserve management strategy typically followed by central banks. We conclude that this strategy is clearly inferior to one in which portfolios include assets that are correlated with sudden stops. As an illustration, we show that holding contracts on the Standard and Poor's (S&P) 100 implied volatility index (VIX) can yield a significant reduction in the average cost of sudden stops.

This result should not be surprising to anyone who follows the practices of hedge funds and other leading investors. Institutional investors seldom immobilize large amounts of cash to insure against jumps in volatility and risk-aversion—except in the case of extremely frequent events, which sudden stops are not. The use of derivatives and the creation of the VIX are designed precisely to satisfy hedging needs. Why should central banks, which are the quintessential public risk management institutions, not adopt best practices for risk management?

In this paper we present a simple model designed to isolate the portfolio dimension of the reserves management problem. We estimate the key parameters of the model from the joint behavior of sudden stops

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and the VIX, which we then use to generate optimal portfolios. We show that in an ideal setting, in which countries and investors can identify the jumps in the VIX and in which there exist call options on the VIX, an average emerging market economy may expect to face a sudden stop with up to 40 percent more reserves than when these options are not included in the central bank's portfolio.

The main reason behind this important gain is the close relation we identify between jumps in the VIX and sudden stops. We estimate that the probability of a sudden stop conditional on a jump in the VIX is about four times the probability of a sudden stop in the absence of a jump. Another dimension of the same finding, which speaks directly of the hedging virtues of the VIX, is that the probability of a jump in the VIX is slightly above 30 percent when there is no sudden stop in emerging markets and over 70 percent when a sudden stop takes place in that year.

The paper is organized as follows. Section 1 presents a simple static portfolio model for a central bank concerned with sudden stops. Section 2 then solves the model under various assumptions on hedging opportunities. Section 3 discusses implementation issues. Section 4 quantifies the model, first illustrating the behavior of the VIX and its coincidence with sudden stops in emerging markets (represented by nine economies: Argentina, Brazil, Chile, Indonesia, Korea, Malaysia, Mexico, Thailand, and Turkey). It then estimates the different parameters of the model and reports the optimal portfolios for a range of relevant parameters. Section 5 documents the impact of the different hedging strategies on the availability of reserves during sudden stops, and section 6 concludes.

1. Basic Framework

We analyze the investment decisions of a central bank that seeks to minimize the real costs of a sudden stop of capital inflows. Our goal is to provide a simple model to isolate the portfolio problem associated with such an objective. We refer the reader to Caballero and Panageas (2005) for a dynamic framework that discusses the optimal path of reserves and the microeconomic frictions behind sudden stops. Here we simply take from that paper that when a sudden stop occurs, the country's ability to use its wealth for current consumption is significantly curtailed. The immediate implication of such a constraint is a sharp rise in the marginal value of an extra unit of reserves.

There are two dates in the model: date 0, when portfolio decisions are made, and date 1, when asset returns realize and a sudden stop may take place. We assume that a central bank's objective has the following form:

$$\max_{R_0,\pi} -\frac{\alpha}{2} E\left\{\left[R_1 - K - 1(\mathrm{SS})Z\right]^2\right\}, \tag{1}$$

where R_1 denotes total reserves at date 1. $K \geq 0$ is a target level of reserves at date 1, which we take to be constant throughout; it captures reasons for holding reserves other than the (short-run) fear of sudden stops we emphasize. Deviations from this target are costly: a shortfall from the target implies that the central bank's objectives cannot be adequately met. Similarly, an excess level of reserves implies accumulation costs (which, among other things, capture the difference between the borrowing and the lending rate and the slope of the yield curve). The term $1(\mathrm{SS})Z$ is composed of two terms: an indicator function, $1(\mathrm{SS})$, that becomes 1 during a sudden stop (SS) and is 0 otherwise, and a constant, $Z > 0$, that controls the need for funds during the sudden stop. This constant captures the shift in the marginal utility of wealth that occurs once a sudden stop takes place. Hence, by construction of the optimization problem, a central bank desires to transfer reserves to sudden stop states. The program of equation (1) is to be solved subject to

$$R_0 = \pi P_0 + B_0 \text{ and} \tag{2}$$

$$R_1 = B_1 + \pi P_1,$$

where R_1 is the initial level of reserves, π is the amount of risky securities held by the central bank, P_0 is the price of such securities, and P_1 is the (stochastic) payoff of these assets at $t = 1$. B_0 is the amount of noncontingent bonds held by the central bank, whose interest rate we fix at 0 for simplicity, so that $B_1 = B_0$ and

$$R_1 = R_0 + \pi(P_1 - P_0).$$

Replacing this expression in equation (1) and computing the first-order conditions with respect to R_0 and π yields

$$R_0 = K + \Pr(\mathrm{SS})Z \text{ and} \tag{3}$$

$$\pi = Z \frac{\operatorname{cov}\left[1(\mathrm{SS}), P_1\right]}{\operatorname{var}(P_1)}, \tag{4}$$

where we have removed Merton's portfolio term by assuming fair risk-neutral pricing of the risky asset (an assumption we maintain throughout):

$$E(P_1) = P_0 .$$

We highlight three observations about this simple setup at this stage. First, the central bank has an aversion to overaccumulating reserves. If $Z = 0$ and $K = 0$, then $R_0 = 0$. Under these circumstances, the central bank achieves the maximum of the objective. Our main concern in this paper is with those reserves associated with the possibility of a costly sudden stop, $Z > 0$.

Second, the level of reserves invested at date 0, R_0, is independent of the portfolio, π, or the properties of the risky asset. This is due to the so-called certainty-equivalence property of the quadratic model. With more general preferences that exhibit a prudence motive, such as a constant relative risk aversion (CRRA), an increase in hedging (π) reduces the total amount of reserves held (see Caballero and Panageas, 2005).

Third, and most importantly, risky assets are not held if P_1 is uncorrelated with the sudden stop, 1{SS}. Risky assets are only held to the extent that they succeed in creating attractive payoffs during sudden stops, that is, as long as[1]

$$E(P_1 | SS = 1) > E(P_1 | SS = 0).$$

2. From Conventional Reserves to Hedges

We now characterize the solution for three cases of special interest. The first—our base-case model—assumes away hedging completely, which is not far from what central banks do in practice. The second case is an Arrow-Debreu setup in which contracts can be written contingent on the sudden stop. It captures the opposite extreme. The third is an intermediate case that allows for proxy hedging through contracts that are correlated, but not perfectly, with sudden stops.

1. We have renormalized all potential assets to be held in positive amounts.

2.1 No Hedging

We set $\pi = 0$ in the base-case model and drop the optimization with respect to π. Then,

$$B_0 = R_0 = K + \Pr(SS)Z \,. \tag{5}$$

As one might expect, the possibility of a sudden stop induces the country to hold reserves beyond the target level, K. This is probably one the main reasons why Chile, for example, holds four to five times the reserves of Australia or Canada.

2.2 Hedging with Arrow-Debreu Securities

Taking the opposite extreme, assume that an asset pays

$$\begin{cases} 1 \text{ if } SS = 1 \\ 0 \text{ if } SS = 0 \end{cases}$$

In this case our assumption of fair-pricing implies that

$$P_0 = \Pr(SS)\,.$$

It follows from equation (4) and the fact that in this case

$$\operatorname{cov}\left[1(\mathrm{SS}), P_1\right] = \operatorname{var}\left[1(\mathrm{SS})\right] = \operatorname{var}(P_1)$$

that

$$\pi = Z \,\cdot \tag{6}$$

When we replace this expression in equations (2) and (3), we obtain

$$B_0 = K + \Pr(SS)(Z - \pi) = K \,.$$

With perfect Arrow-Debreu securities (and fair pricing), the central bank will completely hedge away the sudden stop risk, so that

$$R_1 - 1(\mathrm{SS})Z = B_0 = K \,.$$

Now let us express the portfolio of Arrow-Debreu securities as a proportion of total reserves:

$$\phi = \frac{\pi P_0}{R_0} = \frac{\Pr(SS)Z}{K + \Pr(SS)Z} \,\cdot$$

In the interesting special case of $K = 0$ (corresponding to the case in which the country finds it optimal to hold no reserves in the absence of sudden stops), we have

$$\phi = 1 .$$

That is, all resources are invested in Arrow-Debreu securities.

2.3 The Intermediate Case

In reality, one observes neither Arrow-Debreu securities nor contracts written contingent on the sudden stop (at least in an amount sufficient to insulate the country from it). There are good reasons for that: in practice, the sudden stop itself is unlikely to be fully contractible, since its occurrence may depend on a country's actions and private information. The practical relevance of the simple model proposed above thus rests critically on the existence of assets and trading strategies that could function as good substitutes for the idealized assets envisaged above. We develop a simple extension to the Arrow-Debreu world above by introducing an asset that pays 1 when an event that we call J happens (corresponding, for example, to a discrete drop in some asset price). We introduce the notation

$$\psi^h = \Pr(\text{SS} = 1 | J = 1),$$

$$\psi^l = \Pr(\text{SS} = 1 | J = 0),$$

$$\eta = \Pr(J = 1), \text{ and}$$

$$\psi^l = \Pr(\text{SS} = 1) = \eta\psi^h + (1 - \eta)\psi^l ,$$

and we assume that

$$0 \le \psi^l \le \psi^h \le 1 .$$

In this case, it is suboptimal for the country to invest all of its assets in risky securities, but the country is generally willing to invest some, provided that

$$\psi^h > \psi^l .$$

The new optimization problem yields

$$\pi = Z\frac{(\psi^h - \psi)}{(1-\eta)} = Z(\psi^h - \psi^l) \text{ and} \tag{7}$$

$$B_0 = K + \psi Z - \pi\eta \, .$$

These formulas encompass those obtained previously. If $\psi^h = \psi^l$, then the two indicators are independent and thus $\pi = 0$. However, as $\psi^h \to 1$ and $\psi^l \to 0$, then $\psi \to \eta$ and the country insures the sudden stop completely. Short of that, the central bank finds it optimal to hedge sudden stops partly with noncontingent reserves: if $\psi^h < 1$, the risky asset may not deliver during a sudden stop. And if $\psi^h < 1$ $\psi^l > 0$, the country pays for protection it does not need from the risky asset.[2]

As a percentage of total reserves, the risky asset portfolio represents

$$\phi = \frac{\pi P_0}{R_0} = \frac{Z\eta}{R_0}(\psi^h - \psi^l).$$

This expression has a natural interpretation. Let $x \in [0, 1]$ represent the share of reserves allocated to the prevention of sudden stops in the near future:

$$x = \frac{\psi Z}{K + \psi Z} \, .$$

Given quadratic utility, this number is independent of the hedging instruments (the properties of J do not influence this number). Then the optimal portfolio is as follows:

$$\phi = x\frac{\eta}{\psi}(\psi^h - \psi^l). \tag{8}$$

That is, the portfolio is composed of three terms. The first is the fraction of reserves used for the prevention of sudden stops, x.[3] The second

2. With quadratic utility it suffices that $\psi^l = 0$ and $\psi^h > 0$ for the country to invest its entire portfolio in the risky asset (for $K = 0$). The proximity of ψ^h to one only determines how much hedging is achieved by this strategy.

3. Our sense of prevention is different from that in García and Soto (in this volume), where a stock of reserves is needed to prevent runs on the country. Their concept is subsumed in our fixed K, although if runs are related to factors that tighten international financial markets, then this term also should be analyzed as an optimal portfolio decision.

captures the relative frequency of jumps and sudden stops; as this rises, the price of the insurance rises. The third is the difference between the probability of a jump conditional on a sudden stop taking and not taking place. The latter term captures the risky asset's ability to transfer resources to the states where they are needed the most.

Dividing ϕ by x isolates the share of the risky asset in the component of reserves used for hedging sudden stops. This is the concept we emphasize henceforth by setting $x = 1$ (or $K = 0$).

3. Implementation Issues

This section takes the analysis one step closer to actual assets. We start by specifying a state variable, s_t, that is correlated with sudden stops but is not under the country's control. Assume that s_t evolves according to the following discretized stochastic differential equation:

$$s_{t+1} - s_t = \mu\left(s_t\right)\Delta t + \sigma N\left(0,1\right)\sqrt{\Delta t} + \varepsilon dJ_1, \tag{9}$$

where $\mu(s_t)$ is the drift (that is, the mean appreciation rate of the state variable) and σ is the volatility. The most interesting part of this expression is the jump process, dJ_1, which is zero except at date 1, when it takes the value one with probability η and zero otherwise, in perfect analogy to the setup in the last section. We let ε be a normally distributed random variable, with mean $\mu_\varepsilon > 0$ and standard deviation σ_ε.

3.1 Call Options

Given the above framework, we develop a simple strategy that can create an asset of the sort envisaged in section 2.3 by writing contracts contingent on s_t. To do this, we take the continuous time limit of equation (9) and consider a contract with an investment bank or insurer in which the central bank pays an amount, κdt, in exchange for each dollar received if s_t exhibits a jump at $t = 1$. Such a contract is well defined in continuous time. In reality, we can approximate it by signing a sequence of appropriate (sufficiently out-of-the-money) digital options that cost ηdt per unit of time. Such options can also be well approximated by regular puts and calls. The cost of such a position over the full period is

$$\int_0^1 \eta dt = \eta,$$

and the payoff is one if a jump happens at $t = 1$, and zero otherwise. This strategy is also feasible if one extends the model to the case in which a jump in s_t can happen at any time τ, as in Caballero and Panageas (2005). This is the process we estimate in the empirical section.

In conclusion, this sequence of short term digital options is, for all practical purposes, identical to the contract described in section 2.3.[4]

3.2 Futures Contracts

We now consider simple futures contracts. If investors are risk neutral with respect to s_t risk, a futures contract on s_t with maturity at $t = 1$ can be entered into at a forward price of

$$E(s_1),$$

with return

$$s_1 - E(s_1 | s_0).$$

The expected payoff of such a position at $t = 1$ is approximately[5]

$$\tilde{v} \sim N(-\eta\mu_\varepsilon, \sigma) + 1(J)N(\mu_\varepsilon, \sigma_\varepsilon),$$

where $1(J)$ corresponds to an indicator function that takes the value of one when a jump in the state variable takes place, and zero otherwise.

Futures have a price of zero. To keep the analysis comparable with the results obtained in section 2.3, however, we consider a slight variation of a futures contract and assume that the country must pay $\eta\mu_\varepsilon$ upfront for every contract into which it enters in exchange for a payoff of

$$v \sim N(0, \sigma) + 1(J)N(\mu_\varepsilon, \sigma_\varepsilon).$$

The solution to the maximization problem of equation (1) in this case is thus

$$\pi\mu_\varepsilon = Z\frac{\psi^h - \psi}{\left[(\sigma^2 + \eta\sigma_\varepsilon^2)/\eta\mu_\varepsilon^2\right] + 1 - \eta} = Z\frac{1 - \eta}{\left[(\sigma^2 + \eta\sigma_\varepsilon^2)/\eta\mu_\varepsilon^2\right] + 1 - \eta}(\psi^h - \psi^l);$$

$$B_0 = K + \psi Z - \pi\eta\mu_\varepsilon.$$

4. See Caballero and Panageas (2005) for a more extensive discussion of these issues.

5. A continuous time model is necessary to make the argument in this section exact.

Several observations about π are worth highlighting. First, we can set $\mu_\varepsilon = 1$ without loss of generality, since the dollar amount invested in the risky asset is $\pi\mu_\varepsilon$ at a price of η per dollar invested. Moreover, the right-hand side depends only on the ratios (σ/μ_ε) and $(\sigma_\varepsilon/\mu_\varepsilon)$. Hence from now on, we set $\mu_\varepsilon = 1$ and denote

$$\tilde{\sigma} = \frac{\sigma}{\mu_\varepsilon},$$

and similarly for $\tilde{\sigma}_\varepsilon$ and $\tilde{\pi}$. Thus, in dollar amounts we have

$$\tilde{\pi} = Z\left(\psi^h - \psi^l\right)\frac{1-\eta}{\left(\tilde{\sigma}^2/\eta\right) + \tilde{\sigma}_\varepsilon^2 + 1 - \eta}. \tag{10}$$

Comparing equations (10) and (7) shows that the amount invested in risky assets declines when one moves from digital options on the jump to simple futures (that is, the denominator is larger in equation (10)). The ratio between the two portfolios is

$$\frac{1-\eta}{\left(\tilde{\sigma}^2/\eta\right) + \tilde{\sigma}_\varepsilon^2 + 1 - \eta} < 1, \tag{11}$$

which declines as $\tilde{\sigma}$ and $\tilde{\sigma}_\varepsilon$ increase. This is intuitive: the more noise contained in the hedging opportunities, the less appealing they become to a risk-averse central bank. The portfolio ϕ is also attenuated by the ratio in equation (11).

To summarize, sudden stops must be severe to justify adding a risky asset to the central bank's holdings, and the risky asset must be sufficiently correlated with such events. On the other hand, neither causality nor the predictability of sudden stops and returns are part of the argument for a non-zero π.

4. Quantitative Assessment

The theoretical argument for hedging is difficult to dispute. The relevant question is thus an empirical one: do some global financial instruments and indices offer good enough hedging opportunities against sudden stops? The answer to this question is largely country specific, as not all emerging market economies are exposed to the same sources of fragility. In this section, rather than performing a collection of case studies, we show that at least one global asset has significant correlation with emerging market crises. In the absence of better country-specific alternatives, this global asset should constitute a significant share of these countries' portfolios.

4.1 The Basics: Sudden Stops and Jumps

We study a group of nine emerging market economies open to international capital markets in the 1990s, for which we have complete data: Argentina, Brazil, Chile, Indonesia, Korea, Malaysia, Mexico, Thailand, and Turkey.[6] These economies are representative of what is often referred to as emerging market economies. Our main exclusion is the group of Eastern and Central European economies, which became significant participants in international capital markets in the second half of the 1990s. These countries, however, faced economic problems of a somewhat different nature during much of our sample.

The first point to highlight is the well known fact that private capital flows to these economies comove significantly. Figure 1 splits into two panels the paths of the change in capital flows—more precisely, the difference between contiguous four-quarter moving averages of quarterly capital flows—to each of these economies from 1992 to 2002. The shaded areas mark the periods corresponding to the systemic tequila crisis, Asian crisis, and Russian crisis, as well as the sequence of somewhat less systemic Turkish, Argentine, and Brazilian crises. The figure demonstrates that these flows correlate significantly, especially within regions. Turkey is somewhere in between the two regions. These comovements are encouraging, as they indicate the possibility of finding global factors correlated with sudden stops.

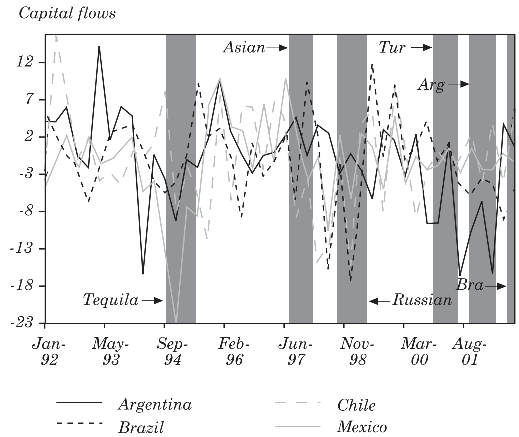
The second, and main, point is that clearly identifiable global factors—in fact, traded factors—are correlated with emerging market sudden stops. The key to finding such factors is that these episodes are generally understood as times when investors are reluctant to participate in risky markets. The VIX precisely captures this reluctance, and it has been available in the United States since 1986. This is an index of the implied volatilities from puts and calls (typically eight) on the S&P 100.[7] Figure 2 reproduces the shaded areas for

6. The exception is Malaysia, for which we do not have quarterly capital flows.

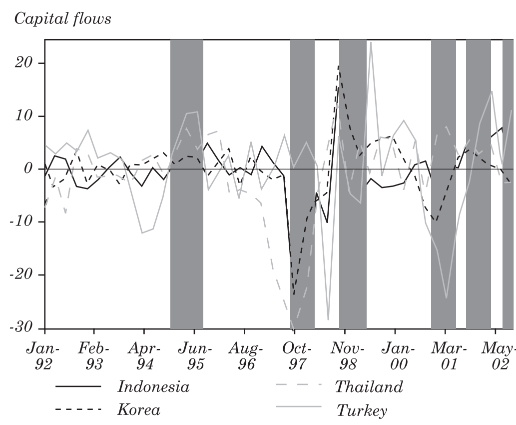
7. Implied volatilities are determined using the Black and Scholes (1973) formula to calculate the level of volatility that would be compatible with the observed prices of puts and calls.

Figure 1. Capital Flows for Varius Countries[a]

A. Capital flows for Latin American countries



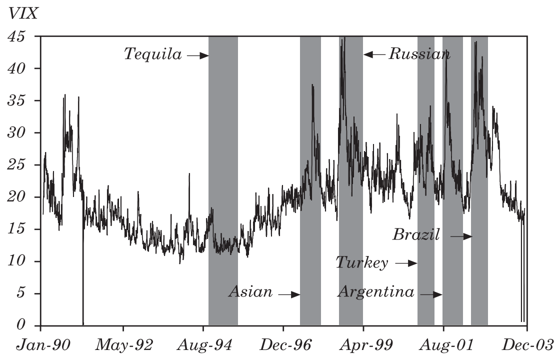
B. Capital flows for East Asian countries and Turkey



Source: International Financial Statistics (IFS).
a. The figure depicts the difference between four-quarter averages of capital flows and the same quantity one year before. The shaded areas depict periods of major crises).

sudden stops described in the previous graph and plots the daily VIX. Some of the largest jumps in the VIX occur precisely during sudden stops. In fact, the only systemic sudden stop that does not coincide with a jump is the tequila crisis, when the rise in the VIX was not large enough to count as a distinct jump.

Figure 2. Daily VIX Series[a]



Source: Chicago Board of Options Exchange (CBOE).
a. The shaded areas depict the periods of major crises.

The next section formally documents the joint behavior of sudden stops and jumps in the VIX. First, however, we explore the behavior of the VIX during the two largest systemic crises of the 1990s (namely, the Asian and Russian crises). The top panel in figure 3 plots the path of the VIX during the last two weeks of October 1997 (that is, the onset of the Asian Crisis), while the bottom panel does the same for August–September 1998 (the peak of the Russian long-term capital management crisis). In these events, the VIX reached levels above 30 and 45 percent, respectively, which are close to the maximum levels of the index. The VIX doubled in a matter of days.

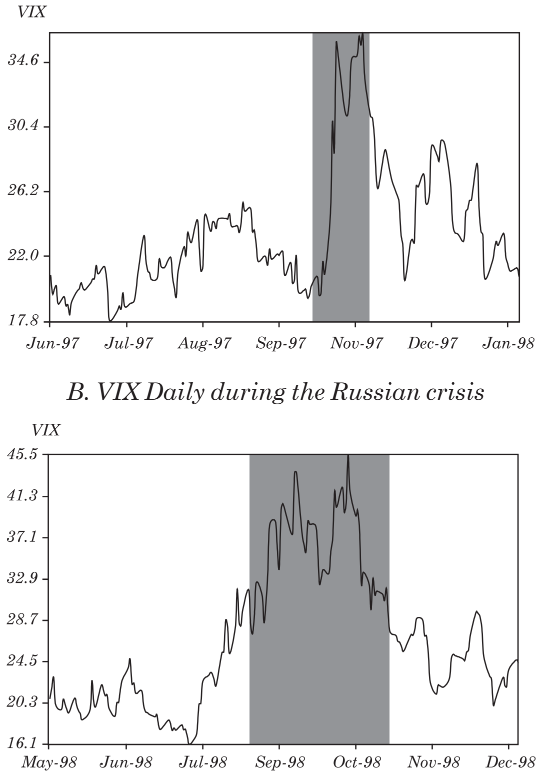
Finally, figure 4 reinforces the message of high correlation by plotting the path of the VIX together with J.P. Morgan's Emerging Market Bond Index (EMBI) for three of the most fragile emerging markets in recent years: Argentina, Brazil, and Turkey. The dips in the EMBIs correspond with the sharp rises in the VIX.[8] The VIX—a variable that is primarily meant to capture the "feelings" of investors in U.S. equity markets—thus happens to be highly correlated with the fortunes of emerging market economies. This highlights another important aspect of our methodology, according to which the only requirement for a variable like the VIX to be useful in hedging is that there also be a change in the conditional probability of having a crisis in emerging markets. This is not a statement about causation, but about correlation.

8. The EMBI data are from Datastream. Note that the Argentine (permanent) crash also coincides with a spike in the VIX.

Figure 3. Plots of the VIX in the Weeks Surrounding Major Crises in International Financial Markets

A. Daily VIX during the Asian crisis

B. VIX Daily during the Russian crisis



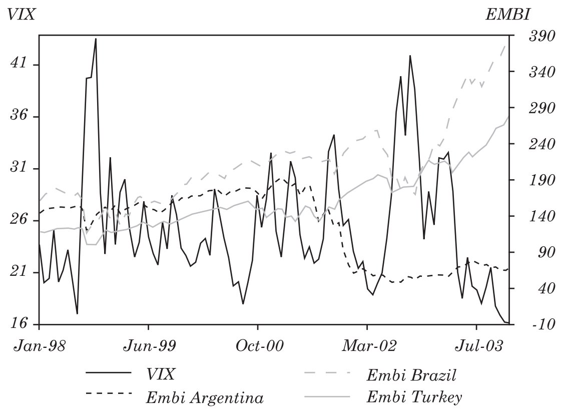
Source: Chicago Board of Options Exchange (CBOE).

We are not claiming that domestic factors do not play a paramount role in crises. Quite the contrary, we chose Argentina, Brazil, and Turkey for the previous figure precisely because their own domestic weaknesses make them more responsive to global factors. This compounding effect often raises, rather than dampens, the need for hedging global risk factors.

4.2 Quantification

We now turn to a structural analysis of the correlations highlighted above.

Figure 4. The VIX and the EMBI for Argentina, Brazil, and Turkey



Sources: CBOE and Datastream.

Estimation of the VIX process

To operationalize the model of the previous section, we take log(VIX) to be the state variable, s_t, which follows the continuous time process,

$$ds_t = -\theta\left[\log(s_t) - y\right]dt + \sigma dB_t + \varepsilon dJ_t\,.$$

This is the continuous time limit of equation (9), with the modification that jumps can happen at any point in time.[9] The functional form,

$$\mu(s_t) = -\theta\left[\log(s_t) - y\right],$$

corresponds to a first-order autoregressive, or AR(1), process in discrete time for log(s_t). We thus start by estimating an AR(1) process for log(VIX) with monthly data and focus on the residuals, v, which are distributed (for small Δt) roughly as

$$v \sim (1-p)N\left(-\eta\mu_\varepsilon \Delta t, \sigma\sqrt{\Delta t}\right) + pN(\mu_\varepsilon, \sigma_\varepsilon).$$

9. This is not a serious departure if the horizon in the decision model is understood to be one year and the probability of more than one jump taking place in a single year is small.

Given the very few observations with jumps, we identify these directly by inspection; this process fixes $\eta = 0.417$ and hence $p = 1 - e^{-\eta\Delta t}$. The rest of the parameters are estimated by maximum likelihood of the mixing of two normal distributions, with the following results: $\mu_\varepsilon = 0.356$; $\sigma = 0.353$; and $\sigma_\varepsilon = 0.047$.

The likelihood of sudden stops

The results in the previous section suggest the presence of seven jumps in the VIX in our sample: the first Persian Gulf War, the Asian crisis, the Russian crisis, the terrorist attacks on the United States (9/11), the Turkish crisis, the Brazilian crisis, and the corporate scandals in the United States. Conditional on these jumps, we calculate the probability that a country will experience a sudden stop. We identify an observation as a sudden stop based on a mixture of information on capital flow reversals and reserve losses (see Caballero and Panageas, 2005). Mainly, for an observation to count as a sudden stop, capital flows must decline by at least 5 percent of gross domestic product (GDP) relative to the flows in the previous two years, and reserves must be declining. This procedure yields estimates of ψ^h and ψ^l for each country. We then estimate ψ from the relation

$$\psi = \eta\psi^h + \left(1-\eta\right)\psi^l .$$

The results are reported in Table 1. The country-specific estimates are highly imprecise, however, as they correspond to the product of binary variables with very few transitions in each case.[10] We therefore pool the observations, which yields the results for the sample average. We also report results for two subcategories: high-risk economies (Argentina, Brazil, and Turkey) and the East-Asian economies. The former group is composed of the economies that have the highest estimated likelihood of a sudden stop in the sample.

10. The case of Mexico is particularly revealing. The estimate of $\psi^h = 0$ misses the fact that while Mexico did not experience a very significant capital flow reversal during the Russian/LTCM/Brazilean turmoil, its stock market declined very sharply, reflecting that it experienced significant pressure at the time, but adjusted primarily via prices instead of quantities. Chile and the East Asian countries have a $\psi^l = 0$ because we identify only a single SS for each of them and we observe a jump in the VIX during the same period.

Table 1. Estimates for ψ, ψ^h, and ψ^l

Country or group	ψ	ψ^h	ψ^l
Argentina	0.42	0.80	0.14
Brazil	0.42	0.60	0.29
Chile	0.17	0.40	0.00
Indonesia	0.17	0.40	0.00
Korea	0.08	0.20	0.00
Malaysia	0.25	0.40	0.14
Mexico	0.17	0.00	0.29
Thailand	0.17	0.40	0.00
Turkey	0.33	0.60	0.14
Average	0.24	0.41	0.11
High-risk countries	0.39	0.67	0.19
East Asia	0.17	0.35	0.04

Source: Authors' calculations.
a. ψ^h is estimated as the number of years in which we observe a joint jump in the VIX and a sudden stop in the country, divided by the number of jumps in the VIX. Symmetrically, ψ^l is the ratio of the number of years in which a sudden stop was not accompanied by jump, divided in the total number of years without a jump. To determine whether a sudden stop and a jump coincide, we allow for a two-quarter window around the date of the identified jump, because jumps are identified at a higher frequency than sudden stops. With the estimates for η, ψ^l, and ψ^h in hand, we obtain the estimate for ψ presented in the first column of the table.

The pooled estimate indicates that an average emerging market economy is nearly four times more likely to experience a crisis when the VIX has jumped than when it has not. Again, this is not a statement of causation, but of correlation. When the VIX spikes, the average emerging market economy has a 41 percent chance of experiencing a sudden stop. This chance drops to 11 percent when the VIX is tranquil.

Representative VIX portfolios and reserves gains

We use the above numbers to operationalize formulas 8 and 11 and thus estimate the portfolios implied by the model. Again, country-specific numbers are very imprecise, so attention should be placed on the pooled results. Table 2 reports the portfolios.

The values of ϕ are large. The futures contracts show shares of risky assets of 10 percent or higher for the different groupings, despite the large amount of noise in the VIX. When the call-options strategy is followed and hence the "noise" is removed, the shares rise to above 50 percent in all cases, and to nearly 80 percent for the Asian economies. The share is high among East Asian economies because in the sample, they experience mainly systemic crises (again, this is not a causal

Table 2. Representative Portfolios for Options and Futures

Country	ϕ *(Options)*	ϕ *(Futures)*
Argentina	0.66	0.13
Brazil	0.31	0.06
Chile	1.00	0.20
Indonesia	1.00	0.20
Korea	1.00	0.20
Malaysia	0.43	0.08
Mexico	0.00	0.00
Thailand	1.00	0.20
Turkey	0.57	0.11
Average	0.53	0.10
High-risk countries	0.51	0.10
East Asia	0.79	0.16

Source: Authors' calculations.

statement); this contrasts with the high-risk economies, which also experience idiosyncratic crises.[11]

These portfolios are dramatically different from those normally held by central banks in emerging markets. Finding out why seems imperative. Is it the potential markets' lack of liquidity, domestic political constraints, or simple institutional herding?

5. The Benefits

Our reduced-form portfolio model is not well suited for a thorough welfare comparison. In assessing the benefits of the hedging strategy, we thus focus on statistics that are robust across preferences. In particular, we report the expected gains conditional on the occurrence of a sudden stop. We illustrate this for the call-options scenario.

The first step in computing this statistic is to estimate the likelihood of a jump given that the country has experienced a sudden stop. Using Bayes' rule yields

$$\Pr\left(J = 1 \middle| SS = 1\right) = \psi^h \frac{\eta}{\psi}.$$

11. Note also that the difference between the optimal precautionary behavior of a high risk and an average economy is not only reflected in the different values for ϕ, but also on the level of reserves held. Recall that $R_0 = K + \psi Z$.

Table 3. Revised Probabilities and Expected Gains When Following the Options Strategy

Country	*Pr*(J = *1 ½ SS = 1)*	Expected gain (options)
Argentina	0.80	0.60
Brazil	0.60	0.14
Chile	1.00	1.40
Indonesia	1.00	1.40
Korea	1.00	1.40
Malaysia	0.67	0.26
Mexico	0.00	0.00
Thailand	1.00	1.40
Turkey	0.75	0.46
Average	0.72	0.39
High-risk Countries	0.71	0.36
East Asia	0.88	0.86

Source: Authors' calculations.

Table 3 reports the estimates, which are around 70 percent for an average emerging market economy and close to 90 percent for the relatively stable East Asian economies. This is important. The VIX jumps with a high likelihood at times when the countries need it to do so.

The rate of return for the call strategy is

$$\begin{cases} 1/\eta - 1 & \text{if } J = 1 \\ -1 & \text{if } J = 0 \end{cases}$$

and the expected gain in reserves conditional on entering a sudden stop is thus

$$\phi\left[\psi^h \frac{\eta}{\psi}\left(\frac{1}{\eta} - 1\right) - \left(1 - \psi^h \frac{\eta}{\psi}\right)\right].$$

Table 3 also reports these results. For an average economy, the expected gain is around 40 percent. That is, an average economy following the strategy described here can expect a 40 percent rise in its reserves on entering a sudden stop.[12] This is a significant number, which exceeds the actual reserve losses of many of these economies during their respective sudden stops.

12. The counterpart of this expected gain during sudden stops is that the economy may expect to lose 13 percent of its reserves when there is no sudden stop.

Many caveats can be raised here, and they are likely to reduce these large numbers. For example, in a dynamic model, the central bank might find it optimal to hold a level of reserves above a certain minimum in all contingencies, even in good states. In the present model, this is equivalent to assuming that the central bank targets a nonzero level of reserves (that is, $K > 0$), which implies that $x < 1$. As shown in expression 8, the portfolio of risky assets is scaled down proportionally with x. Alternatively, one could imagine a situation in which a central bank wishes under no circumstances to lose more than c percent of its reserves, in which case the optimal portfolio would become

$$\min(c, \phi) .$$

Notwithstanding these caveats, the above calculations make a simple point: no matter which assumptions we make about preferences and constraints, the driving force behind our results is the strong correlation between the VIX index and the incidence of sudden stops. The simple quadratic framework that we propose is particularly well suited to making this separation between preferences (which solely affect x) and correlation explicit. While a more elaborate model like that in Caballero and Panageas (2005) is required to develop a satisfactory theory for x, the effects that come from the strong correlations are independent of the specifics of the model.

6. Final Remarks

We start our conclusion with a disclaimer. The portfolios we illustrate for the emerging market economies we study, and our emphasis on the VIX, are neither country-specific nor instrument-specific recommendations. Our goal is simply to illustrate the potential benefits of enriching the portfolio options of central banks and searching for assets and indices that are global in nature but correlated with capital flow reversals.

Within this limited goal, our results are promising: the expected gains in reserves during sudden stops can be significant (slightly less than 40 percent of reserves for an average country). This is noteworthy, considering that we are only considering a single risky asset which is not optimized to capture the risks faced by emerging market economies.

The latter point raises an issue of international financial architecture. The VIX is useful because it is correlated with implied volatilities and risks in emerging markets, but it also captures problems that are specific to the United States. Ideally, one would want an index that weights U.S. events that are likely to have worldwide systemic effects differently from those that are not. It should be relatively easy to construct implied volatility indices that isolate the former factors and still preserve the country-exogeneity properties of the VIX. Constructing such indices is important for creating benchmarks and developing liquid hedging markets for economies exposed to capital flow volatility.

An issue that we avoided entirely is the incentive effects that a modified central banks' policy of hedging external shocks may have on the private sector. This is an important concern, since the private sector may undo some of the external insurance in anticipation of a central bank's intervention. The hedging policy should probably be coordinated with monetary and regulatory policies (see Caballero and Krishnamurthy, 2003). Even in the absence of these complementary policies, however, perverse incentive effects are unlikely to be strong enough to fully offset the justification for more aggressive hedging practices. After all, current reserve policies also suffer from these problems and are justified on the grounds that many in the private sector are simply not forward-looking enough to hedge aggregate risks in sufficient amount.

If such practices were to be adopted collectively, we would soon observe the emergence of new instruments that better match the needs of emerging market economies. The welfare improvement from such enhancements could be very significant and therefore may justify a coordination role by the international financial institutions and central banks around the world. Such coordination may be a necessity for limiting the potential political costs from hedging losses.

To conclude, we reiterate that our emphasis on external sources of capital flow volatility does not seek to shift the blame for much of capital flow volatility away from the countries themselves. Our goal is simply to show that a significant component can be hedged. Moreover, the issue we highlight here interacts with the domestic sources of external fragility: weak countries are more likely than strong countries to be hit by global turmoil, and they should therefore put an even bigger effort into hedging against these global shocks.

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