Insurance and Reserves Management in a Model of Sudden Stops

Ricardo J. Caballero — MIT and NBER

Stavros Panageas — The Wharton School

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Preliminary

Abstract

Emerging market economies, which have much of their growth ahead of them, run persistent current account deficits in order to smooth consumption intertemporally. The counterpart of these deficits is their dependence on capital inflows, which can suddenly stop. In this paper we develop and estimate a quantifiable model of sudden stops and use it to study practical mechanisms to insure emerging markets against them. We first assess the standard practice of protecting the current account through the accumulation of international reserves and conclude that, even when optimally managed, this mechanism is expensive and incomplete. External insurance, on the other hand, is hard to obtain because sudden stops often come together with distress in emerging market investors themselves (the most natural insurers). Thus, one needs to find global (non-emerging-market-specific) assets that are correlated to sudden stops. We show an example of such an asset based on the S&P 500's implied volatility index. If added to these countries portfolios, it would significantly enhance their sudden stop risk-management strategies. In our simulations, the median gain in terms of reserves available at the time of sudden stop exceeds 35 percent. Moreover, in instances where the level of uncontingent reserves is low (lower quintile) and hence the cost of a sudden stop is high, the median gain exceeds 200 percent.

JEL Codes: E2, E3, F3, F4, G0, C1.

Keywords: Capital flows, sudden stops, international reserves, financial and collateral constraints, specialists, world capital markets, swaps, insurance, hedging, options, hidden states, Bayesian methods.

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1 Introduction

Emerging market economies, which have much of their growth ahead of them, run persistent current account deficits in order to smooth consumption intertemporally. The funding of these deficits is a perennial source of fragility since it requires ongoing capital inflows which can suddenly stop. While in many circumstances the breakdown in capital inflows simply amplify domestic deficiencies, there is extensive evidence that in many others the main culprit is not the country itself but the international financial markets' response to shocks only vaguely related to the country's actions.

The real costs of this volatility for countries that experience open crises are dramatic and well known. Less noticed, but at least as important in terms of their pervasiveness and cumulative impact, are the large costs paid by prudent economies. These economies do not fall into open crises but are forced to incur in a variety of costly precautionary measures and build large war-chests of international reserves, a trend that has only increased in the aftermath of the capital flow crises of the late 1990s. Chile and South Korea, for example, hold close to 20 percent of GDP in reserves, which contrasts with the 4 to 5 percent held by developed open economies such as Australia or Canada. How effective are reserves in smoothing the impact of sudden stops unrelated to a country's actions? How much of them should be accumulated? How fast? Are there potentially less costly prudential mechanisms to deal with capital flow volatility? Who would be the natural counterpart for these mechanisms? How are these mechanisms limited by financial and collateral constraints?

These are among the most pressing questions for policy-makers and researchers in emerging market economies and the international financial institutions. Unfortunately, while there has been significant conceptual progress over the last two decades in understanding some of the limitations of financial contracting with emerging markets, there has been much less progress in providing an integral framework to analyze these questions quantitatively. In this paper we take one step in this direction.

In a nutshell, our framework considers three type of agents: An emerging market country, specialist investors, and the world capital markets at large. The essence of an emerging market economy for the problem we wish to model has two ingredients: First, its future income is significantly higher than its current income so it would like to borrow and run persistent current account deficits. Second, it has great difficulty in pledging future income to finance these deficits. Specialists can alleviate this problem but they themselves are subject to shocks that limit their ability to commit to deliver resources. These shocks, which in our model are driven by a Poisson process, are the sudden stops of capital inflows. That is, sudden stops are episodes when specialists are unable to rollover all their explicit or implicit short term commitments. The country would like to insulate its current account financing from these sudden stops, but it cannot do so with its specialists since they are constrained during these events. Resorting to the world capital markets after the sudden stop takes place does not work either, since the country has very limited credibility with non-specialists. However, world capital markets can still be used ex-ante, as long as contracts and investments are made contingent on variables that do not require emerging markets knowledge.

One of the main obstacles in building this type of structure for quantitative analysis is that it is in principle quite complex, involving several layers of potential financiers, contractual problems, and multiple state variables. Our framework preserves some of this richness but it is at the same time manageable. We make several stylized assumptions that allow us to represent the problem in terms similar to those of managing the risk associated to an exogenous non-diversifiable "income" diffusion-jump process, and is amenable to estimation.

A key simplification is that countries' and their specialists engage in growth-swaps. These swaps eliminate debt-overhang type considerations and focus the analysis on the obtention of new, uncommitted, resources. This is probably not an overly costly simplification in terms of realism, as it isolates the most fragile source of external financing. Unlike existing liabilities, uncommitted resources cannot be forced to stay in through renegotiation. It is perhaps for this reason that in practice sudden capital flow reversals are more closely associated to the current account deficit (a flow variable) than to the stock of debt (see, e.g., Calvo, Izquierdo and Mejia (2004)).

In the first part of the paper we discuss the pure reserves-management problem. Countries hoard (non-contingent) international reserves to smooth the impact of sudden stops on the current account. Since this is more or less what countries do in practice, we use this structure to estimate and calibrate the key parameters of the model. We use a Bayesian-hidden-state model to estimate the sudden stop processes for Chile and Malaysia, two countries whose sudden stops can be attributed to external factors (especially during the 1990s). In both cases the findings are similar: Sudden stops are infrequent, but recurrent and costly events. In a typical sudden stop, external funding declines by 10 percent or more, and its main impact lasts for about three to four years. We conclude from this part that holding non-contingent international reserves, as central banks do in practice, is a costly and incomplete sudden-stop insurance mechanism even when managed optimally. Reserves require large consumption sacrifices prior to sudden stops per unit of protection, especially while their stock is being built. This is costly for emerging market economies, which experience limited access to external resources even during normal times.

This takes us to the second part of the paper, where we expand the set of investments (or contracts) countries can make. In particular, we consider the optimal inclusion of digital options on the VIX in the country's portfolio. The VIX is an index of implied volatilities extracted from options on S&P500 firms, that simultaneously satisfies the conditions to appeal to world capital markets and to provide a good hedge against sudden stop for emerging markets: It is a developed world variable that is highly correlated with sudden stops. We discuss implementation and run the economy through simulations with the same sample paths of sudden stops used in the case with only uncontingent reserves. Relative to the latter case, the median gain in terms of reserves available at the time of sudden stop exceeds 35 percent. Moreover, in instances where the level of uncontingent reserves is low (lower quintile) and hence the cost of a sudden stop is high, the median gain exceeds 200 percent.

Our paper relates to several strands of literature. The main shock that concerns us here is a sudden stop of capital inflows. The literature on sudden stops gained new life since the Asian and Russian crises. The work of Calvo (1998) describes the basic mechanics and implications of sudden stops and Calvo and Reinheart (1999) document the pervasiveness of the phenomenon. The modelling of these sudden stops as the tightening of a Kiyotaki-Moore (2001) style collateral constraint is also present in the work of Caballero and Krishnamurthy (2001), Arellano and Mendoza (2002) and Broner et al. (2003), among others.

As an intermediate step in developing our substantive argument and quantifying the effects we describe, we model reserves accumulation as a buffer stock model against capital flow reversals. The view that reserves can be used to cushion the impact of external shocks exists at least since Heller (1966), was enhanced by the work on precautionary savings in macroeconomics during the 1980s (see, e.g., the surveys in Tweedie (2000) and Caroll (2004)), and has recently returned to the fore with the large accumulation of reserves exhibited by emerging markets since the crises at the end of the 1990s (see, e.g., Lee (2004)).

Importantly, the main reason for seeking insurance and hedging in our context is not income fluctuation per-se but the potential tightening of a financial constraint. This motive parallels that highlighted by Froot et al (1993) at the level of corporations, and by Caballero and Krishnamurthy (2001) for emerging markets. While the substantive themes developed in those articles differ from ours, the basic model in our paper is in many respects a dynamic version of theirs.

Closely related to our recommendations are those in the sovereign debt literature. The optimality of contingent debt and the limitations to it imposed by financial frictions are also a feature of that literature. In particular, the work of Kletzer, Newbery and Wright (1992) and Kletzer and Wright (2000), characterize feasible financial structures consistent with different degrees of commitment by a sovereign borrower and its lenders. Our collateral constraints capture features similar to those of their richer limited enforcement framework. Our paper reinforces much of the message in that literature and provides a tractable model that can be estimated and quantified.

The interaction between precautionary savings and financial constraints is also present in the closed economy framework of Aiyagari (1994). He calibrated such a model to estimates of US microeconomic income processes and other parameters and concluded that eventually agents would save enough to relax all financial constraints. Our model has similar ingredients, in that countries tend to accumulate resources over time and in that there is a level after which sudden stops would have no consequences on consumption. However, in sharp contrast with his quantitative results, ours suggests that historically countries have not gotten close to that level of savings. The main reason is the high opportunity cost of accumulating reserves for these countries, which face two financial constraints. On one hand, countries are unable to transfer enough resources from the post- to the pre-development phase. On the other, within the pre-development phase the country experiences sudden stops. The problem equivalent to that in Aiyagari is the buffer stock built to smooth the sudden stop. The long run constraint, on the other hand, raises the opportunity cost of such buffering.

Over recent years there has been a significant rise in the volatility trades, including the VIX. The finance literature has studied the impact of such trades on the performance of hedge funds and other markets participants (see, e.g., Bondarenko (2004)). From a risk management perspective, the issues faced by these economic agents are similar to those faced by emerging market policymakers.

We setup the model in Section 2 while constraining the precautionary options of the country to the accumulation of uncontingent reserves. In Section 3 we estimate the sudden stop process, quantify the basic model, and assess the effectiveness of reserves as a precautionary mechanism. In section 4 we let the country purchase digital options from world capital markets. Section 5 implements the extended model using the VIX as the contingent indicator on which options are written. Section 6 concludes and is followed by several appendices.

2 Sudden Stops and Reserves

While there are many important issues that arise from decentralization in economies with poor institutional development, we leave these aside and focus on the problems between the country as a whole and international investors. We study a representative agent economy with a benevolent government that seeks to maximize the expected present value of utility from consumption:

$$\mathrm{E}\left[\int_t^\infty U(C_s)e^{-r(s-t)}\,ds\right]$$

with r being both the discount and riskless interest rate. While it is not essential, assuming a CRRA utility of consumption also simplifies the exposition:

$$U(C) = \frac{C^{1-\gamma}}{1-\gamma}$$

2.1 Emerging Market Economies, Specialists and Sudden Stops

There are two features of an emerging market economy that are important for our analysis. First, its current income is low relative to its future income (it has yet to catch up), and thus it would like to borrow and run current account deficits. Second, it has difficulty pledging future income to finance these deficits.

Let Y_t represent the country's income *after* it has achieved development, and follow the geometric Brownian motion:

$$dY_t = \mu_Y Y_t dt + \sigma_Y Y_t dB_t$$

with $0 \leq \mu_Y \leq r$. Income before development, on the other hand, is equal to:

$$\kappa Y_t \qquad \kappa < 1.$$

A transition from the pre- to the post-development phase is irreversible and takes place at a random time τ^G. The focus of the paper is on the former phase. In order to eliminate inessential time dependency, we assume that τ^G is governed by a Poisson process with constant hazard g and independent of all other sources of uncertainty in the model. Note that $g(1-\kappa)/\kappa > 0$ is the difference in the expected rate of growth of a developing and a developed economy.

A country in the pre-development phase would like to borrow against its post-development income. We split potential financiers into world capital markets at large, and specialists. The former have no ability or information to induce the country to repay once the country transits into development, while the latter do.

Specialists are those investors that have developed some expertise and connections in the country and can reduce the extent of its financial constraint. During normal times, they accept pledges up to a share z of post-development "excess" output, $(1-\kappa)Y_s$, for all $s \geq \tau^G$. In aggregate —that is after netting out the multiple type of financial contracts that individuals may sign and are not of our concern in this paper — risk neutral specialists optimally engage in "swap-like" contracts with the country. At each time t, the specialists commit to provide resources at a rate f_t over the next infinitesimal time interval dt, in exchange for receiving a promise to a stream of payments $z(1-\kappa)Y_t$ forever if development $\left(\tau^G\right)$ arrives in the interval dt and 0 otherwise. By risk neutrality this stream is valued at $z(1-\kappa)Y_t/(r-\mu_Y)$.

The Poisson transition (as opposed to smoother non-stochastic growth or any other non-i.i.d. process) and the corresponding growth-swaps mean that risk neutral specialists absorb the transition risk, so that no debt is accumulated if no transition takes place. This removes a state variable from the analysis and keeps the problem tractable.

The maximum flow that competitive specialists are willing to commit for the next dt is:[1]

$$\overline{f_t} = gz(1-\kappa)\frac{Y_t}{r-\mu_Y}.$$

We capture the (long-run) financially constrained aspect of emerging market economies with the assumption:

[1] Formally, this expression can be derived from the pricing equation:

$$rP_t = -\overline{f_t} + g(z(1-\kappa)Y_t/(r-\mu_Y) - P_t)$$

and noting that a swap at the time of its inception has value $P_t = 0$.

Assumption 1 *(Limited Unsecured Borrowing)* $z < \frac{r-\mu_Y}{r+g-\mu_Y}$

which ensures that the funds provided by specialists before development are less than the unpledged income after development. During non-sudden stop times, abbreviated as "NSS" and sometimes referred to as "normal" times, an emerging market economy "borrows" at much as it can:

$$f_t^{NSS} = \overline{f_t}$$

in order to smooth pre- and post-development consumption.

Let us now introduce the sudden stops. We assume that there are episodes when specialists' ability to pledge resources is significantly reduced. We neither specify the particular agency problem or capital constraints that afflict specialists during sudden stops, nor let them take precautionary measures against these. Instead, we simply state the aggregate constraint implied by these shocks and focus on the country's side of the problem:

Assumption 2 *(Sudden Stops) During sudden stops, specialists (collectively) can commit at most $\underline{f_t} < \overline{f_t}$ resources to the country. Specialists transit from the normal to the sudden stop stage with hazard λ and do the reverse with hazard $\tilde{\lambda}$, both of which are independent of the transition to development.*

That is, the maximum flow of resources received from the specialists before development drops to $\underline{f_t}$ during sudden stops, and can be expressed as:

$$\underline{f_t} \equiv g(1-\kappa)z^{SS}Y_t/(r-\mu_Y)$$

with $z^{SS} < z$. This tightening of the aggregate financial constraint can be interpreted as a drop in the share of swaps rolled over by the specialists, which are clearly binding:

$$f_t^{SS} = \underline{f_t}$$

If the country transits from the SS to development, it transfers $z^{SS}(1-\kappa)Y_t$ to the specialists forever.[2]

Letting a_t denote the sum of income and capital flows, we can write in a mathematically compact form:

$$a_t = \left(\theta^{NSS}1\{NSS\} + \theta^{SS}1\{SS\} + \theta^{G|SS}1\{G|SS\} + \theta^{G|NSS}1\{G|NSS\}\right)Y_t \quad (1)$$

[2] Note that we could have assumed a transfer of $z(1-\kappa)Y_t$, or anything in between, in which case not only the shadow but also the observed interest rate would rise during sudden stops. This modification is trivial but not a first order issue in our analysis.

with

$$\theta^{NSS} = \kappa + (1-\kappa)\frac{g}{r-\mu_Y}z \quad (2)$$

$$\theta^{SS} = \kappa + (1-\kappa)\frac{g}{r-\mu_Y}z^{SS} \quad (3)$$

$$\theta^{G|NSS} = 1-(1-\kappa)z \quad (4)$$

$$\theta^{G|SS} = 1-(1-\kappa)z^{SS} \quad (5)$$

where $1\{NSS\}$ and $1\{SS\}$ indicate whether the country is in normal times ("NSS"), or in a sudden stop ("SS"). Importantly, for it is behind the external crises we wish to capture,

$$\theta^{SS} < \theta^{NSS}.$$

Finally, $1\{G|SS\}, 1\{G|NSS\}$ indicate that the country is currently developed and the transition to development took place from SS or NSS, respectively. Note that,

$$\theta^{NSS} < \theta^{G|NSS} < \theta^{G|SS}.$$

The first of these inequalities is important since it captures the constraint to transferring resources to the emerging market (pre-development) phase. The second one is inessential, except for implicitly stating that the former constraint binds regardless of whether the particular transition into development takes place from NSS or SS.

2.2 Reserves and World Capital Markets

While the country cannot borrow beyond the swaps, it can accumulate assets,

$$X_t \geq 0.$$

These assets, which we call reserves, are purchased in world capital markets and, for now, correspond to riskless global bonds that pay return r per unit time.

Hoarding reserves during the pre-development phase is costly for an emerging market, primarily because the country as a whole is already constrained in its ability to transfer resources from the post-development phase. This means that any accumulation of reserves in aggregate carries with it a costly reduction in *current* consumption.[3]

[3] But wouldn't the country have an incentive to accumulate reserves in order to build collateral and relax the financial constraint? The answer is clearly no. The logic behind this natural question is built on the implicit assumption that collateral is self-financing, in the sense that reserves can be built from additional "borrowing" on the commitment that the reserves so built will be pledged back to those that lent for that purpose. But this cannot be done without violating the commitment limits we have stated for the country. At the outset, the country is still bound by its maximum pledgable resources $z(1-\kappa)Y_t/(r-\mu_Y)$.

This reduction in current consumption is particularly costly if it ends up financing post-development consumption, which in our setup can take place because transitions to development occur at random times. However, countries need not absorb all this risk since reserves are primarily composed of international financial instruments that can be pledged even to non-informed world capital markets. We assume that world capital markets accept up to a share $\alpha \leq 1$ of reserves as margin for contracts that swap a flow of g per unit of pledged reserves if no growth takes place in exchange for taking the unit of reserve if transition does take place. Letting $\overline{X_t}$ denote the reserves pledged into these swaps:

$$\overline{X_t} \leq \alpha X_t$$

we have that in the pre-development phase, $t < \tau^G$, reserves accumulation is described by:

$$dX_t = \left(rX_t + g\overline{X_t} - C_t + a_t\right) dt.$$

When the country transits into development it pays $\overline{X_t}$ and from then on ($t \geq \tau^G$):

$$dX_t = (rX_t - C_t + a_t)\, dt.$$

2.3 The Problem

Let us now collect the ingredients into the country's optimization problem. Our assumptions are such that, in most regions, we have reduced the financial problem of the country to a more or less standard precautionary savings problem in the presence of income (here income plus capital flows) fluctuations:

$$\begin{aligned}
V(X_t, Y_t) &= \max_{C_s, \overline{X}_s} E\left[\int_t^{\tau^G \wedge \tau^{SS}} e^{-r(s-t)} u(C_s) ds + e^{-r\left(\left(\tau^G \wedge \tau^{SS}\right)-t\right)} \tilde{V}(X_\tau, Y_\tau)\right] \\
V^{SS}(X_t, Y_t) &= \max_{C_s, \overline{X}_s} E\left[\int_t^{\tau^{NSS} \wedge \tau^G} e^{-r(s-t)} u(C_s) ds + e^{-r\left(\left(\tau^G \wedge \tau^{NSS}\right)-t\right)} \tilde{V}^{SS}(X_\tau, Y_\tau)\right] \\
V^{G|SS}(X_t - \overline{X_t}, Y_t) &= \max_{C_s} E\left[\int_t^{\infty} e^{-r(s-t)} u(C_s) ds\right] \\
V^{G|NSS}(X_t - \overline{X_t}, Y_t) &= \max_{C_s} E\left[\int_t^{\infty} e^{-r(s-t)} u(C_s) ds\right] \\
& \quad s.t. \\
\tilde{V}(X_\tau, Y_\tau) &= V^{G|NSS}(X_\tau - \overline{X}_\tau, Y_\tau) 1\{\tau = \tau^G\} + 1\{\tau = \tau^{SS}\} V^{SS}(X_\tau, Y_\tau) \\
\tilde{V}^{SS}(X_\tau, Y_\tau) &\equiv V^{G|SS}(X_\tau - \overline{X}_\tau, Y_\tau) 1\{\tau = \tau^G\} + V(X_\tau, Y_\tau) 1\{\tau = \tau^{NSS}\} \\
dX_t &= \left[r X_t - C_t + g \overline{X}_t + a_t\right] dt \qquad (6) \\
a_t &= \left(\theta^{NSS} 1\{NSS\} + \theta^{SS} 1\{SS\} + \theta^{G|SS} 1\{G|SS\} + \theta^{G|NSS} 1\{G|NSS\}\right) Y_t \\
dY_t &= \mu_Y Y_t dt + \sigma_Y Y_t dB_t \\
\overline{X_t} &\leq \alpha X_t \text{ if } t < \tau^G \text{ and } \overline{X_t} = 0 \text{ otherwise} \\
X_t &\geq 0 \text{ for all } t \geq 0 \\
\lim_{t \to \infty} e^{-rt} X_t &= 0
\end{aligned}$$

where V, V^{SS} and V^G denote the value functions in the states NSS, SS and G, respectively.

In words, in post-development (in the state G) the country faces a standard precautionary savings problem. This state is absorbing, so that there can be no further transitions to the states "SS" or "NSS". The first (and final) time that development arrives is denoted by τ^G, which occurs with hazard g. Prior to development, the country can be either in a sudden stop "SS" or in normal times "NSS". Transitions from normal times to sudden stops occur with a constant hazard rate of λ, at the stochastic times τ^{SS}. The reverse transitions (from SS to NSS) occur at the rate $\widetilde{\lambda}$, at stochastic times τ^{NSS}. Aside from the different potential transitions, the practical implication of being in any of the three regimes is that the maximum amount of resources available differs.

Aside from the decision of how many growth-swaps to engage with specialists, which we have already discussed and solved out of the problem, the country is faced with two decisions. The first one is how much to consume (C_t), and the second one is how many swaps to enter with world capital markets $\left(\overline{X}_t\right)$ backed by collateral of at most αX_t. Reserves play the dual role of providing the country with resources during sudden stops, while also relaxing the constraint on the amount of swaps that can be entered with world capital markets. However, accumulating them is costly because the country is already constrained in normal times, since it cannot borrow to the full extent against its post-development income.

While a full characterization of the solution to this problem has to wait until the quantitative section, here we gauge the nature of the solution analytically.

Let us start backwards, from the post-development phase, where the problem is a conventional income-fluctuation problem. When not leading to confusion, we use the generic notation V^G for both $V^{G|SS}$ and $V^{G|NSS}$, since they both satisfy the Bellman equation:

$$0 = \max_{c_t} \left\{ \frac{C_t^{1-\gamma}}{1-\gamma} - C_t V_X^G \right\} + V_X^G \left(rX_t + \theta^G Y_t \right) - rV^G + +V_Y^G \mu_Y Y_t + \frac{1}{2}\sigma_Y^2 Y_t^2 V_{YY}^G \tag{7}$$

where θ^G should be taken to be $\theta^{G|SS}$ for $V^{G|SS}$ while it should be taken to be $\theta^{G|NSS}$ for $V^{G|NSS}$. Defining

$$x_t \equiv \frac{X_t}{Y_t} \qquad c_t \equiv \frac{C_t}{Y_t},$$

noticing that

$$V^G(X_t, Y_t) = Y_t^{1-\gamma} v^G(x_t),$$

plugging this expression back into (7) and simplifying, we obtain:

$$\begin{aligned} 0 \quad = \quad & \max_{c_t} \left\{ \frac{c_t^{1-\gamma}}{1-\gamma} - c_t v_x^G \right\} + \left(rx_t + \theta^G \right) v_x^G - rv^G \\ & + \mu_Y \left[(1-\gamma)v^G - x_t v_x^G \right] + \frac{1}{2}\sigma_Y^2 \left(-\gamma(1-\gamma)v^G + 2\gamma x_t v_x^G + x_t^2 v_{xx}^G \right) \end{aligned} \tag{8}$$

The first order condition for consumption (normalized by potential income) is:

$$c_t = \left(v_x^G \right)^{-\frac{1}{\gamma}} \tag{9}$$

An immediate implication of this first order condition is that the consumption to (potential) income ratio is a function of the reserves to (potential) income ratio only. Following similar steps in NSS, we obtain:

$$\begin{aligned} 0 \quad = \quad & \max_{c_t} \left\{ \frac{c_t^{1-\gamma}}{1-\gamma} - c_t v_x^{NSS} \right\} + \max_{\overline{x}_t \le \alpha x_t} \left(g v^G (x_t - \overline{x_t}) + g \overline{x}_t v_x^{NSS} \right) \\ & + \left(rx_t + \theta^{NSS} \right) v_x^{NSS} - (r + \lambda + g) v^{NSS} + \lambda v^{SS} \\ & + \mu_Y \left[(1-\gamma)v^{NSS} - x_t v_x^{NSS} \right] + \frac{1}{2}\sigma_Y^2 \left(-\gamma(1-\gamma)v^{NSS} + 2\gamma x_t v_x^{NSS} + x_t^2 v_{xx}^{NSS} \right) \end{aligned} \tag{10}$$

Once again, the first order condition for consumption is

$$c_t = \left(v_x^{NSS} \right)^{-\frac{1}{\gamma}} \tag{11}$$

whereas (adjoining the Lagrange multiplier $\phi \ge 0$), the second optimization problem in (10) leads to the first order condition:

$$v_x^G (x_t - \overline{x_t}) + \psi^{NSS} = v_x^{NSS} \tag{12}$$

Notice that if the pledged-reserves constraint is non-binding , then (9), (11) and (12) imply that consumption would not jump if the country were to transit from NSS to post-development. This in turn can only happen if x_t is at (or above) the critical level x^* which is determined from:

$$v_x^G\left((1-\alpha)x^*\right) = v_x^{NSS}\left(x^*\right)$$

However, for levels of reserves lower than x^* the constraint $\overline{x_t} \leq \alpha x_t$ is binding, and there is a consumption jump when the country transits into post-development.

Finally, we obtain the Bellman equations for the sudden stop region:

$$\begin{aligned} 0 \quad = \quad & \max_{c_t}\left\{\frac{c_t^{1-\gamma}}{1-\gamma} - c_t v_x^{SS}\right\} + \max_{\overline{x}_t \leq \alpha x_t}\left(g v^G(x_t - \overline{x_t}) + g\overline{x}_t v_x^{SS}\right) \\ & + \left(r x_t + \theta^L\right) v_x^{SS} - (r + \widetilde{\lambda} + g) v^{SS} + \widetilde{\lambda} v^{NSS} \\ & + \mu_Y\left[(1-\gamma)v^{SS} - x_t v_x^{SS}\right] + \frac{1}{2}\sigma_Y^2\left(-\gamma(1-\gamma)v^{SS} + 2\gamma x_t v_x^{SS} + x_t^2 v_{xx}^{SS}\right) \end{aligned} \tag{13}$$

which has first order condition similar to those on the NSS region:

$$c_t = \left(v_x^{SS}\right)^{-\frac{1}{\gamma}} \tag{14}$$

$$v_x^G(x_t - \overline{x_t}) + \psi^{SS} = v_x^{SS} \tag{15}$$

It is instructive to study and compare the first order conditions across the regions, in the (positive) neighborhood of $x_t = 0$. It follows from the condition $\theta^{G|SS} > \theta^{G|NSS} > \theta^{NSS} > \theta^{SS}$ that:

$$v_x^{G|SS}(0) < v_x^{G|NSS}(0) < v_x^{NSS}(0) < v_x^{SS}(0)$$

There are two important implications from these inequalities. First, ψ^{NSS} and ψ^{SS} are strictly positive, which means that $\overline{x_t} = \alpha x_t$ for small x_t. That is, since the pre- post-development financial constraint is binding, the country pledges as much of its reserves as possible. Second, and more importantly for our substantive argument, the last inequality implies that consumption drops at the sudden stop.

It turns out that, as we show in the next section, these two features of the solution carry over to most of the empirically relevant range of reserves.

3 Quantitative Analysis

In this section we estimate the main parameters of the model, calibrate others, and assess the optimal reserves strategy quantitatively.

3.1 The Sudden Stop Process

The core of our analysis is the sudden stop process. In this section we estimate the main parameters of such process: λ, $\widetilde{\lambda}$, and θ^{SS}/θ^{NSS}.

The first step is to find empirical counterparts for the processes describing available resources during NSS and SS. For this, we note that in the model these resources can be decomposed into income, κY_t, and financial flows, $(\theta_t - \kappa)Y_t$. In practice, there are several additional complexities in doing such decomposition. These stem from the existence of multiple goods whose relative prices change during the transitions between NSS and SS and viceversa, the presence of temporary terms of trade shocks, and endogenous domestic output declines during sudden stops. The Data Appendix describes our methodology to deal with these issues. In a nutshell, we approximate κY_t with the permanent component of domestic national income, and $(\theta_t - \kappa)Y_t$ with the sum of capital flows in terms of imported goods and the transitory component of exports and terms of trade effects. Our main left hand side variable is the ratio of these two, which can be loosely interpreted as external financing over "normal" pre-development income:

$$\psi_{it} \equiv \frac{\theta_{it}}{\kappa} - 1 = \frac{(\theta_{it} - \kappa)Y_{it}}{\kappa Y_{it}}.$$

The solid lines in Figures 1 and 2 illustrate the path of this variable for Chile (1976-2003) and Malaysia (1980-2002). We selected these two economies, one from Latin America and one from South East Asia, because their sudden stops, especially during the 1990s, were mostly exogenous to their actions.

In our model, ψ can take only two values: $(\theta^{NSS}/\kappa - 1)$ and $(\theta^{SS}/\kappa - 1)$. In actual data this stark characterization does not hold exactly, but Figures 1 and 2 show that the processes for ψ are naturally described by two regimes. It is this feature we seek to identify below and associate to the NSS and SS regimes. Note also that in the model $\psi > 0$ while in the data it takes negative values as well; this is just a matter of renormalizing (and reinterpreting) κY so it has not substantive meaning.

Let,

$$\widetilde{\psi}_{it} = \psi_i(s_{it}) + e_{it}(s_{it})$$

with

$$e_{it}(s_{it}) \sim N(0, \sigma_e^2(s_{it})), \qquad s_{it} \in \{SS, NSS\}.$$

Then $\widetilde{\psi}_{it}$ follows a process described by a standard regime-switching model a la Hamilton (1989, 1990), with parameters: $\{\psi_i^{NSS}, \psi_i^{SS}, \sigma_{e,i}^{NSS}, \sigma_{e,i}^{SS}, p_i(NSS \to SS), p_i(SS \to NSS)\}$, such that:

$$p_i(NSS \;\to\; SS) = \Pr(s_{i,t+\Delta} = SS | s_{i,t} = NSS) = 1 - e^{-\lambda_i \Delta} \tag{16}$$

$$p_i(SS \;\to\; NSS) = \Pr(s_{i,t+\Delta} = NSS | s_{i,t} = SS) = 1 - e^{-\widetilde{\lambda}_i \Delta} \tag{17}$$

where we have approximated the continuous time model by its discrete analog assuming that there can be at most one transition in a time interval of Δ.

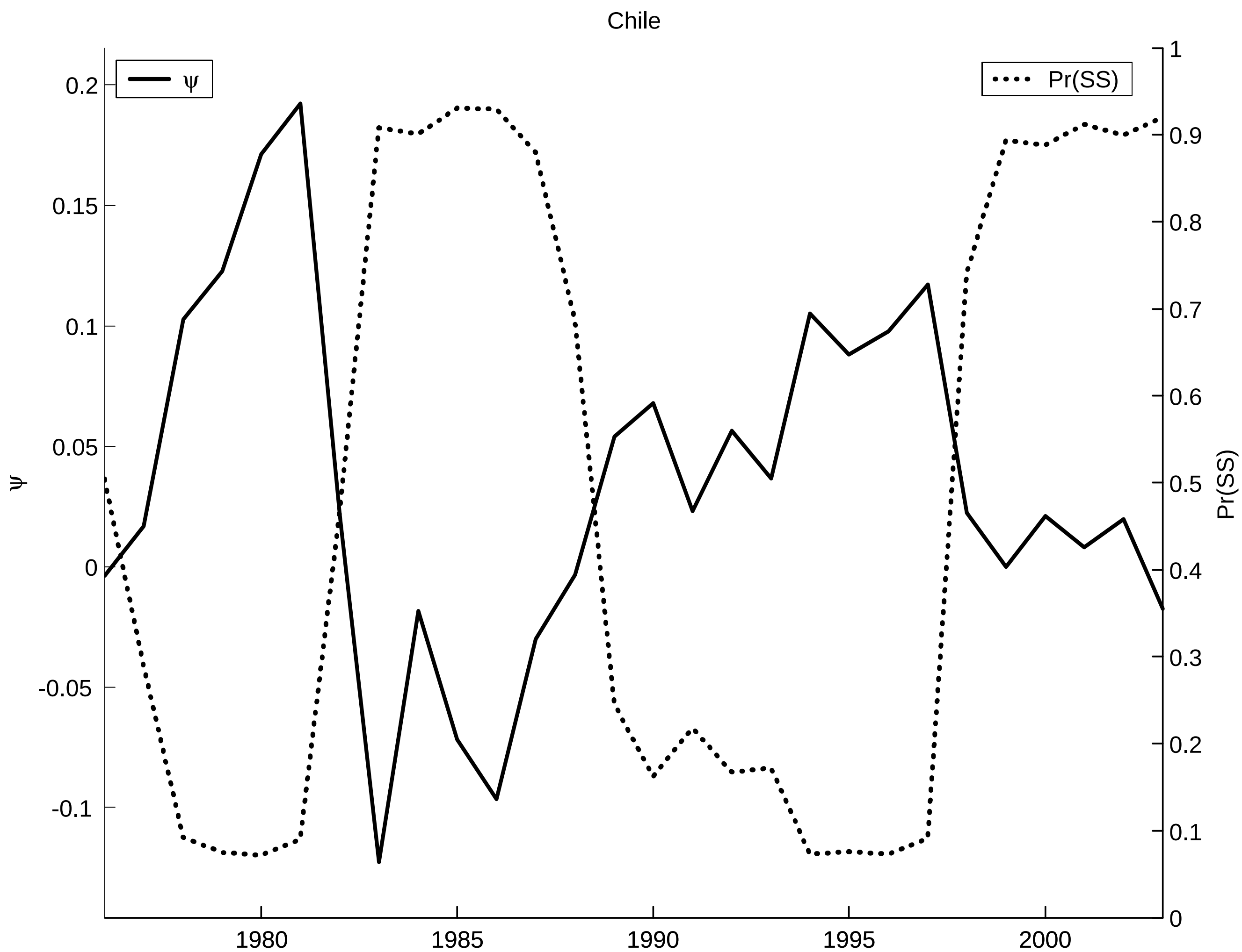

Figure 1: Chile: States

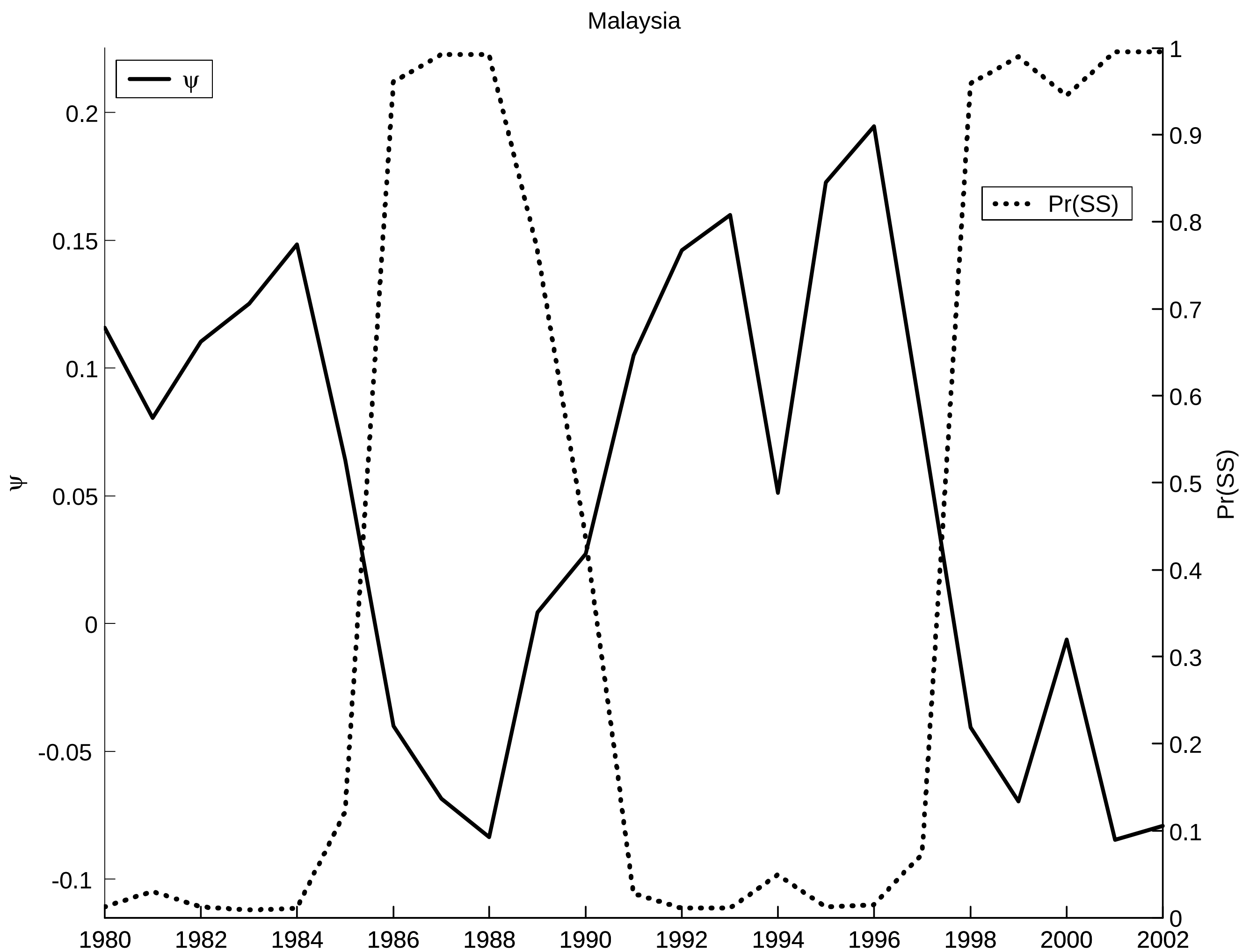

Figure 2: Malaysia: States

Given the limited number of SS observations we have for each country and the highly nonlinear nature of the hidden states model we are estimating, we use a robust Bayesian approach based on a Gibbs Sampler (see Kim and Nelson 1999). We describe the precise procedure in the Appendix, but the main steps are as follows:

- We fix arbitrary starting parameters.
- Conditional on these parameters, we filter the data using Hamilton's algorithm to find the posterior probability that at a given point in time the country is in a SS or in NSS.
- We draw a sample path from this joint distribution. Such a path takes the value 1 if the country is in a SS and 0 otherwise.
- We condition on this path and derive the joint posterior distribution of the parameters. Throughout we use uninformative priors.
- Finally, we draw a new set of parameters from this posterior distribution and iterate the procedure several times.

Tables 1 and 2 present the estimates we obtain form this procedure for the parameters $\psi_i^{NSS}, \eta_i \equiv \psi_i^{SS} - \psi_i^{NSS}, \lambda_i, \widetilde{\lambda}_i$. Note that from the first two parameters we can recover $\frac{\theta_i^{SS}}{\theta_i^{NSS}}$ since:

$$\frac{\theta_i^{SS}}{\theta_i^{NSS}} = 1 + \frac{\eta_i}{1 + \psi_i^{NSS}} \simeq 1 + \eta_i$$

The results confirm what the eye tells from the solid lines in Figures 1 and 2. Based on the medians, we conclude that sudden stops are large, leading to declines in available income beyond 10 percent, last for about 5 years and occur about every 10 years (about 5 years after exiting the previous sudden stop).

The dashed lines in Figures 1 and 2 show the corresponding output of the Gibbs sampler run for Chile and Malaysia. They illustrate the posterior probabilities that each country is in a sudden stop during a given period. There are two observations to make: First, the posterior probabilities are very close to 0 or 1 at all times, showing that each country has clearly identifiable transitions. Second, which will be useful later on in the paper, each country's transition into a sudden stop during the nineties is associated with well known events: the Asian crisis (for Malaysia) and the aftermath of the LTCM crisis (for Chile).

3.2 Other parameters

In addition to λ, $\widetilde{\lambda}$ and θ^{NSS}/θ^{SS}, which we set to be the average of those obtained for Chile and Malaysia, we also need to determine r, μ_Y, σ_Y, g, α, γ, $\theta^{G|SS}/\theta^{SS}$ and $\theta^{G|NSS}/\theta^{NSS}$ before simulating the model. r represents both the interest and the discount rate and we set it to 0.04, which is more or less the standard

Chile

	Mean	Median	5%	95%
ψ^{NSS}	0.0721	0.0735	0.0339	0.1055
η	-0.0880	-0.0952	-0.1269	-0.0179
$\widetilde{\lambda}$	0.3358	0.2139	0.0466	1.0213
λ	0.3577	0.2229	0.0576	1.1538

Table 1: Estimates for Chile.

Malaysia

	Mean	Median	5%	95%
ψ^{NSS}	0.1138	0.1145	0.0845	0.1402
η	-0.1607	-0.1619	-0.1945	-0.1242
$\widetilde{\lambda}$	0.2561	0.2034	0.0424	0.6295
λ	0.2394	0.2028	0.0592	0.5168

Table 2: Estimates for Malaysia.

value used in the RBC literature. We set the post-development growth rate μ_Y to 0.02, which is approximately the rate of growth of per-capita income in the US. We set $\sigma_Y = 0.05$, which is higher than the developed economies volatility in national income because emerging markets also have significant terms of trade fluctuations. The parameter g is set to 0.025, which matches the speed of convergence estimated by Barro and XalaMartin (199?). We set $\theta^{G|NSS}/\theta^{NSS}$ to 2, so that the expected rate of growth of income in an emerging market economy during normal times is:

$$\mu_Y + g \log\left(\frac{\theta^{G|NSS}}{\theta^{NSS}}\right) = 3.7\%$$

which is on the conservative end of an emerging market economy's expected growth during normal times. The parameter $\theta^{G|SS}/\theta^{SS}$ follows from the previous ones since:

$$\frac{\theta^{G|SS}}{\theta^{SS}} = \frac{r-\mu_Y}{g}\left(\frac{\theta^{NSS}}{\theta^{SS}} - 1\right) + \frac{\theta^{G|NSS}}{\theta^{NSS}}\frac{\theta^{NSS}}{\theta^{SS}}$$

As for γ, we choose a high level of 7. This ensures that the country wants to accumulate significant reserves despite facing a severe financial constraint with respect to transferring resources from the post- to the pre-development phase. Even in this context, it is hard to justify the current reserve management strategies followed by conservative emerging market economies.

Finally, we determine α from the conventional country-spread associated to the cost of holding reserves.[4]

[4] Often central banks think of this as the *only* opportunity cost of reserves. This is incorrect, as our analysis has shown.

Since our model has no debt, we need to find an implicit interest rate that can play the role of a spread. For this, we note that a higher α increases the incentive to hold reserves, which now have a higher collateral value, and hence earn a higher effective interest rate. To see this interpretation more formally, let us assume for simplicity that $\mu_Y = \sigma_Y = 0$, and that there are no sudden stops. In this case the dynamics of consumption are given by:

$$\frac{\frac{dc_t}{dt}}{c_t}|_{x_t=0} = -\frac{1}{\gamma}g\left(1-\alpha\right)\left(1-\frac{V_x^G(0)}{V_x^{NSS}(0)}\right) = -\frac{1}{\gamma}g\left(1-\alpha\right)\left(1-\frac{u'(\theta^G Y_t)}{u'(\theta^{NSS}Y_t)}\right) = -\frac{1}{\gamma}g\left(1-\alpha\right)\left(1-\left(\frac{\theta^{G|NSS}}{\theta^{NSS}}\right)^{-\gamma}\right)$$

where the second equality holds because a) the discount rate and the interest rate are equal post development and b) pre development the constraint $x_t = 0$ binds and hence $V_x^{NSS}(0) = u'(\theta^{NSS})$. Even though we have assumed that discount and interest rates are equal, this derivation shows that the pre- post-development financial constraint, and the chance that some of the reserves hoarded during pre-development end up being used in post-development, means the country faces a situation *as if* there were a spread between the (borrowing) rate (R) and the discount rate equal to:

$$R - r = g\left(1-\alpha\right)\left(1-\frac{u'^G(0)}{u'^{NSS}(0)}\right)$$

This reasoning motivates a choice of $\alpha = 0$, since this implies spreads close to 250 basis points which, with very few and recent exceptions, is on the low end of the spreads paid by emerging market economies.

3.3 Implications

We now proceed to quantify the implications of the model for parameters corresponding to the average of our estimates for Chile and Malaysia. Without loss of generality, we renormalize Y so that $\theta^{NSS} = 1$. This allows us to interpret all the quantities reported as a ratio of the quantity to the available resources during NSS. For example, c^{SS}, now represents $C^{SS}/\theta^{NSS}Y$ and x is $X/\theta^{NSS}Y$.

Figure 3 depicts the policy functions. The upper curve represents consumption during NSS and the lower one represents consumption during SS, both as a function of the level of reserves. The vertical distance between these two curves illustrates the instantaneous drop in consumption once the country transits into SS. In the neighborhood of 0 this drop is largest and around 9%, and it declines as the level of reserves rises. Because the drop is very large when the country has no reserves, precautionary savings is also maximum a this point, which is reflected in the difference between one and c^{NSS}.

Panels (a) and (b) in Figure 4, plot the paths of consumption and reserves, respectively, for a case where the country starts with 0 reserves, then a sudden stop takes place exactly at its expected time, $\frac{1}{\lambda}$, and the sudden stop lasts exactly its expected time, $\frac{1}{\lambda^{SS}}$. For clarity, we also set $dB_t = 0$ (in the path but not the value and policy functions). Early on, the consumption path is increasing and below one, as the country accumulates reserves, which it then uses during the sudden stop. The country's incentive to accumulate reserves is very steep initially and less intense once some reserves have been accumulated. Importantly, even though the sudden stop in this example takes place exactly at its expected time, there is a significant consumption drop at the time of the sudden stop, reflecting the imperfect nature of the reserves accumulation self-insurance mechanism.

The next two figures contain the distributions of the main quantities generated by the model, associated to a large number of paths in our economy. Recall that randomness stems from Y as well as from the transitions in and out of sudden stops. We start with a country that has 0 reserves initially and simulate 5000 paths for $T = 30$ years, without a transition into development.

Figure 5 displays the histogram of reserves available at the point in which the country enters a sudden stop. The possibility of a sudden stop leads to an accumulation of reserves between 10 and 18% in most cases. However it is critical to observe that there a significant mass concentrated at very low levels of reserves. This mass corresponds to those cases where the country has not had the time to accumulate reserves since the previous sudden stop. These early crises are an important source of risk, that reserves are particularly inefficient in dealing with.[5]

Figure 6 displays average consumption during NSS and SS. The average difference between consumption is large, around 8 percent. Moreover, often the country simply runs out of reserves during sudden stops and consumption falls by the full extent of the capital flow reversal.

In summary, these results raise the question of whether there are other ways to manage reserves that could increase their efficiency and avoid the risk that is associated with the unpredictability of sudden stops. We turn to this question in the next section.

4 Contingent Instruments

In practice, how much better could countries do by holding contingent instruments in their reserves? Obviously, the answer to this question depends on the specific factors behind a country's sudden stops and the financial markets available to hedge those specific factors. Our goal here is less ambitious. We simply want to illustrate, in a conservative scenario in terms of information and financial development requirements, the significant potential gains from improving current sudden-stop-risk-management practices by adding contingent instruments that are largely independent of the country's actions and, more generally, of factors exclusively related to emerging markets (and hence not appealing to world capital markets).

[5] In practice, countries often deal with this risk by not using reserves very aggressively during sudden stops, which is a clearly suboptimal strategy.

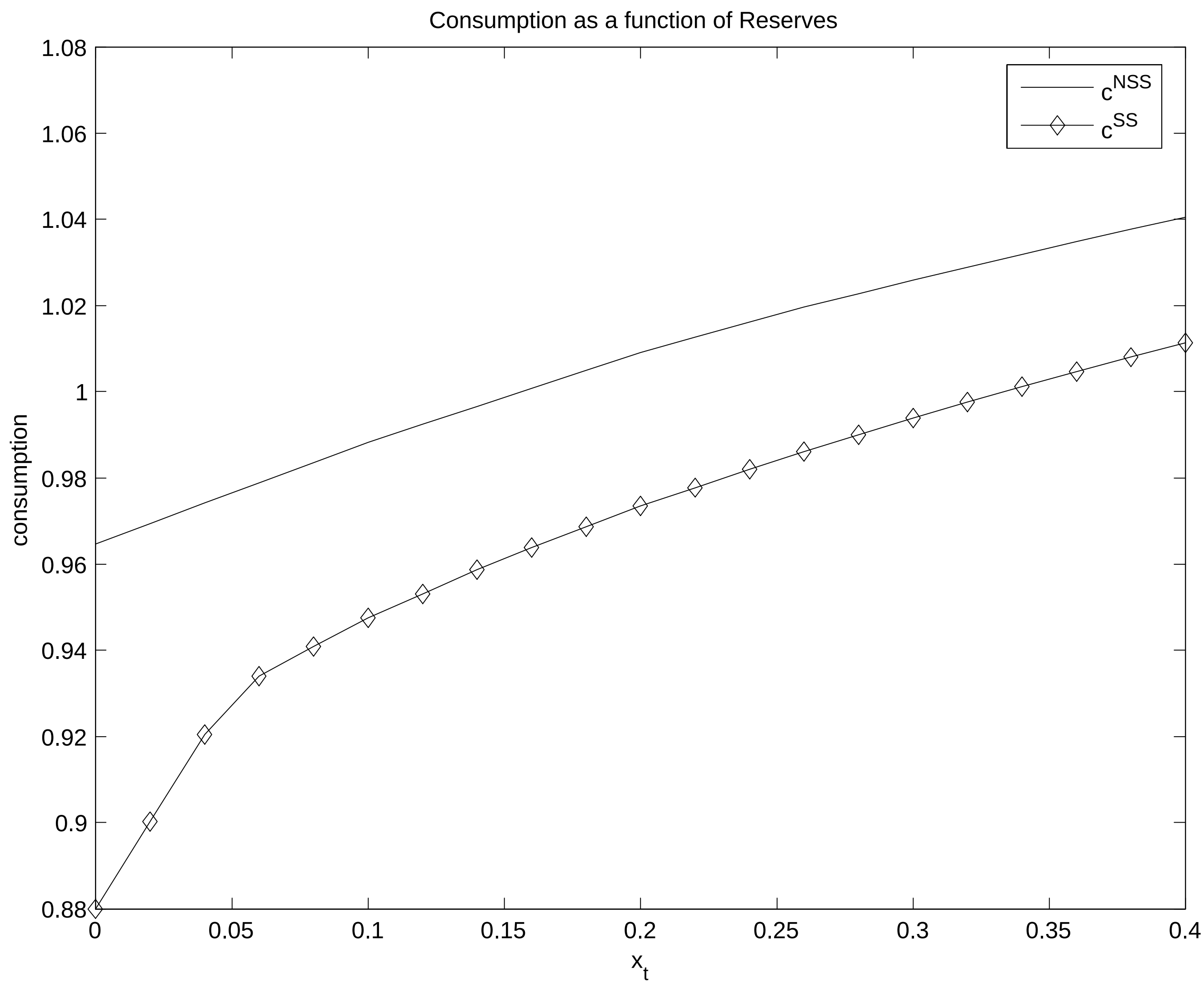

Figure 3: Consumption functions in NSS and SS

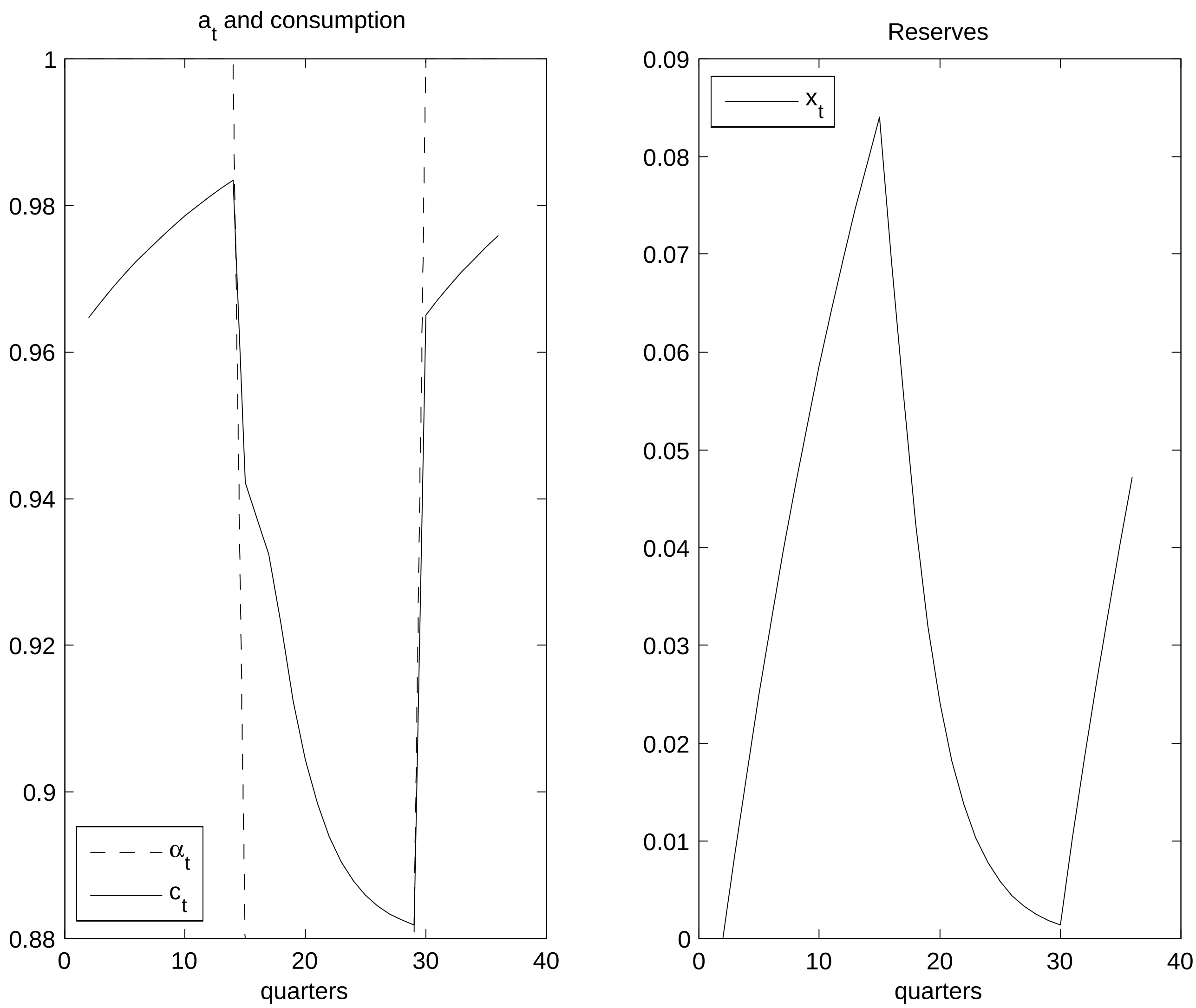

Figure 4: Typical path of consumption and reserves.

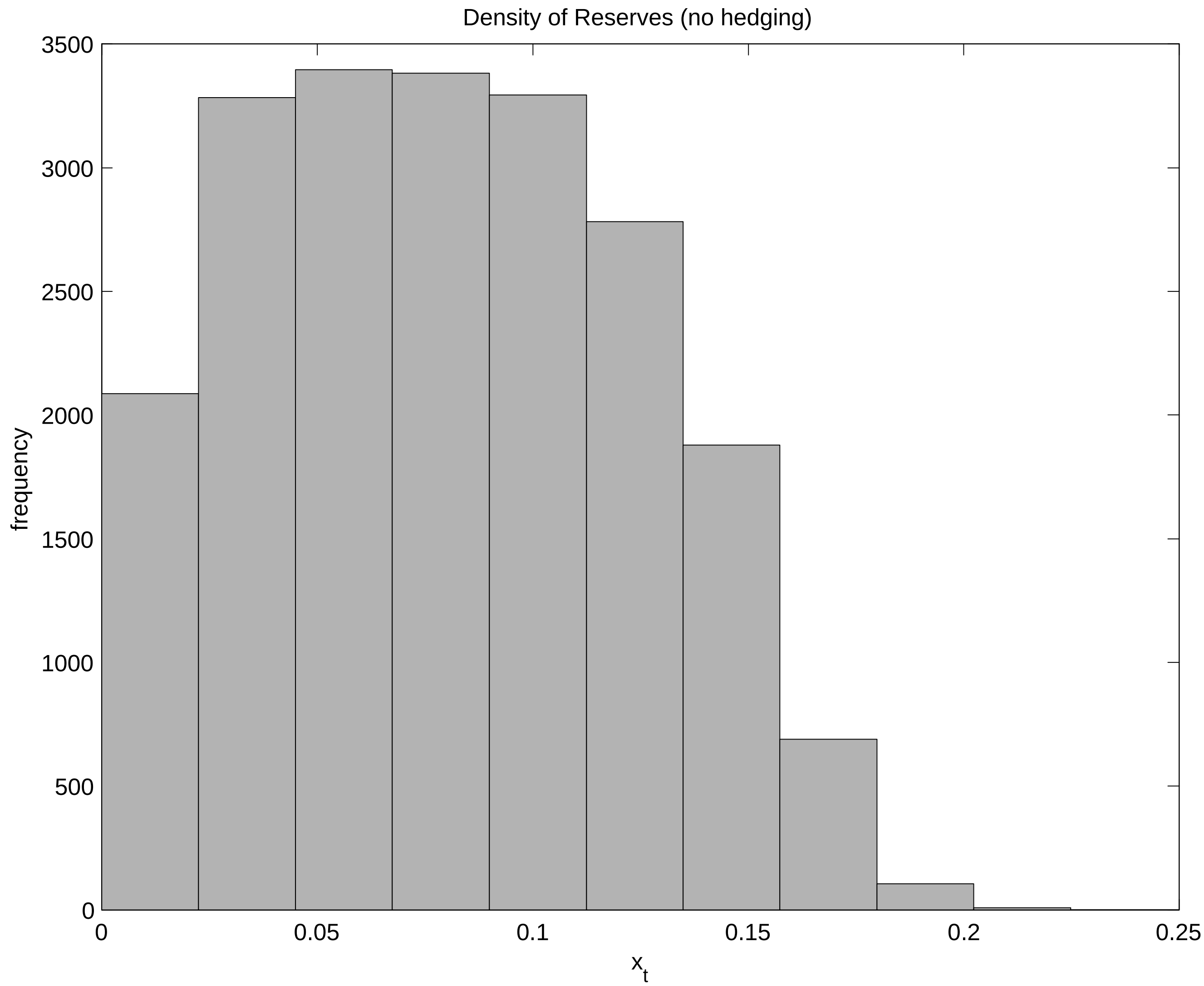

Figure 5: Distribution of Reserves immediately prior to SS.

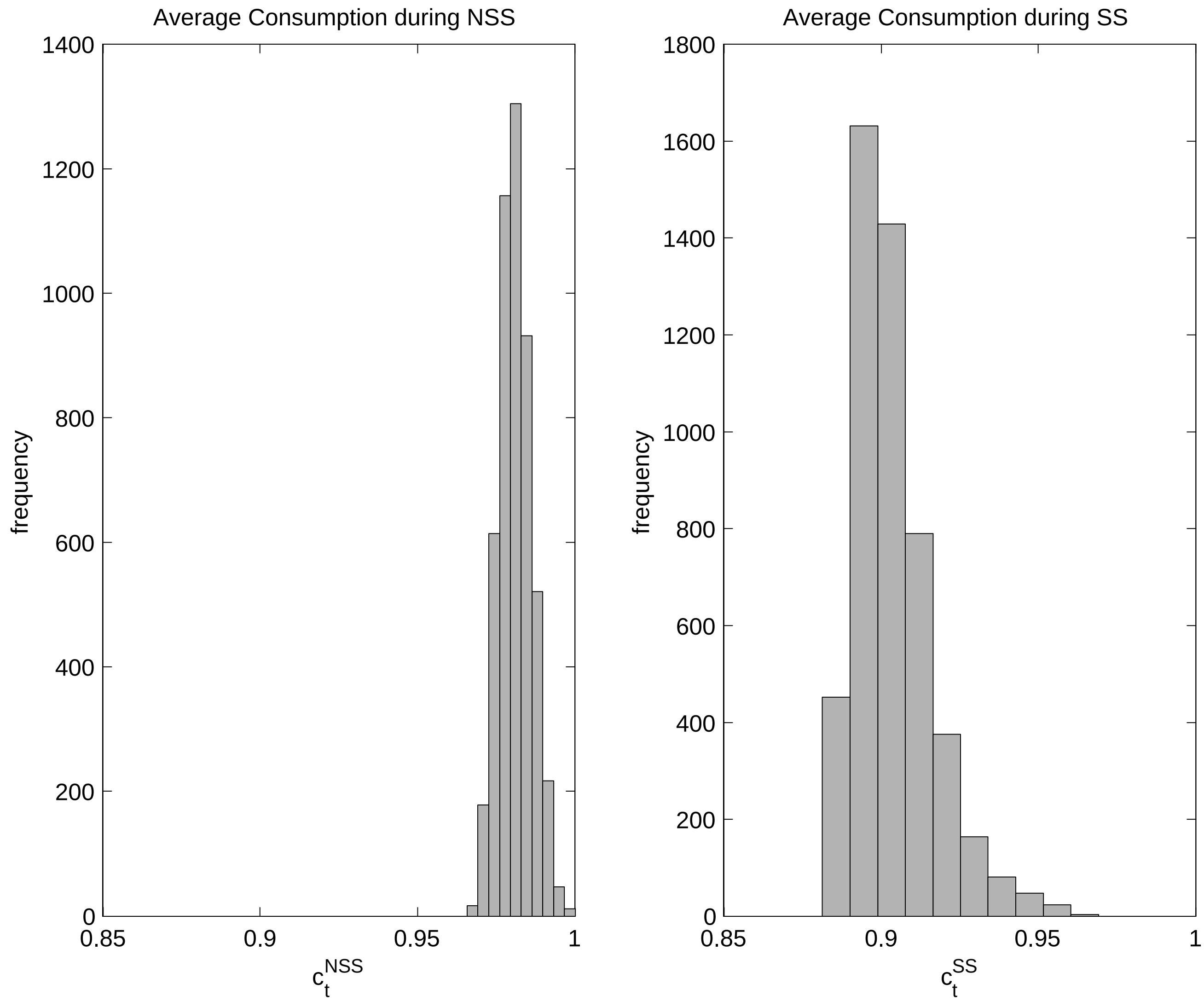

Figure 6: Average consumption during SS and NSS.

4.1 Portfolio decision

Before introducing additional assets, let us develop in more detail the events behind a transition into a sudden stop. It is useful to think of this transition in two steps. First, there is a Poisson process with intensity χ that puts the economy in a "danger zone" at stochastic times τ^D. Second, at τ^D, the country enters a sudden stop with probability $P_{\tau^D}(SS = 1)$ and avoids it with probability $P_{\tau^D}(SS = 0) = 1 - P_{\tau^D}(SS = 1)$. It is evident that,

$$\lambda = \chi P_{\tau^D}(SS = 1) \tag{18}$$

and that nothing in our analysis up to now is modified by this decomposition of events.

Let us now assume that there is a financial asset with payoff F_t, that also has the potential to exhibit a jump in "danger zones" τ^D, which we denote by ζ. When $\zeta = 1$ the asset's payoff exhibit a jump at τ^D, while $\zeta = 0$ denotes the absence of a jump at such time. Correspondingly, the probability of each event (conditional on τ^D) are denoted by $P_{\tau^D}(\zeta = 1)$ and $P_{\tau^D}(\zeta = 0)$, respectively. It follows that this jump process also follows a Poisson process with intensity:

$$\lambda_\zeta \equiv \chi P_{\tau^D}(\zeta = 1) \tag{19}$$

Note that sofar we have not excluded the possibility that the jump in the asset with payoff F_t is independent from the transition into the SS ($\Pr(\zeta = 1, SS = 1) = 0$)), although clearly our interest is in the case where:

$$\Pr(\zeta = 1, SS = 1) > 0$$

In what follows we condition on those times τ^D where we observe *either* a jump ($\zeta = 1$) *and/or* a transition into SS. This is without loss of generality, since (as we show shortly) the Bellman equation only depends on those events and not on situations where neither takes place. Hence from now on let us define:

$$\chi^* = \chi(1 - \Pr(SS = 0 \& \zeta = 0))$$

which is the hazard rate for observing either a jump in ζ or a transition into SS. An obvious corollary is that there are only three possible outcomes that can take place at those times $(SS = 1, \zeta = 1)$, or $(SS = 0, \zeta = 1)$, or $(SS = 1, \zeta = 0)$.

To complete the description of the data generating process we assume that once in a sudden stop, the transition out of it, which happens with intensity $\widetilde{\lambda}$, is independent of the jumps in ζ.

We can now write the risky asset's payoff process as:

$$dF_t = rF_t dt + F_t \left(\zeta dN_t - \chi\overline{\zeta} dt\right) \tag{20}$$

where dN_t is a jump process that takes the value of one at time τ^D and zero otherwise, and $\overline{\zeta} = P_{\tau^D}(\zeta = 1)$ is the mean of ζ. Correspondingly, the asset has a return $\frac{dF_t}{F_t}$.

The addition of this risky assets modifies the scenario without it in only two respects. First the evolution of reserves (6) becomes

$$dX_t = \left(r(X_t - \xi_t F_t) - c_t + g\overline{X}_t + a_t\right) dt + \xi_t dF_t$$

where ξ_t is the amount invested in the risky asset F_t. Second, the optimization problem now involves a portfolio decision.[6] This decision is straightforward in the post-development and sudden stops regions since investing in the asset F_t only means adding risk to the country's reserves holdings, without reward in terms of hedging value. Accordingly, the country picks $\xi_t = 0$ in these regions and the associated Bellman equations of section 2.3 remain unchanged.

Thus the portfolio decision is interesting only in the pre-development normal region (NSS), where the country is preparing itself for a potential sudden stop. Letting:

$$\xi_t = \frac{\widetilde{\xi}_t}{Y_t}$$

the Bellman equation in the NSS region is now:

$$\begin{aligned} 0 \quad = \quad & \max_{c_t}\left\{\frac{c_t^{1-\gamma}}{1-\gamma} - c_t v_x^{NSS}\right\} + \left(rx_t + \theta^{NSS}\right) v_x^{NSS} + \max_{\overline{x}_t \le \alpha x_t}\left(gv^G(x_t - \overline{x_t}) + gv_x^{NSS}\overline{x}_t\right) \\ & + \max_{\widetilde{\xi}_t}\left\{\chi^*\left[\sum_{i,j\in\{0,1\}} P_{\tau^D}(\zeta = i, SS = j | SS = 1 \text{ or } \zeta = 1) v^{SS1\{SS=j\}}(x_t + \widetilde{\xi}_t F_t 1\{\zeta = 1\})\right] - \widetilde{\xi}_t F_t \chi^* \overline{\overline{\zeta}} v_x^{NSS}\right\} \\ & -(r + \chi^* + g) v^{NSS} \\ & + \mu_Y\left[(1-\gamma)v^{NSS} - v_x^{NSS} x_t\right] + \frac{1}{2}\sigma_Y^2\left(-\gamma(1-\gamma)v^{NSS} + 2\gamma v_x^{NSS} x + v_{xx}^{NSS} x^2\right) \end{aligned}$$

where:

$$v^{SS1\{SS=j\}} = \begin{cases} v^{SS} \text{ if } SS = 1 \\ v^{NSS} \text{ if } SS = 0 \end{cases}$$

and

$$\overline{\overline{\zeta}} = E\left(\zeta | SS = 1 \text{ or } \zeta = 1\right)$$

The additional first order condition is:

$$\sum_{i,j\in\{0,1\}} \Pr(\zeta = 1, SS = j | SS = 1 \text{ or } \zeta = 1) v_x^{SS1\{SS=j\}}(x_t + F_t\widetilde{\xi}_t) 1\{\zeta = 1\} = \overline{\overline{\zeta}} v_x^{NSS} \qquad (21)$$

Notice that this is a standard Euler equation. Defining the rate of return on asset F_t as:

$$R = \frac{1\{\zeta = 1\}}{\overline{\overline{\zeta}}}$$

[6] Note that the constraint $X_t \geq 0$ still holds throughout. That is, consistent with the financial constraint, risky assets must be "purchased in advance."

and using the first order condition for consumption given in (11) we can rewrite (21) as:

$$E\left[\frac{u'(C_{\tau^{D+}})}{u'(C_{\tau^{D-}})}R|SS=1 \text{ or } \zeta=1\right]=1$$

where the expectation is taken at time τ^D but without knowledge of which of the three possible combinations of ζ and SS is about to materialize.

4.2 Implementation

The strategy described above assumes that the country and the world capital market can write a contract that is contingent on a jump in the price of a traded asset. It is not immediately obvious how to write such a contract. In this section we describe a practical way to create a contract that pays 1 if a traded asset exhibits a jump and 0 otherwise. Assume that there exists a state variable with dynamics:

$$dz_t = \mu_z dt + \sigma_z dB_t + \zeta_z dN_t$$

and that there exist call and put options that are written on this state variable. Fix first $\Delta, \varepsilon, \varepsilon_1 > 0$ and assume that the country goes long a call option with exercise price $z_t + \sigma_z\sqrt{\Delta} + \varepsilon$ and short a call option with strike price $z_t + \sigma_S\sqrt{\Delta} + \varepsilon + \varepsilon_1$. Such a scheme will pay ε_1 if $z_{t+\Delta} > z_t + \sigma_S\sqrt{\Delta} + \varepsilon + \varepsilon_1$ and 0 if $z_{t+\Delta} < z_t + \sigma_S\sqrt{\Delta} + \varepsilon$. Now suppose that such a scheme can be repeated N times, so that $\varepsilon_1 \to 0$ and $N\varepsilon_1 \to 1$. Then, one obtains in the limit a contract that pays 1 if $z_{t+\Delta} > z_t + \sigma_S\sqrt{\Delta} + \varepsilon$, and 0 otherwise. In simple terms, one obtains a "digital" option. Furthermore assume that we take Δ to 0, by considering contracts of very small maturity. Then we have a contract that will pay 1 if $z_{t^+} - z_{t^-} > \varepsilon$, i.e. if z_t exhibits a discontinuity larger than ε. If the distribution of ζ_S has a positive lower bound then taking ε to be that lower bound will provide us with a contract that has a payoff of 1 if there is a jump and 0 otherwise.[7] The payoff of such a strategy would then be equivalent to the payoff of an asset following the process in equation (20) and the analysis of the previous section follows.

It is important to note that the above argument is an approximation argument. We obtain a contract that delivers a payoff conditional on a jump as the limit of trading strategies with existing securities. From a practical perspective, creating a payoff that resembles a digital option from puts and calls is relatively straightforward. Investment banks are often willing to provide quotes for such contracts directly. The more subtle part of the argument is the limit as $\Delta \to 0$. In the econometric estimations that follow we therefore estimate the "correlation" between a contract that would have a payoff of 1 if $z_{t+\Delta} - z_t$ is larger than a fixed amount ε and Δ is taken to be a month.

[7] If the distribution of the jump has no lower bound then we can still obtain a payoff similar to the above with high enough probability as long as we set the "cutoff" ε low enough and $\Pr(\zeta_S > \varepsilon)$ is close to 1.

5 Quantitative Analysis

Our goal here is not to conduct a thorough search for the optimal risky instrument for specific countries' portfolios. Rather, we seek to illustrate the kind of properties that such instruments ought to have and their implications. With this purpose, we chose the CBOE Volatility Index (VIX). This is a traded index formed from quoted put and call options on the S&P 500, available since the late 1980s. This index extracts the "implied" volatility from the underlying options. Traders then can take positions in this index to implement hedges or speculate. In line with the model, this index is primarily driven by US and not emerging market events. Moreover, as we show below, sudden stops are highly correlated with jumps in the VIX. These two properties are key for useful and potentially liquid SS-hedging instruments.

5.1 The VIX Process

Let us postulate a continuous time process of the VIX, described by an Ornstein-Uhlenbeck with jumps:

$$d\log(VIX) = A\left(B - \log(VIX)\right)dt + \sigma_{VIX}dB_t + \left(\phi dN_t - \lambda_\zeta \mu_\phi dt\right)$$

Notice that this process is of the form considered in section 4.2. The first term captures the predictable component of the process, which plays no interesting role in what follows. For simplicity we shall take A, B, σ_{VIX} to be constant and ϕ to be a normal distribution with mean μ_ϕ and standard deviation σ_ϕ. The jump process dN_t takes the value 1 when a jump takes place and 0 otherwise. The parameter λ_ζ denotes the hazard rate for the jump process. Finally, note that the second and third terms in the process are martingale differences.

In estimation, we shall approximate the above process by its discrete time counterpart. The first step is to remove the predictable component, for which we estimate an AR(1) process for $\log(VIX)$ and focus on the residuals. These residuals are characterized by a mixture of normals:

$$z_t = \mu_{VIX}\Delta + \sigma_{VIX}\sqrt{\Delta}\varepsilon_{t+\Delta} + \phi_{t+\Delta}1\{J = 1\} \tag{22}$$

with $\mu_{VIX} \approx -\lambda_\zeta \mu_\phi \Delta$ and $1\{J = 1\}$ denotes an indicator that takes the value 1 if a jump takes place between t and $t + \Delta$, and $\left(\varepsilon_{t+\Delta}, \phi_{t+\Delta}\right)$ are i.i.d. Normal:

$$\begin{pmatrix} \varepsilon_{t+\Delta} \\ \phi_{t+\Delta} \end{pmatrix} \sim N\left(\begin{matrix} 0 \\ \mu_\phi \end{matrix}, \begin{matrix} 1 & 0 \\ 0 & \sigma_\phi^2 \end{matrix}\right)$$

The source of the approximation to the continuous time limit, is that the discrete approximation excludes the possibility of more than one jump in the interval Δ, which seems reasonable if we want to focus on relatively large and infrequent jumps and relatively small time intervals Δ.

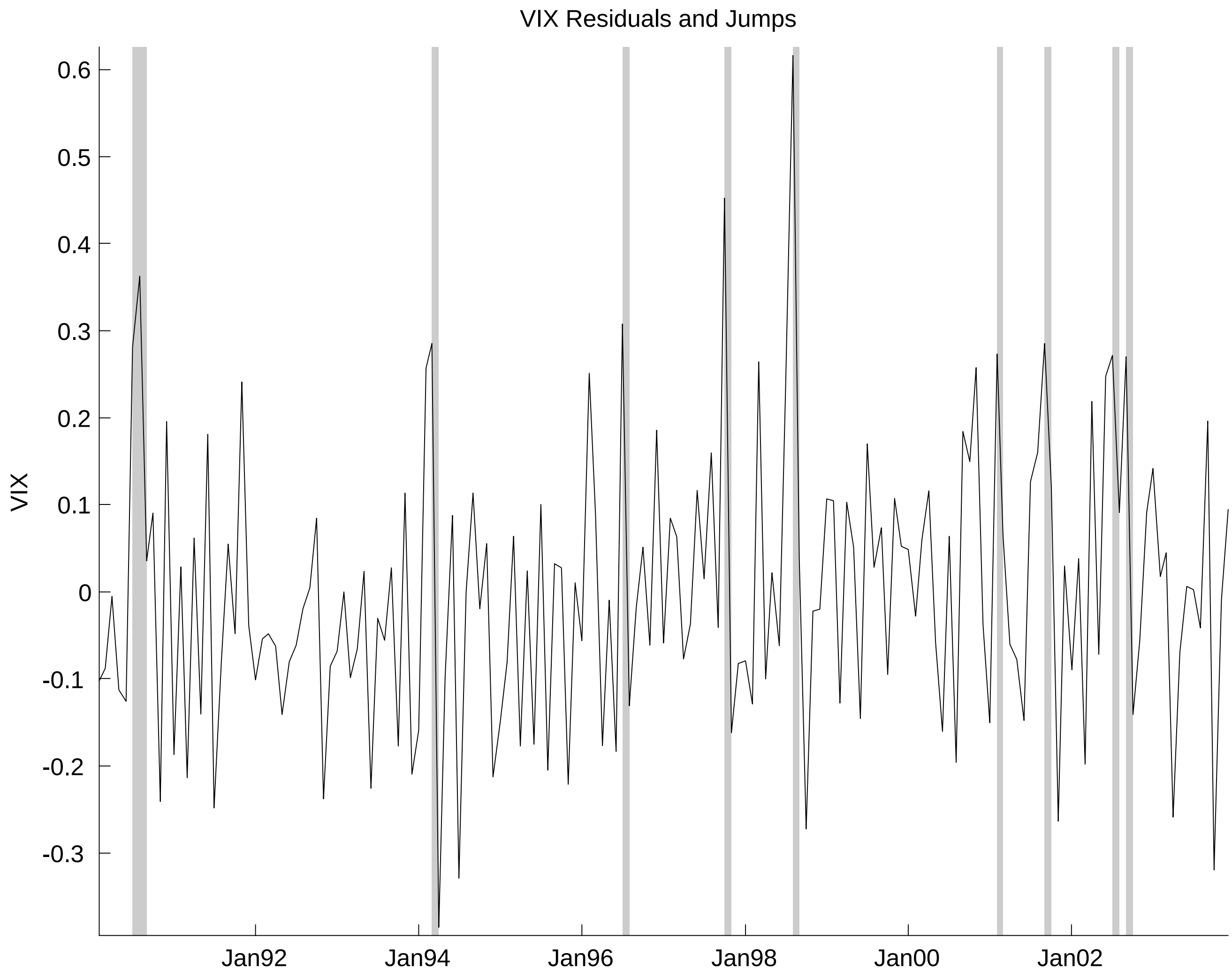

Figure 7: VIX residuals. The grey areas correspond to instances where the VIX is above x.

Note that (22) can be rewritten as:

$$z_t = (1 - p_{VIX})N(\mu_{VIX}\Delta, \sigma^2_{VIX}\Delta) + p_{VIX}N(\mu_{VIX}\Delta + \mu_\phi, \sigma^2_{VIX}\Delta + \sigma^2_\phi) \tag{23}$$

with $p_{VIX} = \Pr(J = 1) = 1 - e^{-\lambda_\varsigma \Delta}$.

In principle estimation can proceed from this point on along conventional jump-diffusion estimation (see, e.g., Caballero and Panageas (2004)). Instead of following this path, we adopt a strategy that is more directly linked to the implementation strategy described in section 4.2. We assume that the country can obtain contracts that pay off 1 unit if the change in the residuals of $log(VIX)$ is above 0.259. Note that this rule clearly selects the jumps, but there is also some noise from the diffusion component of z_t. However, the residuals-cutoff was chosen so that $Pr(z_t > 0.259|J = 0) < 0.01$.

Figure 7 shows the residuals of an an AR(1) model for log(VIX). The shaded areas represents those instances when this statistic is above x. The VIX exhibits significant jumps in the early 90's (at the onset of the gulf war) in 1997 (around the Asian crisis), in 1998 (around the Russian/LTCM crisis), after 9/11/2001, and around the beginning of the U.S. corporate scandals and the Argentinean default.

In terms of calibrating the model, we use this procedure to determine p_{VIX} , i.e. the probability that in a given month there is a residual larger than 0.259. The estimate of λ_ζ then is given by the relation:

$$1 - p_{VIX} = e^{-\lambda_\varsigma \frac{1}{12}} \tag{24}$$

Substituting the empirical probability $\widehat{p_{VIX}} = 0.0659$ we obtain our estimate $\lambda_\zeta = 0.818$ which we use in the simulations that follow.

5.2 Conditional Probabilities

The final step to be able to assess the benefits of hedging, is to find an estimate of the degree of correlation between jumps in the VIX and transitions into SS. In particular, we estimate

$$p_{J,SS} \equiv \Pr(J = 1 \& s_{t+\Delta} = SS | J = 1 \text{ or } s_{t+\Delta} = SS, s_t = NSS).$$

If this probability is zero, then the VIX and transitions into sudden stops are independent events. By contrast, if this probability is close to one the VIX is a perfect hedge.

We use a limited information procedure to estimate this parameter, described in the appendix. In essence, we first retrieve the path of the states associated to jumps in the VIX and transitions into SS from the corresponding Gibbs samplers (using the parameters estimated before on quarterly data data for the 1990s). Second, we update our (uniform - uninformative) prior on $p_{J,SS}$ by counting the number of times that the VIX jumps and the country transits from an NSS state into an SS state. Third, we condition on the NSS states and count the total number of jumps in the VIX and the transitions into SS from the NSS states.

	Mean	Median	5%	95%
Chile	0.29	0.20	0.05	0.47
Malaysia	0.36	0.25	0.06	0.55

Table 3: Posterior Distribution of $Pr\,(SS, J)$.

Fourth, we obtain a (beta) posterior distribution for $p_{J,SS}$, from which we sample to obtain the posterior mean and standard deviation of the stationary distribution of $p_{J,SS}$.

Now we can identify all the key parameters of the joint VIX and SS process, which can be recovered from the following relations:

$$\begin{aligned} \lambda_\zeta &\equiv \chi^* P_{\tau^D}(\zeta = 1 | NSS \to SS \text{ or } \zeta = 1\ ) = \chi^*\left(p_{J,SS}(i) + p_{J=1,SS=0}(i)\right) \\ \lambda &\equiv \chi^* P_{\tau^D}(SS = 1 | NSS \to SS \text{ or } \zeta = 1\ ) = \chi^*\left(p_{J,SS}(i) + p_{SS=1,J=0}(i)\right) \\ 1 &= p_{J,SS}(i) + p_{J=1,SS=0}(i) + p_{SS=1,J=0}(i) \end{aligned} \tag{25}$$

Thus:

$$p_{SS=1,J=0}(i) = \frac{1 - p_{J,SS}(i)\frac{\lambda_\zeta}{\lambda}}{1 + \frac{\lambda_\zeta}{\lambda}} \tag{26}$$

and

$$p_{J=1,SS=0}(i) = 1 - p_{J,SS}(i) - p_{SS=1,J=0}(i) \tag{27}$$

Hence the estimates of λ and λ_ζ that we obtained in sections 3.1 and 5.1, along with the estimate for $p_{J,SS}(i)$ obtained here, allow us to infer $p_{SS=1,J=0}(i)$ from (26) and $p_{J=1,SS=0}(i)$ from (27). Then χ^* can be determined from (25).

5.2.1 Implications

In this section we calibrate the model with the same parameters as the ones used in section 3.2. To provide a base case scenario we use the average (across the two countries) $p_{J,SS}$. Using the same λ as in section 3.2 and the λ_ζ obtained in 5.1 we can determine χ^*, $p_{SS=1,J=0}$ and $p_{J=1,SS=0}$ from the procedure described above and solve the model numerically.

For the same realizations in section 3.2, plus the corresponding realizations of simulated VIX processes, panel (a) in Figure 10 reports the difference in reserves at the time of the sudden stop between the contingent and uncontingent strategies, normalized by the average of the latter. The empirical mean of this distribution is 35 percent. This is a direct consequence of the efficiency of hedging compared to uncontingent reserve accumulation. By adopting the optimal hedging strategy the country manages to transfer more resources towards the states it is concerned with, namely the onset of a SS.

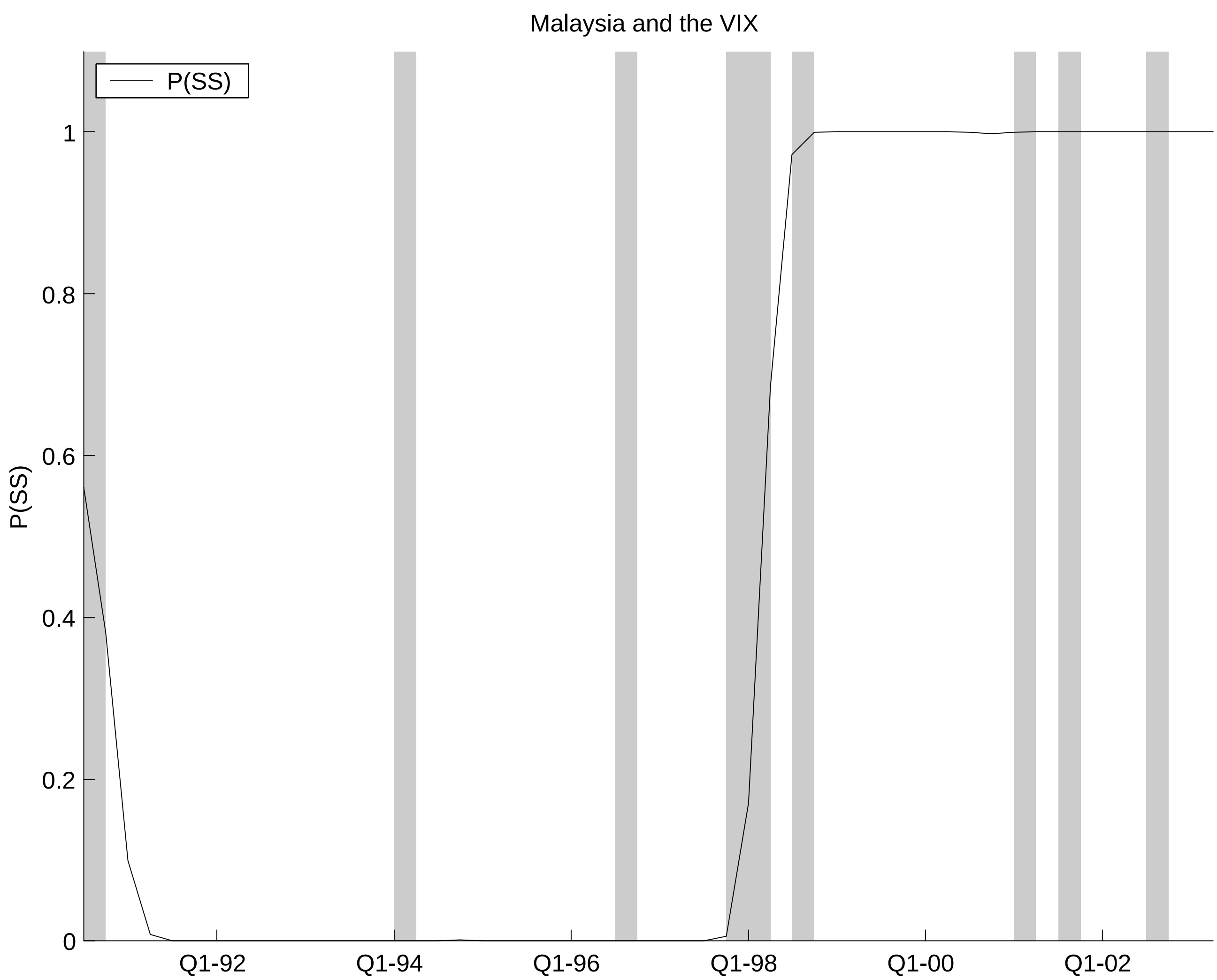

Figure 8: Posterior probabilities of being in a SS. Results for Malaysia

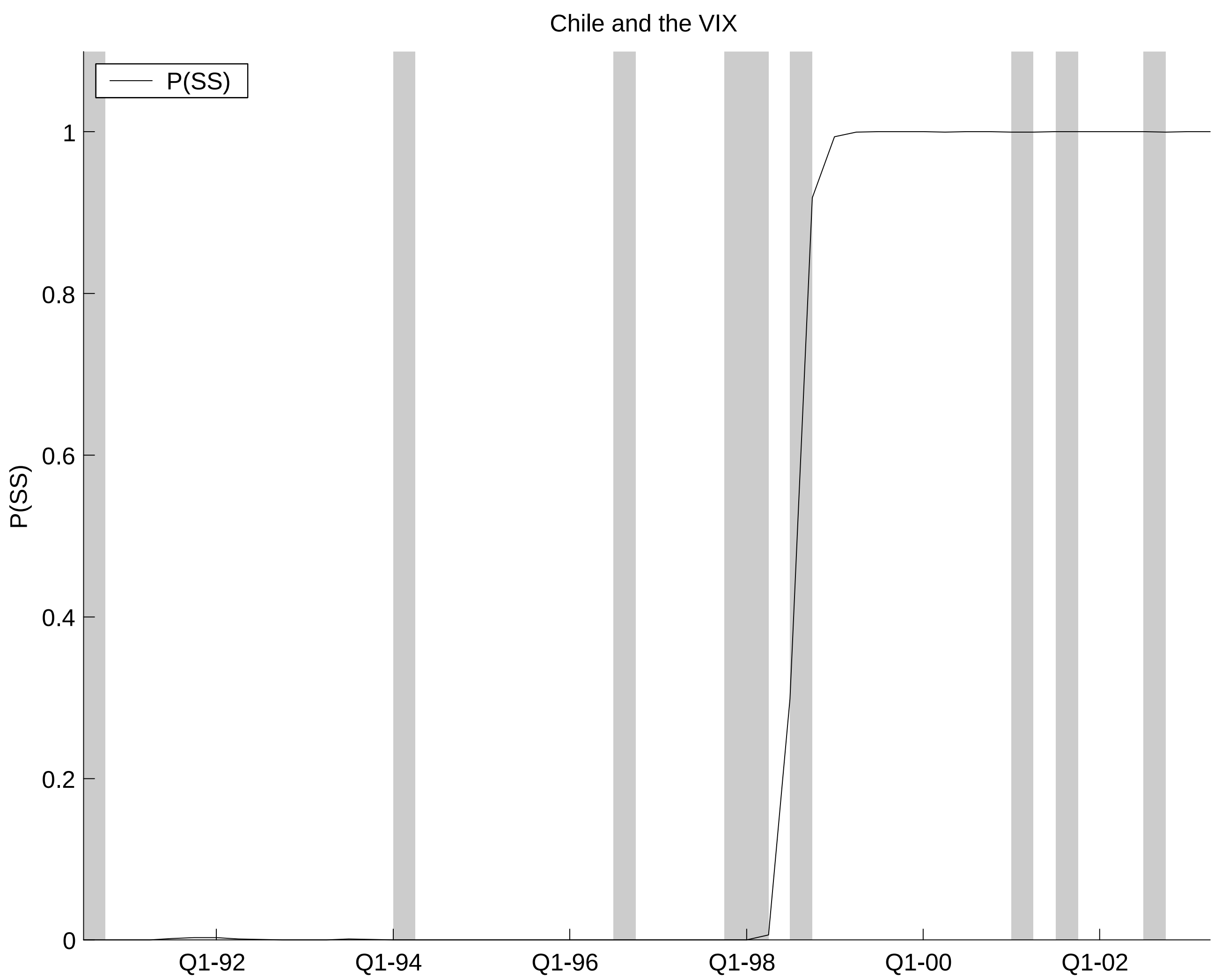

Figure 9: Posterior probabilities of being in a SS. Results for Chile

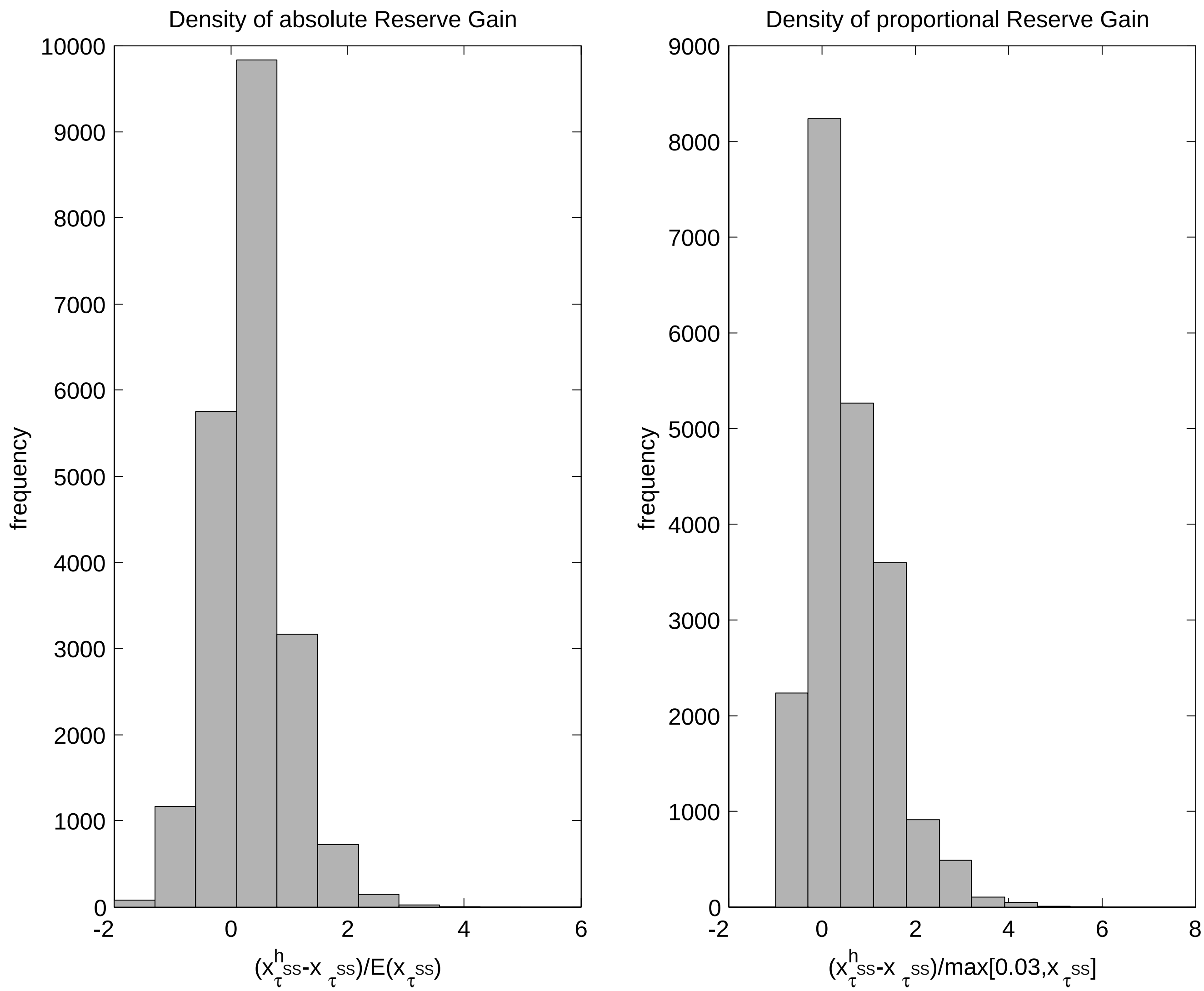

Figure 10: Reserves Gain (in absolute and proportional terms)

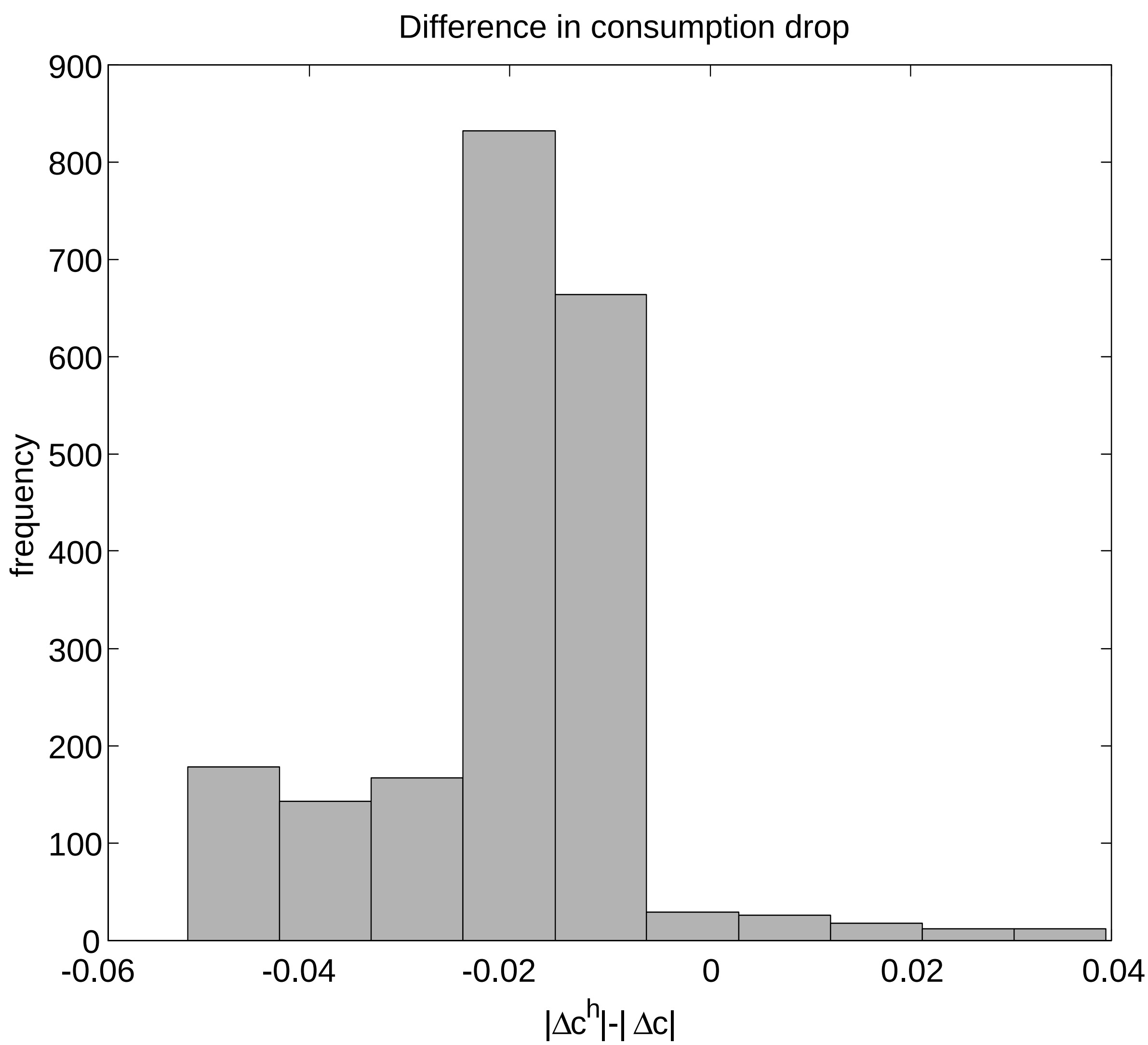

Figure 11: Difference in the magnitude of consumption drop upon entering the SS

However, the above distribution and its mean underestimates the benefits of hedging. It is apparent that it is much worse to have less reserves when there is little of them to start with (which is when the hedging strategy typically dominates by a wide margin), than to have fewer reserves when the country has had plenty of time to prepare for the sudden stop (which is when the unhedged strategy may do better). To capture this important asymmetry, panel (b) in figure 10 plots the histogram for:

$$\Delta x^R = \frac{x^h_{\tau^{SS}} - x_{\tau^{SS}}}{\max(0.03, x_{\tau^{SS}})}$$

This expression gives the relative reserves gain. We take the max in the denominator in order to avoid the few cases where the sudden stop happens when $x_t = 0$ and hence the country has not had time to accumulate any reserves. As might be expected the distribution of Δx^R is right skewed. The hedge performs especially well when the country has not had the time to accumulate uncontingent reserves. The median of this distribution exceeds 35 percent and its mean is over 55 percent. Moreover, in instances where the level of uncontingent reserves is low (lower quintile) and hence the cost of a sudden stop is high, the median gain exceeds 200 percent.

In terms of the drop of consumption at the instant of the sudden stop, the above difference translate into a median difference that exceeds 2 percent of maximum NSS-consumption and, as shown in Figure 11, has significant mass at drop-differentials twice as large as that.

Finally, we report the size of the optimal portfolio. Figure 12 displays the notional amount of contingent contracts normalized by reserves as a function of x_t. Two observations emerge from this figure: First, as a percentage of x_t, the amount invested in contingent contracts declines. Second, the country enters a large number of these contracts. For instance when $x = 0.05$, the country enters contracts that exceed these reserves by 20 percent. And when x is as large as 0.15, the contracts still exceed 40 percent of reserves. In terms of dynamics, these two observations mean that the country should first build the contingent part of the portfolio aggressively, adding uncontingent reserves only gradually.

6 Final Remarks

Emerging market economies hold levels of international reserves that greatly exceed the levels held by developed economies (relative to their size). This would seem paradoxical given that, unlike the latter, the former face significant financial constraints with much of their growth ahead of them. The paradox disappears once these greater financial constraints also become an important source of volatility, which countries seek to smooth. This is the context we have modelled, analyzed, and began to assess quantitatively.

Once such perspective is adopted, one must ask whether current practices, consisting primarily in accumulating non-contingent reserves, are the best countries can or should aim to do. How effective are reserves

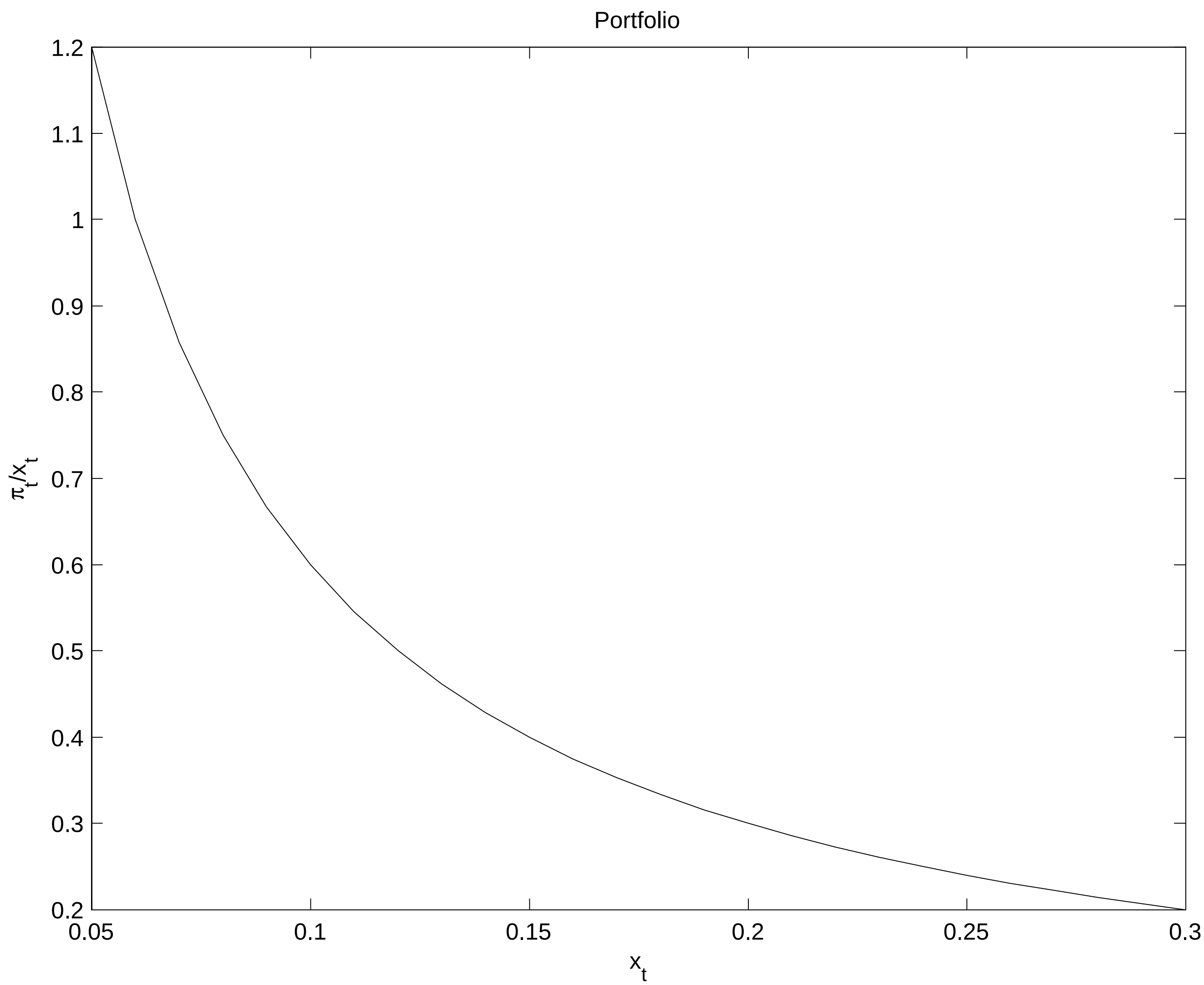

Figure 12: Notional amount invested in contingent instruments normalized by reserves.

in smoothing the impact of sudden stops unrelated to a country's actions? How much of them should be accumulated? How fast? Are there potentially less costly prudential mechanisms to deal with capital flow volatility? Who would be the natural counterpart for these mechanisms? How are these mechanisms limited by financial and collateral constraints?

Our framework provides aspects of an answer to each of these questions: Even if optimally managed, reserves offer limited insurance, should be accumulated at a slower pace and used more aggressively during sudden stops, than is being done by prudent emerging market economies. However, the most important message of the paper is that there are potential insurance contracts, credit lines and hedging markets, that could significantly reduce the cost and improve the efficiency of mechanisms to smooth sudden stops. The natural counterpart of these instruments and contracts are not the regular emerging market specialist investors but the world capital markets at large. This is an important consideration to have in mind when designing such instruments. The much touted GDP-indexed and peso-bonds, for example, while a natural and useful instrument to trade with specialists (in fact, our swaps with specialists are a form of the former bonds) are unlikely to appeal to the broad markets. Non-contingent reserves have a place as well, since in practice hedges are unlikely to be perfect, and overcommitting to an imperfect hedge comes with its own risks. It is clear, nonetheless, that there are enough verifiable and contractible global variables that are significantly correlated with sudden stops and should form the basis for a better contingent strategy. Importantly, the very same financial constraints that are behind these countries' troubles, limit the type and amount of insurance and hedging strategies these countries can engage in. In particular, since sudden stops are mostly times when specialists are constrained as well, the strategies must be such that require little credibility and commitment on the country side. This means, essentially, policies and investments that are paid (or collateralized) up-front rather than simple swaps of future contingencies.

Aside from the many stylized assumptions of the model, there are three substantive omissions that seem important to consider in future work. The first one is the absence of plain debt contracts or bonds . The second one is the lack of an aggregate demand mechanism that amplifies the decline in consumption following a sharp reduction in the current account deficit. The third one is the representative agent nature of the model, with a public and private sector working for each other.

We view the first omission as less limiting than it may appear as first sight. Debt, one way or the other, has always an element of contingency in it, especially when dealing with sovereigns. Thus, our swaps may not be that different from regular debt at the critical times that concern us. The flow of new capital, on the other hand, is mostly ex-post financing and hence much harder to insure implicitly. It is perhaps for this reason that debt variables have very little relation with costly sudden stops while large current account deficits (which require a flow of new financing) are feared by practitioners regardless of the country's indebtedness (for evidence on these see, e.g. Calvo et al (2004)). Our model is designed to isolate the current account problem. Of course, this does not mean that debt composition and levels are irrelevant considerations, but only that a significant share of the essence of the precautionary problem faced by emerging market economies can be captured in a model that removes the idiosyncrasies of debt.

The second omission is quantitatively important but not too hard to incorporate into the analysis in a straightforward manner. In a sense, our empirical implementation of the model already considers some of these amplification effects since it counts as part of the sudden stop the early face of the recovery where capital flows could be brought back but the country is still regaining its dynamism. We also have done preliminary explorations of this issue adding a nontradable sector. In some instances this can nearly double the cost of sudden stops.

The third omission is an important one. In practice many, if not most, of the actions by central banks and governments on this regard are attempts to induce their private sectors to adopt precautionary measures that they are not naturally inclined to follow. Optimal central bank reserve management strategies need to consider the positive and negative reactions that the anticipation of such policies induce in their private sector (see, e.g. Caballero and Krishnamurthy (2003)).[8] We intend to explore decentralization issues in future work.

[8] And, of course, problems may also run counter, with private sector actions facilitating imprudent behavior by the government.

Series	**Source**
Nominal GDP (GDP)	World Development Indicators (quarterly and annual)
CPI (P)	IFS (quarterly and annual)
Nominal Exports ($P_X X$) (local currency)	World Development Indicators and IFS (quarterly and annual)
Nominal Imports ($P_M M$) (local currency)	World Development Indicators and IFS (quarterly and annual)
Real Exports (X) (local currency)	World Development Indicators (annual)
Real Imports (M) (local currency)	World Development Indicators (annual)
Nominal Capital Flows (CF) (dollars)	IFS (quarterly and annual)
Nominal Exchange Rate (E)	World Development Indicators and IFS (quarterly and annual)
Net Factor Payments (NFP) (dollars)	IFS (annual)

Table 4: Data used in the construction of ψ.

7 Appendix

A Data

The VIX is publicly available from the CBOE on a daily frequency. For an introduction to the construction of this index, see CBOE (2003). We used monthly frequency in order to smooth spurious daily volatility.

For the construction of ψ_{it}, we used data from the World Bank's World Development Indicators Database, and from the International Monetary Fund's International Financial Statistics (IFS). Table 4 presents a list of the variables and corresponding sources.

While in the model ψ is straightforward, in the data its computation is more cumbersome since there are multiple goods, exchange rate fluctuations, intermediate goods, and so on. All our steps below are aimed at isolating in ψ the component of external resources and income which is transitory in nature. For this, we let:

$$\psi_t = \frac{(\theta_t - \kappa)}{\kappa} = \frac{\frac{E_t CF_t}{P_{M,t}} + \left[\left(\frac{P_{X,t}X_t}{P_{M,t}} - 0.5X_t\right)\right]^{Cycle}}{[N_t]^{Trend} + \left[\left(\frac{P_{X,t}X_t}{P_{M,t}} - 0.5X_t\right)\right]^{Trend}}, \tag{28}$$

where N and X correspond to real nontradables and exports; P_X and P_M to export and import prices in local currency; and E and CF to the nominal exchange rate and capital flows.

Real nontradeables are constructed from:

$$N_t = \frac{1}{P_{N,t}} \left(GDP_t - (P_{X,t} - 0.5P_{M,t})X_t\right)$$

where GDP is the country's GDP, $P_{N,t}$ is the price of nontradables approximated by the local CPI, and the term $0.5P_{M,t}$ removes a proxy for intermediate inputs in export-production. The expression $\left(\frac{P_{X,t}X_t}{P_{M,t}} - 0.5X_t\right)$ captures the terms of trade effect.

We decompose between trends and cycles using a standard Hodrick-Prescott filter; extending the series as much as we could in order to reduce the effect of the end-of-series bias in this procedure. We applied the filter the log of the corresponding variable.

In summary, the denominator in equation (28) measures the average (trend level) of total income and resources, while the numerator attempts to capture the cyclical component of *external* resources.

We made one more adjustment to the data. In the case of Chile, the cycle around the debt crisis is significantly larger than that of the 1990s. Thus in a first stage we standardized the 1980s and 1990s in order to estimate the hidden-states and the transition probabiblities. After that, we inverted the standardization to recover the means of each state in each sub-sample. We report the mean of these two sets of values in Table 1.

Finally, we constructed quarterly series for ψ_t using a related series approach with quarterly data on capital flows. We restrict the average of the quarterly values to be equal to the annual figure we computed directly using equation (28).

B Details on the econometric procedure of Sections 3.1, 5.1, 5.2

Section 3.1: To estimate the process described in this section we apply a Bayesian methodology, by using a Gibbs Sampler. The Gibbs Sampler is by now a standard methodology in estimating models involving hidden states (See Kim and Nelson [1999] for an introductory treatment). The basic idea is to exploit knowledge about the conditional distribution of one parameter at a time (fixing all the others) to construct the joint posterior distribution of all parameters. The first step of the procedure is to fix a set of intial parameters $\Phi = \{\psi_i^{NSS},\, \psi_i^{SS} - \psi_i^{NSS},\, \sigma_{e,i}^{NSS},\, \sigma_{e,i}^{SS},\, p_i(NSS \rightarrow SS),\, p_i(SS \rightarrow NSS)\ \}$ and then determine the posterior probabilities that a particular realization of $\widetilde{\psi}_{it}$ was drawn from the first (NSS)or the second (SS) distribution. To do that we run a standard Hamilton type filter (1989,1990) as described in Kim and Nelson (1999). This allows us to determine a sequence of posterior probabilities that a given realization of the data was drawn from the second (SS) normal distribution. We shall denote this as $\Pr(SS = 1|\widetilde{\psi}_i; \Phi)$. In the next step we draw an (artificial) sample of 1's and 0's from these posterior probabilities. In a next step we take these 1's and 0's as given. Effectively this allows us to proceed *as if we knew* whether an economy is in SS or not. In a next step we use this information to determine the posterior distributions of the elements of Φ. Once again we do this in steps as described in Kim and Nelson (1999). To facilitate the updating we use conjugate priors: a) a beta prior for $p_i(NSS \to SS)$, $p_i(SS \to NSS)$ with $\alpha = \beta = 1$ which coincides with a uniform prior on $[0, 1]$ b) an (improper) normal prior for ψ_i^{NSS} and an (improper) inverse gamma prior for $\left(\sigma_{e,i}^{NSS}\right)^2$ that lead to posteriors that depend only on the data (see Kim and Nelson (1999)) c) a truncated (improper) normal and an inverse (improper) gamma prior for $\psi_i^{SS} - \psi_i^{NSS}$, $\left(\sigma_{e,i}^{SS}\right)^2$ as explained in Kim and Nelson (1999). Finally, we assume that all priors are independent of each other. By well known results in Bayesian Statistics the posterior distributions are in the same class as these conjugate priors. Moreover there are simple closed form expressions for the parameters of the posterior distributions. This allows us to determine the posterior distribution of the parameters (one at a time), and then iterate the procedure until we converge to a (joint) stationary distribution of all the parameters (and the states) involved.

Section 5.1: In order to choose the cutoff point x we proceeded as follows. First we estimated a mixture of normals distribution for z_t which is a standard mixture of normals. Having an estimate of the p_{VIX}, μ_{VIX}, σ^2_{VIX}, μ_ϕ, σ^2_ϕ, we then proceeded to determine the cutoff in the same way that one would proceed in hypothesis testing. Namely, given our estimate of μ_{VIX}, σ^2_{VIX} we set the threshold x high enough so that:

$$P(z_t > x|J = 0) < 1\%$$

In statistical terms this would correspond to the "size" of a test that would (wrongly) accept the hypothesis of a jump with probability less than 1%. We then estimate λ_ζ from the interarrival times between two observations (z_t) larger than c using MLE.

Let us reiterate that we adopt this procedure in order to be able to assess the performance of realistic hedging contracts. We also tried an alternative approach in order to determine λ_ζ and $p_{J,SS}$ jointly: We ran a Gibbs Sampler to determine p_{VIX}, μ_{VIX}, σ^2_{VIX}, μ_ϕ, σ^2_ϕ and the posterior probability of a jump in z_t. Subsequently we used the estimate of p_{VIX} to determine λ_ζ. In a next step we sampled (jointly) from the posterior distribution of the states of $\widetilde{\psi}_i$ in section 3.1 and the posterior probabilities of a jump in the VIX to determine $p_{J,SS}$. Under either procedure we obtained similar results. We adopt the first procedure because it is the more conservative of the two and is closer to how such contracts would be implemented in practice.

Section 5.2: The procedure to determine a distribution of $p_{J,SS}$ proceeds as follows. We first sample a path from the posterior distribution of the states (NSS, SS) at each repetition of the Gibbs Sampler, as described in section 3.1. Since data on z_t are available monthly, whereas data on $\widetilde{\psi}_{it}$ are available quarterly, we determine first all those times where the states switch from NSS to SS and simultanously there is a jump in the VIX either in that quarter or the quarter before. Let this number be given by $n_{SS,J}$. Similarly, we also determine all the times when there was either a jump in the VIX *or* a transition into SS. Let this number be $n_{SS \text{ or } J}$. Assuming then a uniform prior on $p_{J,SS}$ it follows that its posterior has a beta distribution with characteristics $(n_{SS,J} + 1, n_{SS \text{ or } J} + 1)$. It is interesting to note that the posterior mean of this distribution concides for a large number of observations with $\frac{n_{SS,J}}{n_{SS \text{ or } J}}$. From this distribution we sample $p_{J,SS}$ at each repetition of the Gibbs sampler and report the posterior mean and the posterior standard deviation of the stationary distribution of this variable.[9]

C Details on the numerical procedure

To solve the model numerically, we proceeded as in Kushner and Dupuis (2001). The procedure is explained in great detail in Section 5.2 of that book and hence we only provide a sketch. The basic idea is to approximate the derivatives in all Bellman equations by discretizations. This way one can reexpress the value function at each point as an appropriately probability weighted average of the value function evaluated at *neighboring* points in the state space. That way the discretized version of the Bellman equation coincides with the solution to a particularly simple dynamic programming equation in discrete time, where the processes can only transit to neighboring states. For the exact formulas of the transition probabilities as well as the treatment of jumps we refer the reader to Kushner and Dupuis (2001) Ch. 13.2. Once this simple markov chain has been determined, determination of the Value function can proceed by the standard value function iteration procedure.

[9] For simplicity we don't use $p_{J,SS}$ when we update our posteriors about the states. Simply put, the updating is done in a univariate fashion for both series. This biases the results slightly against hedging, because it effectively filters the data as if $p_{J,SS} = 0$. This is done both for simplicity and in order to provide conservative estimates.

(INCOMPLETE)

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