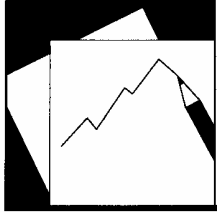


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Debt Crises and the Development of International Capital Markets

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International Capital Markets Department

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Abstract

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Crises on external sovereign debt are typically defined as defaults. Such a definition accurately captures debt-servicing difficulties in the 1980s, a period of numerous defaults on bank loans. However, defining defaults as debt crises is problematic for the 1990s, when sovereign bond markets emerged. In contrast to the 1980s, the 1990s are characterized by significant foreign debt-servicing difficulties but fewer sovereign defaults. In order to capture this evolution of debt markets, we define debt crises as events occurring when either a country defaults or its bond spreads are above a critical threshold. We find that our definition outperforms the default-based definition in capturing debt-servicing difficulties and, consequently, in fitting the post-1994 period. In particular, liquidity indicators are significant in explaining our definition of debt crises, while they do not play any role in explaining defaults after 1994.

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I. INTRODUCTION

What is a debt crisis? The literature has so far paid little attention to the definition of a debt crisis in the context of foreign lending. Instead, most studies typically assume that sovereign defaults are the most relevant credit events for foreign debt contracts. As a result, a large body of work has focused on the determinants of default risk.

Sovereign defaults are not, however, the only possible outcome of serious foreign- debt-servicing difficulties. For instance, the period starting with the Mexican “crisis” in 1994–95 has been characterized by turbulent sovereign debt markets and substantial IMF assistance to a number of countries. Yet, according to Moody’s (2003) only seven rated sovereign bond issuers have defaulted on their foreign-currency denominated bonds since 1985 and all of those defaults happened between 1998 and 2002. The surprisingly low number of sovereign bond defaults by emerging market sovereign borrowers is in contrast to the numerous defaults on bank loans in the 1980s.

In this paper, we argue that defining debt crises as sovereign defaults overlooks the development of international capital markets and notably the advent of the bond market for emerging market sovereign issuers. We show how sovereign defaults have become a less sensitive indicator of debt-servicing difficulties and suggest an alternative definition of debt crisis which takes into account turbulence in emerging bond markets.

More precisely, we define debt crises as events when either there is a sovereign default or secondary market bond spreads are higher than a critical threshold. In practice, market participants often view sovereign bond spreads above the 1,000 basis points (10 percentage points) mark as signaling a significant probability of default. Using extreme value theory as well as kernel density estimation, we also find that the 1,000 basis points threshold corresponds to significant tail events.

More formally, we assume that foreign-debt-servicing difficulties can be represented by an unobservable latent variable. Indicators such as sovereign defaults or our proposed market-based measure can, however, be used to infer the seriousness of such debt-servicing difficulties. Using a definition which incorporates information from sovereign bond markets enables us to overcome the data limitation associated with the dearth of defaults in the 1990s.

We also find that typical determinants of debt-servicing difficulties—solvency and liquidity measures, as well as macroeconomic control variables—explain better our definition of debt crises. In contrast, typical models of debt-servicing problems fail to explain debt crises when they are defined solely as defaults, especially in the period after 1994. In particular, liquidity indicators are significant in explaining our definition of debt crises although they do not play any role in explaining defaults after 1994.

The rest of the paper is organized as follows. We review the literature in Section II and in particular ask the question what exactly are debt crises. In Section III, we propose an alternative model of sovereign debt crises based on secondary bond markets. In particular, we

motivate our measure using a theoretical model and a number of statistical methods. In section IV, we estimate our model and compare its out-of-sample performance with models defining debt crises as defaults only. Section V concludes.

II. REVIEW OF LITERATURE

What is a sovereign debt crisis or alternately what is a credit event for a sovereign borrower or creditor? Strictly speaking, a breach of anyone of the bond or loan covenants is a “technical default,” which triggers a renegotiation process. In practice, however, the focus is on payments of interest and principal and on debt restructuring events. The literature has so far paid little attention to the definition of a debt crisis in the context of foreign lending and has instead typically assumed that the relevant sovereign credit event is a sovereign default. As a result, a large body of work has focused on the determinants of default risk.

In most theoretical studies of foreign debt crises, a credit event is defined as a non-repayment of pre-agreed debt service (Sachs, 1984). In addition and in the context of domestic nominal government debt, a sovereign credit event can occur through surprise inflation (Calvo, 1988, and Alesina, Prati, and Tabellini, 1990).

Episodes of foreign debt servicing difficulties in the 1980s in Latin America and Africa have led to a number of studies on the determinants of sovereign default risk (see McDonald and Donough (1982), Edwards (1984), and Eichengreen and Mody (1998, 1999) among others).

A common empirical methodology consists in using spreads between the interest rate charged to a particular country and a benchmark as a proxy of the probability of default of a particular country (see Edwards (1984) for instance). Alternately, it is possible to back out the probability of default from spreads (see Edwards, 1984), Duffie and Singleton, 2003, or credit default swaps (Chan-Lau, 2003).

Another method prefers to use credit ratings as a proxy of the probability of default (Schmukler, 2001). Rating downgrades are therefore perceived as an increase in the probability of defaults. Some authors have focused on the intensity of rating actions by international rating agencies such as Juttner and McCarthy (1998) who study “rating crises.” It is also possible to back out the probability of default from an estimated transition matrix of sovereign ratings such as in Hu, Kiesel and, Perraudin (2001).

The relevance of sovereign debt variables in explaining financial crises other than debt crises or events that may associated with credit events has also been studied. In Radelet and Sachs (1998) and Rodrick and Velasco (1999), large reversal of capital flows are seen as relevant events, whereas in Frankel and Rose (1996), Milesi-Ferretti and Razin (1998), Berg and Pattillo (1999), and Bussière and Mulder (1999) currency crises are considered to be important. In addition, Reinhart (2002) studies the relationship between default and currency crises.

But what is a relevant sovereign credit event? Recently, there has been a growing literature aiming at defining sovereign credit events as debt crises, more specifically foreign debt crises.

A. What Is a Debt Crisis?

Debt Crises as Sovereign Defaults

Rating agencies typically focus on default event. For instance, Moody's (2003) defines a sovereign issuer as in default when one or more of the following conditions are met:

- There is a *missed or delayed disbursement of interest and/or principal*, even if the delayed payment is made within the grace period, if any;
- A *distressed exchange* occurs, where
 - the issuer offers bondholders a new security or package of securities that amount to a diminished financial obligations such as new debt instruments with lower coupon or par value or
 - the exchange had the apparent purpose of helping the borrower avoid a “stronger” event of default (such as missed interest or payment).

Similarly, **Standard and Poor's** (Chambers and Alexeeva, 2002) generally defines default as the failure of an obligor to meet a principal or interest payment on the due date (or within the specified grace period) contained in the original terms of the debt issue. The agency notes that

- For local and foreign currency bonds, notes, and bills, each issuer's debt is considered in default either when *scheduled debt service is not paid* on the due date or when an *exchange offer of new debt contains less favorable terms* than the original issue; and
- For bank loans, when either scheduled debt service is not paid on the due date or a rescheduling of principal and/or interest is agreed to by creditors at less-favorable terms than the original loan. Such rescheduling agreements covering short- and long-term bank debt are considered defaults even where, for legal, or regulatory reasons, creditors deem forced rollover or principal to be voluntary.²

In addition, many rescheduled sovereign bank loans are ultimately extinguished at a discount from their original face value. Typical deals have included exchange offers (such as those linked to the issuance of Brady bonds), debt/equity swaps related to government

² For central bank currency, a default occurs when notes are converted into new currency of less-than-equivalent face value.

privatization programs, and/or buybacks for cash. Standard and Poor's considers such transactions as defaults because they contain terms less favorable than the original obligation.

Beim and Calomiris (2001) use a variety of sources to compile a list of major periods of sovereign debt servicing incapacity from 1800 to 1992. They consider bonds, suppliers' credit, and bank loans to sovereign nations and exclude intergovernmental loans. Beim and Calomiris (2001) focus on extended periods (six months or more) where all or part of interest and/or principal payments due were reduced or rescheduled. Some of the defaults and rescheduling involved outright repudiation (a legislative or executive act of government denying liability), while others were minor and announced ahead of time in a conciliatory fashion by debtor nations.

The end of each period of default or rescheduling was recorded when full payments resumed or a restructuring was agreed upon. Periods of default or rescheduling within five years of each other were combined. Where a formal repudiation was identified, its date served as the end of the period of default and the repudiation is noted in the notes (e.g., in Cuba 1963). Where no clear repudiation was announced such as in, the default was listed as persisting through 1992 (e.g., in Bulgaria). Finally, voluntary refinancing (Colombia in 1985 and Algeria in 1992) were not included.

Debt Crises as Large Arrears

In **Detragiache and Spilimbergo (2001)** an observation is classified as a debt crisis if either or both of the following conditions occur:

- There are *arrears of principal or interest* on external obligations towards commercial creditors (banks or bondholders) of more than 5 percent of total commercial debt outstanding;
- There is a *rescheduling or debt restructuring* agreement with commercial creditors as listed in the World Bank's Global Development Finance.

Detragiache and Spilimbergo (2001) argue that the 5 percent minimum threshold is to rule out cases in which the share of debt in default is negligible, while the second criterion is to include countries that are not technically in arrears because they reschedule or restructure their obligations before defaulting.

As a sensitivity test they also set the minimum threshold on arrears at 15 percent of commercial debt service due. Also, since they are interested in defaults with respect to commercial creditors, arrears or rescheduling of official debt do not count as crisis events. Finally, observations for which commercial debt is zero are excluded from the sample because they cannot be crisis observations best on their definition.

A second issue is how to distinguish the beginning of a new crisis from the continuation of the preceding one: an episode is considered concluded when arrears fall below the 5 percent threshold; however, crises beginning within four years since the end of a previous episode are treated as a continuation of the earlier event. In a sensitivity test, Detragiache and Spilimbergo (2001) exclude all episodes that follow the first crises, so that each country has at most one crisis. Finally, since the authors seek to identify the conditions which prompt a crisis rather than the impact of the crisis on macroeconomic developments, all observations while the crisis is ongoing are excluded from the sample.

These criteria identify 54 debt crises in the baseline sample. While events tend to cluster in the early 1980s, when most Latin American countries and several African countries defaulted on their syndicated bank debt following the borrowing boom of the 1970s, there are crises throughout the sample period. Episodes on external payment difficulties that do not result in arrears or rescheduling, such as the Mexican crisis of 1995, are not captured by their definition of crisis. Notably, they identify only 4 crises in the 1994-1998 period

Debt Crises as Large IMF Loans

Manasse, Roubini, and Schimmelpfennig (2003), hereinafter referred to as MRS, argue that there are different types of sovereign-debt servicing difficulties which range from an outright default (Russia, 1998, Ecuador, 1999, and Argentina, 2001) on domestic and external debt, to semi-coercive restructuring i.e., (under the implicit threat of default) (Ukraine 2000, Pakistan 1999, Uruguay 2003), and rollover/liquidity crises (Mexico 1994–95, Korea/Thailand 1997–98, Brazil 1999–2002, Turkey 2001, Uruguay 2002) where a solvent but illiquid country is on the verge of default on its debt because of investors' unwillingness to rollover short-term debt coming to maturity, and a crisis was in part avoided via large amounts of official support by international financial institutions as well as less coercive forms of private sector involvement.

MRS argue that sovereign debt servicing difficulties (both of the illiquidity and insolvency varieties) that were severe during the 1980s debt crisis have become relatively frequent phenomena again in the last decade. As a result, the authors argue that the data in Detragiache and Spilimbergo (2001) may exclude some incipient debt crises that were only avoided by large scale financial supports from official creditors. They therefore consider a country to experience a debt crisis if

- It is classified as being in *default* by Standard and Poor's as previously defined, or
- If it receives a *large non-concessional IMF loan* defined as access in excess of 100 percent of quota.

Standard and Poor's rates sovereign issuers in default if a government fails to meet principal or interest payment on external obligation on due date (including exchange offers, debt

equity swaps, and buy back for cash). For MRS, debt crises include not only cases of outright default or coercive restructuring but also situations where such near-default was avoided through the provision of large scale official financing by the IMF.

Debt Crises as Distress

Given the limited number of sovereign bond defaults, even under a very broad definition such as Moody's, Sy (2003) suggest a parallel with the distressed debt literature in corporate finance and defines debt crises as sovereign bonds distress events. The author assumes that sovereign bonds are distressed securities

- when *bond spreads are trading 1,000 basis points or more* above U.S. Treasuries.

Sy (2003) argues that in practice, the 1,000 bps mark for spreads is often considered as a psychological barrier by market participants. Under the above definition of sovereign distress, the author finds 140 distressed debt events (about 14 percent of observations) from 1994 to 2002, which were associated with reduced access to the sovereign bond market.

III. AN ALTERNATIVE MODEL OF SOVEREIGN DEBT CRISIS

Typically, the literature has focused on sovereign defaults to proxy for foreign-debt servicing difficulties. However, data on sovereign defaults show that, while such credit events were good proxies for sovereign-debt servicing difficulties in the 1980s, they do not fare well post-1994. Indeed, the data show a dearth of defaults post-1994 although this period is often associated with a number of sovereign credit events in emerging market economies, starting with the Mexican and the Asian "crises" (See Figure 1 and Table 1).

Our concern that defaults are not a measure fine enough to capture changes in the nature of debt-servicing difficulties and the evolution of international capital markets is shared by other authors. For instance, MRS propose to complement defaults with events in which a sovereign receives substantial IMF assistance.

IMF bailouts, however, do not show a structural change between the two periods before and after 1994. In fact, the percentage of countries receiving IMF assistance of more-than-100 percent of quota has barely increased to 4.8 percent post-1994 from 4.5 percent in the previous period. Moreover, the percentage of countries receiving IMF bail-outs without defaulting has barely increased to 36 percent post-1994 from 32 percent in the previous period³. In other words, the MRS-methodology of complementing default events with IMF bail-outs although it

³ For a broad sample of 76 countries mostly not members of the Organization for Cooperation and Development (OECD).

increases the total number of crisis events does not change the relative number of crisis per period—that is, the ratio of number of crisis events in the 1980s over the number of crisis events in the 1990s. So we are still left with the puzzle of a drastic drop in debt crises post-1994.

A possible explanation of the rarity of default events post-1994 could be that the determinants of defaults have improved in the 1990s relatively to their earlier levels. If so, the factors that successfully explained defaults in the 1970s and 1980s should have no problem predicting the reduced number of defaults in the 1990s. Our regression results show, however, that this may not be the case. Empirical models of debt crises that worked well until the 1980s cannot explain the few default events in 1990s and instead predict a greater number of such events.

It could also be the case that there was a structural break between the regressors and the dependent debt crisis variables. Such a break could be attributed to development in international financial markets in the 1990s. In this case, we should expect that models estimated for the 1970s and 1980s no longer work for the 1990s. We will, however, show that this may not be the case although we believe that financial development deserves a closer view. In particular, we will attempt to show that the rapid development of the sovereign bond market for emerging economies can be used to obtain a relevant definition of debt crises.

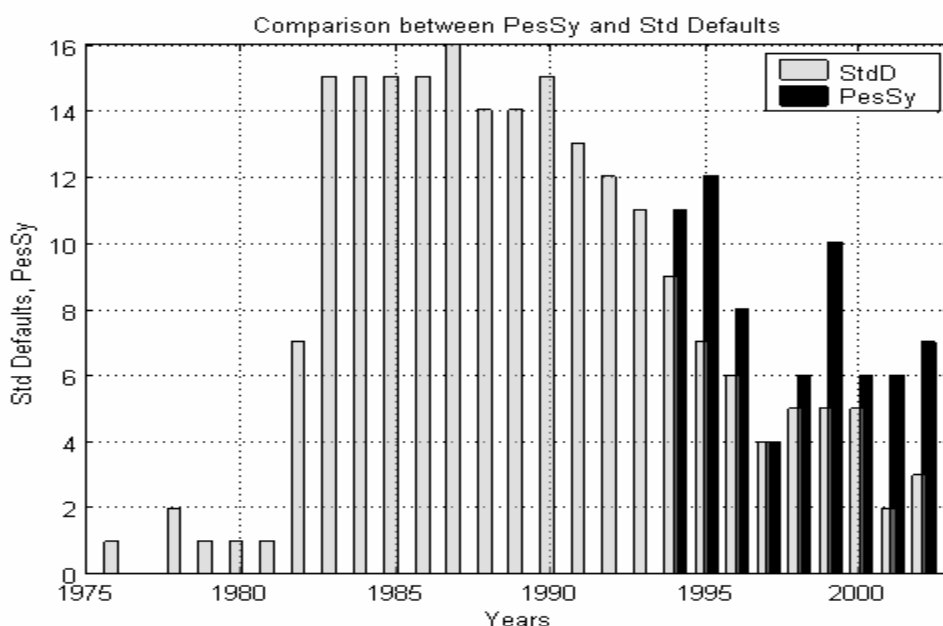
We start from the following simple consideration. The more emerging countries have gained access to sovereign bonds markets, the more they have reduced the fraction of bank loans debt over total debt. This means that defaulting could be associated to both forms of debt contract but also to just one of the them. So as a first step it seems sensible to proxy for foreign-debt servicing difficulties using bank-loans, bonds or both types of debt instruments.

A second consideration is that very few countries have defaulted on their foreign bonds in the post-1994. As a result, the usual definition of bond default must be the one that is not fine enough to capture the wide range of debt-servicing difficulties. The anonymous structure of bond markets makes renegotiation more difficult for bond contracts than bank loans. Renegotiation, however, is one of the most common credit events for other types of debt contracts such as bank loans and is a clear sign of debt-servicing difficulties. In contrast, we are likely to miss important periods of debt-servicing difficulties when we restrict ourselves to the usual definition of default, because of the difficulty of renegotiating bond contracts.

In order to overcome this problem, we add a more market-oriented definition of foreign-bonds servicing difficulties in the bond market based on sovereign spreads. More precisely, a debt crisis happens when there is either a default as defined by rating agencies (in this case S&P's) or when the secondary market sovereign bond spreads are higher than a critical

threshold. For simplicity we will refer to debt crises defined as above as the PesSy indicator of foreign-debt servicing difficulties.⁴

Figure 1.



Source: Authors' calculations.

Figure 1 shows the number of crises signaled by defaults—as defined by Standard and Poor's—and by our crisis-indicator.⁵ In Table 1, we divide the overall sample – that goes from 1975 to 2002—into two subsamples ranging from 1975 to 1993 and from 1994 to 2002. The data show a dramatic drop in the number of defaults to 16 percent of total observations in the 1994–2002 period, from 28 percent in the 1975–1993 period. In contrast, our proxy for sovereign debt-servicing difficulties indicates a more stable behavior with a proportion of 24 percent of debt crises in the 1994–2002 period.

⁴ We also think there are advantages of using sovereign bonds spreads given the high frequency and quality of the data as well as the simplicity in distinguishing between entry, continuation and exit from a crisis.

⁵ The data for spreads start from 1994 so that the two variables overlap in the period before.

Table 1. Number of Crises, by Definition			
	Total obs.	Percentage	Number of Crises
Defaults (1975–2002)	886	24	214
PesSy (1975–2002)	886	27	238
Defaults (1994–2002)	287	16	46
PesSy (1994–2002)	287	24	70
Defaults (1975–1993)	599	28	168
Source: Authors' calculations.			

In order to formalize the previous argument and compare the two definitions of debt crises, namely sovereign defaults and the indicator of debt-servicing difficulties (PesSy). We assume that there is an unobservable state of nature which corresponds to a country experiencing foreign-debt servicing difficulties. These foreign debt servicing difficulties are not observable per se⁶ by creditors, but the observation of some indicators such as the inability of a sovereign to repay its debt may be used to infer the true state of nature.

We assume the existence of a latent variable, y^* , that represents foreign debt-servicing difficulties for a particular country. The underlying response variable is then defined by a regression relationship:

$$y_t^* = \beta' x_t + u_t \quad (1)$$

The next step is to link the latent variable to some observable variables. For the *default events* as defined by international rating agencies we claim they miss the bonds market. Thus, the default indicator I is consequently defined as

$$I_t = \begin{cases} 1 & \text{if } y_t^* > 0 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

On the other hand, we assume that a sovereign credit event is also signaled when a country's bond spreads, s , cross a threshold, τ . Typically, market participants use the 1,000 basis points mark as a psychological level and focus on recovery values rather than price quotes when a country's spreads exceed this level. Later, we will use statistical analysis to test for the existence of such a threshold. We define the spreads in excess of the threshold as:

$$s_t - \tau_t = h(y_t^*)$$

Where $h(\cdot)$ is any strictly increasing Borel Function defined on the y^* probability space such that $h(0)=0$. We then construct a binary indicator related to the latent variable, S such as:

⁶ It is private information for the sovereign debtor.

$$S_t = \begin{cases} 1 & s_t - \tau_t > 0 \\ 0 & \text{otherwise} \end{cases} \quad \text{or} \quad \begin{cases} 1 & y^*_t > 0 \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

We therefore suggest that a sovereign credit event is no longer measurable as described just by equations (1)-(2), that is by sovereign defaults only, or solely by equation (1) and (3), that is by bond spreads crossing a threshold. Instead, we propose a more general model combining the default indicator with the spreads-based indicator.

We may think of our latent variable as being linked to a bivariate observable variable, $\tilde{y}_t \equiv (I_t, S_t)$ such that,

$$\tilde{y}_t = \begin{cases} (1, 1) \\ (1, 0) & y^*_t > 0 \\ (0, 1) \\ (0, 0) & \text{otherwise} \end{cases} \quad (4.a.)$$

which can be reduced to the following univariate variable:

$$y_t = \begin{cases} 0 & \text{if } \tilde{y}_t = (0, 0) \\ 1 & \text{otherwise} \end{cases} \quad (4.b.)$$

If specification (4) is the true model, this means that models (2) and (3) are misspecified. Furthermore, using model (2) means treating a conditional probability as an unconditional one. From model (2) we get:

$$P(I_t = 1) = P(y^*_t > 0) = 1 - F(-\beta' x_t)$$

From model (4) we have

$$1 - F(-\beta' x_t) = P(y^*_t > 0) = P(I_t = 1 / S_t = 0)$$

Until the beginning of the 1990s, conditioning on $S=0$ was consistent with the fact that most emerging economies did not have access to international bond markets. In contrast, it seems reasonable to assume that such a specification may miss the information given by bond markets as emerging markets gradually use sovereign bonds as a major source of funding. We therefore complement the typical default indicator by an indicator which uses the information from international bond markets.

Alternately, our proposed indicator can be seen as assuming that there has been historically no structural break between the latent and the covariates. Rather, there have been difficulties in choosing a proper indicator of an unobservable dependent variable.

In the next section, we use anecdotal evidence and statistical methods to estimate the critical threshold for bond spreads, τ .

A. Psychological/Market Threshold

Market participants often consider the 1,000 basis points mark for sovereign bond spreads as a critical psychological threshold. Indeed, anecdotal evidence suggests that price quotes are increasingly based on expected recovery values in case of a default, when bond spreads cross the 1,000 bps mark.

For instance, Altman (1998), defines distressed securities as those publicly held and traded debt and equity securities of firms that have defaulted on their debt obligations and/or have filed for protection under Chapter 11 of the U.S. Bankruptcy Code. Under a more comprehensive definition, Altman (1998) considers that distressed securities would include those publicly held debt securities selling at sufficiently discounted prices so as to be yielding, should they not default a significant premium of a minimum of 1,000 basis points (or 10 percent) over comparable U.S. Treasuries. Similarly, some market participants consider securities to reach distressed levels when they have lost one-third of their value.

In the next section, we attempt to corroborate the observation that the 1,000bps is a critical threshold. We use both extreme value theory and kernel density estimations to assess the relevance of such a ceiling for bond spreads.

B. Estimating the Threshold for Bond Spreads Using Extreme Value Theory

Sovereign bond spreads are characterized by fat tails and volatility clustering. As a result, it is relevant to use an approach that takes into consideration fatness of tails in order to determine what values are to be considered extreme events. Such extreme events could then be used in defining debt crises.

As first attempt, we use extremal analysis as in Pozo-Amuedo (2003), Koedijk (1992), and Hols and De Vries (1991). Typically, studies using extreme value theory focus on the estimation of a tail parameter α or alternately on the inverse of the tail parameter, $\gamma=1/\alpha$, by use of the Hill estimator. This requires stationary and serially uncorrelated data. Our bonds spreads series are clearly stationary, at any frequency, but are not serially uncorrelated at high frequency (daily and monthly). As a result, we focus on annual data (see Table A.1).

We pool the data and rank-order the observations from the lowest to the highest, $S_1 \dots S_n$ in order to compute the following measure of the tail parameter:

$$1/\hat{\alpha} = \hat{\gamma} = \frac{1}{m} \sum_{i=0}^m \ln(S_{n-1} / S_{n-m})$$

The key point in the estimation of the critical bond spreads threshold is the choice of the variable m . We therefore plot the estimated value of $\hat{\gamma}$ against possible values of m . We then use recursive least squares to regress $\hat{\gamma}$ on a time trend and a constant, successively adding observations and obtaining a one step ahead forecast with the respective 20 percent confidence interval, (see Appendix Figures A.1 to A.3).

For our yearly sample we can conclude that a value of m between 42 and 50 make $1/\hat{\alpha}$ relatively stable. Using the above relationship $m = 42$ leads to a value of 1,073 bps and $m = 50$ to 969 bps. Because the relation between m and the extreme value threshold is clearly monotonic we conclude that our threshold reasonably lies between 696bps and 1,073 bps (see Appendix Table A.2).

We also assess to what extent the threshold for bond spreads estimated using extreme value theory would affect the construction of our binary crisis dependent variable. Table 2 which uses the 1,000 basis points mark shows that the use of a critical threshold from extreme value estimation does not significantly change the classification of the data in crisis periods. Using the upper estimation we just add 2.3 percent crisis periods and using the lower estimation we only ignore 1.4 percent crisis events with respect to the total number of crises.

Table 2. Extreme Value Theory Versus 1,000 bps Thresholds (Sample: 1994–2002)				
	Matching	EVT Adding	EVT Crossing out	Total
Total number	[211, 213]	[5, 0]	[0, 3]	216
As percentage	[0.98, 0.99]	[0, 0.023]	[0, 0.014]	1
Source: Authors' calculations.				
Note: The abbreviation bps denotes basis points (hundredths of a percentage)				

We conclude that the estimated values for the critical bond spreads threshold coming from EVT are consistent with anecdotal evidence (the 1,000 basis points mark is between the lower and upper estimate), and do not affect significantly our dependent binary variable. In the next section, we conduct a second robustness analysis of the data using kernel density estimation.

C. Estimating the Threshold for Bond Spreads Using a Kernel Density Estimation

Intuitively, crossing a rounded number is more “informative” than crossing any other. In our case we assume that passing the 1,000 bps value implies a change in market participants’ perception of the bond. In other words we think crossing 1,000bps is a crucial psychological threshold.

Instead of proving directly that there exist a psychological threshold, we focus on reasonable implications of having such a threshold. So we do assume that the 1,000 basis points mark is a psychological threshold for traders in emerging markets. In such a case we should find

that the distribution of the bond spreads data has a mode with a value close to the psychological value.

The argument is the following. Whenever a price tends to be close to a limit that cannot be passed smoothly the values will concentrate around it till the limit will be finally passed or the surging pressure reduced. Because the body of the distribution lies on the left of our threshold we also should expect that the mode is slightly on the left (see Appendix B for an illustration).

We analyze both yearly and daily data. In this case, the presence of autocorrelation which is very strong for daily data does not spoil the results. Whenever we have a univariate sample that is not identically and independently distributed but autocorrelated, its histogram should show a mode for each relevant turning point. So we expect a large mode around “tranquil” periods values, a mode for 1,000 bps and some smaller modes for very high spread that have been peaks, and so turning points, for some countries.

The kernel density estimation confirms our hypothesis. As shown in figure B1 we do have a mode around 1,000 bps for both daily and yearly data. For yearly data we can even go further. Since the data is not correlated, we try to fit a Gamma and an Extreme Value Distribution for yearly spreads and then assess the 90th percentile. But if we were to use the daily sample no distribution could fit really well– mainly because of the strong multimodality.

To solve the problem we focus on extreme values with respect to tranquil periods. Loosely speaking we want to overlook the modes of high spreads values (over 1000bps). Given that “tranquil” periods are the one corresponding to the highest mode we can accomplish our goal by sampling mainly from the highest mode (the sampling method, an MCMC, is described in the appendix).

The corresponding results for both a Gamma and a Weibul fitted distribution make our 1,000 basis points threshold lay inside the 95 percent confidence bands for the 90th percentile of the fitted distribution (we pick the 90th percentile as a proxy for extremes events).

Table 3. Thresholds for Bond Spreads from Kernel Density Estimations

<u>Estimated 90th Percentile – 95% Confidence Interval</u>		
Gamma distribution	1,036.52	[980.55, 1,093.85]
Weibul distribution	978.82	[795.10, 1,248.05]
<u>Percentile Corresponding to 1,000 bps</u>		
Gamma distribution	0.88	
Weibul distribution	0.91	
Source: Authors' calculations.		

Using both extreme value theory and kernel density estimation and consistent with anecdotal evidence, we find that the 1,000 basis points mark can be used as an appropriate threshold for sovereign bond markets. In the next sections, we use the framework developed above to estimate econometric models of debt crises.

IV. DEFAULTS VERSUS MARKET-BASED DEFINITION OF DEBT CRISES (PESy)

A. Baseline Regressions, 1975–2002

The previous literature on debt crises has highlighted the importance of a number of variables that help predict sovereign credit events, and in particular sovereign defaults. In DS (2001), for instance, empirical tests are based on a “crisis equation” where the dependent variable is the occurrence of a debt crisis. The explanatory variables are (i) liquidity indicators (short-term debt over reserves, or short-term debt, debt service due, and reserves separately), (ii) variables that measure the magnitude and structure of external debt, and (iii) macroeconomic control variables such as measures of openness and real exchange rate overvaluation.

After reviewing the empirical and theoretical literature on debt crises, MRS highlight following determinants of debt crises are as follows:

- Solvency measures such as public and external debt relative to capacity to pay;
- Liquidity measures such as ST external debt and external debt service, possibly in relation to reserves or exports;
- Currency crisis EWS models variables;
- External volatility and volatility in economic policies measures;
- Macroeconomic control variables such as growth, inflation, exchange rate;
- Political and institutional variables capturing a country’s willingness to pay.

We follow the literature and use the typical determinants of debt crises as explanatory variables. As dependent variables we will compare the PesSy indicator with S&P’s defaults on bank-loans and sovereign bonds. First, we estimate a model of debt crises, defined as defaults, for the whole sample from 1975 to 2002. Not surprisingly, we find that solvency measures (total debt over GDP) and liquidity indicators (short term debt over reserves) are statistically significant in explaining debt crises. Macroeconomic control variables, in particular, real growth rate, inflation and real exchange rate overvaluation are also important in explaining crises as is a measure of openness (imports plus exports over GDP). All regressors are significant at 5 percent in both specifications (with or without inflation).

Table 4. Regression Results Using Default Definition, 1975–2002 GEE Logit population-averaged model, correlation exchangeable, Huber-White estimator. 567 Obs.										
Default Definition	Coeff.	Z	P> z	95% CI		Coeff.	Z	P> z	95% CI	
<i>Openness</i>	-0.05	-3.14	0.00	-0.08	-0.02	-0.05	-3.08	0.00	-0.07	-0.02
<i>Overvaluation</i>	0.01	3.40	0.00	0.01	0.02	0.01	3.37	0.00	0.00	0.02
<i>Total debt over GDP</i>	0.06	3.57	0.00	0.03	0.09	0.06	3.56	0.00	0.03	0.09
<i>Short-term debt over reserves</i>	0.19	2.07	0.04	0.01	0.36	0.19	2.05	0.04	0.01	0.37
<i>Real growth rate</i>	-0.08	-2.49	0.01	-0.15	-0.02	-0.08	-2.35	0.02	-0.15	-0.01
<i>Inflation</i>						0.00	2.67	0.01	0.00	0.00
Constant	-1.94	-2.43	0.02	-3.51	-0.37	-2.09	-2.48	0.01	-3.74	-0.44
Wald χ^2 (5) and (6)	44.0					46.1				

Source: Authors' calculations.

Next, we change the definition of debt crisis and use default events complemented with events where bond spreads exceed the 1,000 basis point threshold (PesSy indicator). We use the same explanatory variable as before and find that all regressors are significant at 5 percent in both specifications except for inflation. This is in part explained by the fact that inflation does not give a significant contribution as in the previous case. Indeed, adding the inflation measure to the other explanatory variables does not improve statistically the regression results as illustrated by the Wald statistics. We also find that the estimation using the augmented default model has a higher Wald statistic although this is not a clear-cut indication of which model is performing better.

Table 5. Regression Results Using PesSy Indicator, 1975–2002 GEE Logit population-averaged model, correlation exchangeable, Huber-White estimation. 567 Obs.										
PesSy indicator	Coeff.	z	P> z	95% CI		Coeff.	Z	P> z	95% CI	
<i>Openness</i>	-0.03	-2.06	0.04	-0.07	0.00	-0.03	-2.15	0.03	-0.06	0.00
<i>Overvaluation</i>	0.01	2.75	0.01	0.00	0.02	0.01	2.41	0.02	0.00	0.01
<i>Total debt over GDP</i>	0.06	4.26	0.00	0.03	0.09	0.06	4.46	0.00	0.03	0.09
<i>Short-term debt over reserves</i>	0.30	2.50	0.01	0.06	0.53	0.30	2.47	0.01	0.06	0.53
<i>Real growth rate</i>	-0.09	-2.61	0.01	-0.17	-0.02	-0.08	-2.29	0.02	-0.15	-0.01
<i>Inflation</i>						0.00	1.25	0.21	0.00	0.01
Constant	-2.80	-4.01	0.00	-4.18	-1.43	-3.08	-4.99	0.00	-4.29	-1.87
Wald χ^2 (5) and (6)	48.0					45.4				

Source: Authors' calculations.

B. The 1990s—A New Decade: Subsample Comparisons

To compare the robustness of the two models, we adopt two strategies. First, we estimate them for the period after 1994, rather than for the whole sample, as this period is characterized by the growth of the emerging bond markets. Second, we follow the literature on early-warning system and use a more analytical approach by minimizing a loss function.

We estimate again both models for the 1994–2002 subsample. We find that the model using bond markets to complement defaults perform better than the default-based model.

Without inflation the Wald statistic for the PesSy model is 29.4 compared to 8.4 for the default-based model. When inflation is considered as a regressor, the Wald statistics are 59.5 and 41.6, respectively. Real growth and openness variables are not significant as before whereas inflation is strongly significant in both setups.

Finally, it is worth noting that when debt crises are defined as defaults, the short term debt variable does not play any role. In contrast, short-term debt is significant and has the right sign, when debt crises are defined to include turbulence in bond markets.

Table 6. Regression Results Using Default Definition, Subsample for 1994–2002 GEE Logit population-averaged model, correlation exchangeable, Huber-White estimation. 207 Obs.										
Defaults	Coeff.	z	P> z	95% CI		Coeff.	Z	P> z	95% CI	
<i>Openness</i>	-0.03	-1.47	0.14	-0.07	0.01	-0.03	-1.39	0.17	-0.06	0.01
<i>Overvaluation</i>	0.02	2.03	0.04	0.00	0.03	0.01	1.87	0.06	0.00	0.03
<i>Total debt over GDP</i>	0.04	1.84	0.07	0.00	0.09	0.04	1.80	0.07	0.00	0.09
<i>Short-term debt over reserves</i>	0.12	0.49	0.63	-0.35	0.58	0.13	0.53	0.60	-0.35	0.60
<i>Real growth rate</i>	-0.04	-0.91	0.37	-0.13	0.05	-0.04	-0.93	0.35	-0.14	0.05
<i>Inflation</i>						0.00	2.40	0.02	0.00	0.00
Constant	-2.16	-1.74	0.08	-4.59	0.27	-2.26	-1.75	0.08	-4.80	0.28
Wald χ^2 (5) and (6)	8.4					41.6				

Source: Authors' calculations.

Table 7. Regression Results Using PesSy Indicator, Subsample for 1994–2002 GEE Logit population-averaged model, correlation exchangeable, Huber-White estimation. 207 Obs.										
PesSy Indicator	Coeff.	z	P> z	95% CI		Coeff.	Z	P> z	95% CI	
<i>Openness</i>	-0.02	-1.23	0.22	-0.05	0.01	-0.02	-1.09	0.28	-0.05	0.01
<i>Overvaluation</i>	0.02	1.83	0.07	0.00	0.04	0.01	1.50	0.13	0.00	0.03
<i>Total debt over GDP</i>	0.06	3.31	0.00	0.02	0.09	0.06	3.32	0.00	0.02	0.09
<i>Short-term debt over reserves</i>	0.34	1.89	0.06	-0.01	0.70	0.39	2.00	0.05	0.01	0.76
<i>Real growth rate</i>	0.01	0.17	0.87	-0.09	0.10	0.00	0.08	0.94	-0.10	0.10
<i>Inflation</i>						0.00	3.87	0.00	0.00	0.00
Constant	-3.53	-3.29	0.00	-5.64	-1.43	-3.84	-3.40	0.00	-6.05	-1.62
Wald χ^2 (6) and (7)	29.4					59.5				

Source: Authors' calculations.

C. Out-of-Sample Comparisons

As a second analysis we check which definition of debt crises—defaults or defaults added to spreads crossing a critical threshold—captures better debt crises predicted in the 1994–2002 period by a standard model of debt crises. The idea is to estimate a model using defaults as debt crises up to 1993, and then predict debt crises for the period 1994–2002. We then compare which definition of debt crises matches better the predicted crisis events. In order to penalize the PesSy indicator, we use the baseline model with inflation among regressors.

First, we estimate the model for the 1975–1993 sub-period. In this period there are no bonds spreads available and we consider their impact on total debt as negligible⁷. In other words we consider the Defaults model correctly specified for this sub-sample. As shown in table R5, all variables are significant at 5 percent except for inflation and the Wald statistic is similar to the ones obtained earlier.

Table 8. Regression Results Using Default Definition, Sample for 1975–93 GEE Logit population-averaged model, correlation exchangeable, Huber-White estimation. 360 Obs.					
Default Definition	Coeff.	Z	P> z	95% CI	
<i>Openness</i>	-0.04	-2.92	0.00	-0.07	-0.01
<i>Overvaluation</i>	0.01	2.27	0.02	0.00	0.02
<i>Total debt over GDP</i>	0.07	4.05	0.00	0.03	0.10
<i>Short-term debt over reserves</i>	0.23	1.97	0.05	0.00	0.46
<i>Real growth rate</i>	-0.09	-1.93	0.05	-0.17	0.00
<i>Inflation</i>	0.00	0.88	0.38	0.00	0.01
Constant	-2.37	-4.29	0.00	-3.45	-1.29
Wald χ^2 (6)	39.20				

Source: Authors' calculations.

Next, we compare the out-of-sample prediction between defaults and PesSy actual values and also relatively to the in sample performance. As in the currency crises EWS literature we construct a 2-entry table such that we can count the number of Matched Crises (A), False Alarms (B), Missing Crises (C) and Matched Tranquil periods (D):

	Crisis	Tranquil
Signal	A(T)	B(T)
No Signal	C(T)	D(T)

A signal is sent whenever the estimated probability of having a crises crosses a given threshold, T. Typically, the threshold is set to be equal to the unconditional probability of having a crisis. Since we are trying to match the crisis events, there is no clear reason for setting T to the unconditional probability and we instead leave the variables A, B, C, and, D as function of the threshold T, which is optimally determined. In order to calculate the optimal threshold value for issuing a warning, T*, we minimize the following noise to signal ratio:

$L(T) = B(T)/A(T) + C(T)/D(T)$. Because the standard error for the forecasts are quite high we estimate the values for T* using a bootstrapping method, and hence for A(T*), B(T*), C(T*), D(T*) and L(T*). As first result we show, in Table 9, the ratios for “Matched Crises over Total Crises” $A(T^*)/[A(T^*) + C(T^*)]$ and “False Alarms over Tranquil Periods”

$B(T^*)/[B(T^*) + D(T^*)]$.

⁷We always consider the sovereign bonds market of a country negligible whenever spreads are not available. However, spreads could also not be available because a particular country's bonds are not liquid or because the country has no outstanding bonds issued.

Table 9. “Matched Crises over Total Crises” and “False Alarms over Tranquil Periods” (90 percent confidence intervals in brackets)		
	Matched Crises over Total Crises	False Alarms over Tranquil Periods
Defaults	0.43 [0.33, 0.50]	[0.12, 0.13]
PesSy	.61 [0.55, 0.67]	[0.19, 0.20]
In Sample (point estimate)	0.86	0.14
In Sample	0.69 [0.52, 0.91]	[0.02, 0.20]
Source: Authors’ calculations. Note: The in-sample point estimation refers to the estimated parameters without bootstrapping.		

The dependent variable is much closer to the forecasted values in terms of matched crises. This is not really surprising given that our definition determines more crises comparatively. For a more conclusive answer (or say to aggregate the previous results) we compare the Loss function values for the two crises measures.

Table 10. Bootstrapped Results for Standard and PesSy Distress Definition Loss Function (10th percentile, mean value, 90th percentile for the Loss Function)	
	Mean and CI
Default definition Loss (<i>Out Sample</i>):	1.50 [1.13 – 2.14]
Associated Optimal Threshold:	.34 [0.23 and 0.28]
PesSy definition Loss (<i>Out Sample</i>):	.89 [0.75, 1.07]
Associated Optimal Threshold:	0.32 [0.38 and 0.36]
<i>In Sample</i> Result Loss:	0.39
<i>In Sample</i> Result Optimal Threshold:	0.57
Source: Authors’ calculations.	

Table 11. Comparing Standard and PesSy Distress Definitions: Loss Functions (<i>t-test 2 samples for different means</i>)		
Significance = 0.000	Lower bound = 0551	Upper bound = 067
Source: Authors’ calculations.		

We find that the forecasted debt crisis events, when compared with our crisis definition are much closer to the in-sample values. In contrast, actual defaults do not fare well in capturing predicted debt crises obtained using a debt crises as defaults. We also perform a 2-sample t-test for different means and find that the null is clearly rejected. The PesSy indicator performs better than the defaults definition at any confidence level.

These results corroborate the idea defining debt crises as defaults is too strict to capture debt-servicing difficulties. Furthermore, we do not find evidence of a structural break in 1994. Instead, we show that a debt crisis model estimated up to 1993 still predicts quite well the next decade. However, predicted crises are only well captured by a definition of debt crises which incorporates information from bond markets. In contrast, the usual default definition fails to capture predicted debt crisis events in the 1994–2002 period.

V. CONCLUSION

In this paper, we propose a definition of debt crises which complements the usual default definition. Since there have been very few defaults on emerging market bonds in the 1990s in spite of a succession of turbulent foreign-debt-servicing episodes, we conclude that defining debt crises as defaults is too strict as an indicator of foreign-debt incapacity. We therefore propose a measure which attempts to capture the evolution of capital markets from an environment dominated by bank loans to one where bond markets have become increasingly important.

We define debt crises as events when there is either a default or when secondary-market bond spreads are higher than a critical threshold. In practice, the 1,000 basis points mark is often used by market participants. We show, using extreme value theory and kernel density estimation, that such a value does represent a statistically significant critical threshold.

We find that our definition accurately captures debt-servicing difficulties in the period from 1975 to 2002 and does better than the usual default definition, especially in the period after 1994. More precisely, we find that when our definition is used, the typical determinants of bank loan defaults in the 1980s still have predictive power for debt-servicing difficulties—on both bank loans and bonds—in the period from 1994 to 2002. In contrast, the standard definition of default implies a much worse out-of-sample performance. In addition, we find that liquidity indicators are significant in explaining our definition of debt crises, although they do not play any role in explaining defaults in the period from 1994 to 2002.

Finally, although we have used the level of spreads to capture problems in the bond markets, it is possible to use our approach with secondary-market bond prices. Presumably, debt-servicing problems also arise when bond prices or returns fall below a critical threshold, given the inverse relationship between bond prices and spreads.

I. EXTREME-VALUE-THEORY APPROACH

We have data for 31 countries ranging from 1975 to 2002. For yearly data we have the following Ljung-Box Q-test results (we have 4 rejections-of the null hypothesis of no correlation—mainly for short sample countries):

Table A1.1. Ljung-Box Q-test Results				
Country	Nul l	p-value	Q- Statisti c	Critical Value
Algeria	0	0.11	7.47	9.49
Argentina	0	0.27	11.07	16.92
Brazil	0	0.33	10.20	16.92
Côte d' Ivoire	1	0.04	11.54	11.07
Chile	0	0.37	4.28	9.49
China	1	0.02	12.93	11.07
Colombia	0	0.44	4.81	11.07
Dominican Rep.	0	0.52	1.30	5.99
Ecuador	0	0.33	9.10	15.51
Egypt	0	0.22	3.01	5.99
El Salvador	0	0.16	2.00	3.84
Hungary	0	0.08	8.29	9.49
Korea	0	0.23	6.93	11.07
Lebanon	0	0.24	6.70	11.07
Malaysia	1	0.01	22.60	16.92
Mexico	0	0.54	7.99	16.92
Morocco	0	0.06	10.44	11.07
Nigeria	0	0.48	8.53	16.92
Pakistan	0	0.20	3.27	5.99
Panama	0	0.89	2.90	14.07
Peru	0	0.19	8.73	12.59
The Philippines	0	0.83	5.05	16.92
Poland	0	0.08	15.34	16.92
Russia	0	0.48	5.55	12.59
South Africa	1	0.04	11.71	11.07
Thailand	0	0.24	6.74	11.07
Tunisia	0	0.16	2.00	3.84
Turkey	0	0.48	4.51	11.07
Ukraine	0	0.11	6.00	7.81
Uruguay	0	0.28	2.51	5.99
Venezuela	0	0.71	6.33	16.92

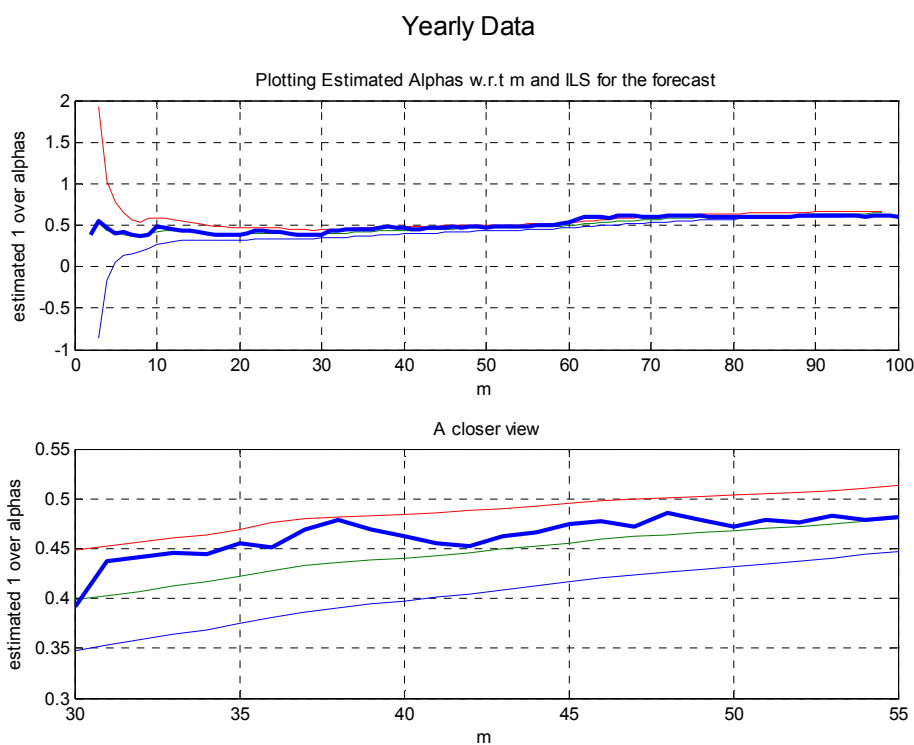
We repeat our extreme-value-theory (EVT) analysis also for monthly and daily data as a robustness check. The interpretation of the estimation results is more difficult probably because of the presence of serial autocorrelation. For the monthly case, it seems more plausible that

there is stabilization around a value of $m = 400$ (i.e., 1,118 bps). For daily data, the critical threshold is $m = 9,000$ (i.e., a bond spreads value of 1,084 bps).

Table A1.2. Extreme Value Theory: Estimated m and Implied Threshold τ .		
Yearly Data	$m \in [42, 50]$	$\tau \in [969, 1072]$
Monthly Data	$m = 400$	$\tau = 1117$
Daily Data	$m = 9000$	$\tau = 1084$

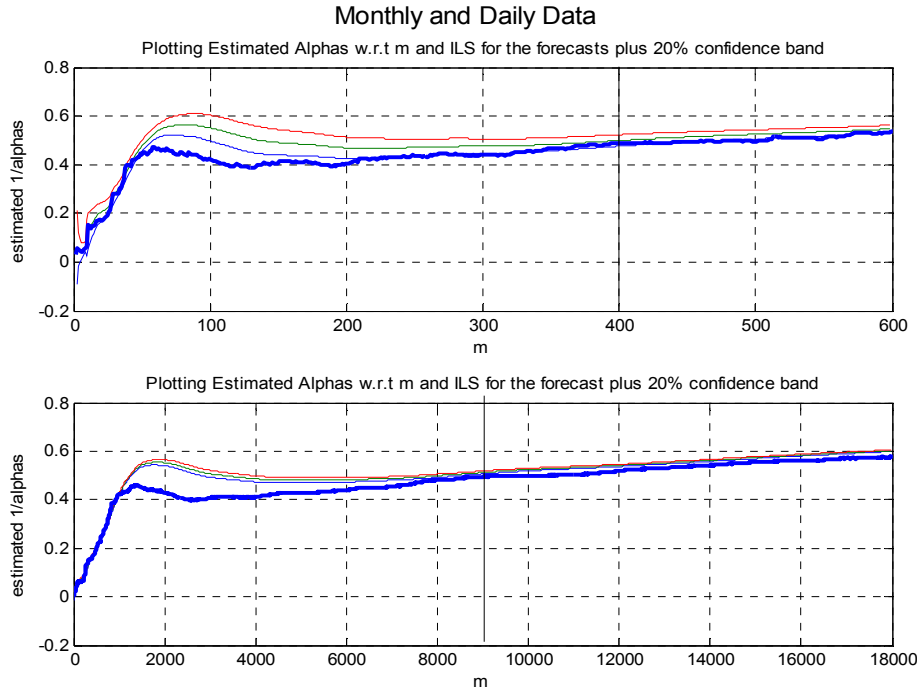
Table A1.3. Comparison: EVT and 1,000 bps Thresholds, Sample for 1994–2002				
Yearly	Matching	EVT Adding	EVT Crossing out	Total
Total number	[211, 213]	[5, 0]	[0, 3]	216
As percentage	[0.98, 0.99]	[0, 0.023]	[0, 0.014]	1
Monthly	-----	-----	-----	-----
Total number	2,252	92	0	2,344
As percentage	96	39	0	1
Daily	-----	-----	-----	-----
Total number	48,863	1,466	0	50,329
As percentage	97	029	0	1

Figure A1.1.



Source: Authors' calculations.

Figure A1.2.



Source: Authors' calculations.

II. KERNEL DENSITY ESTIMATION APPROACH

To have a better idea of why a psychological threshold, τ , should imply a mode around it we present the following example. Suppose we have a stochastic process, $\{y_t\}$, of the following form:

$$\text{for } y_{t-1} < \tau$$

$$y_t = \begin{cases} y_{t-1} + \varepsilon_t & \text{if } \varepsilon_t \leq \tau - y_{t-1} \\ x_t & \text{with } p \\ y_{t-1} + \varepsilon_t & \text{with } 1-p \end{cases} \quad \text{otherwise}$$

$$x_t \mapsto D(\theta_t) \quad \text{and} \quad F_x(x \leq y_{t-1}) = 0, F_x(x \geq \tau) = 1$$

$$\varepsilon_t \mapsto U(-a, a)$$

$D(\theta_t)$ is a generic distribution with the interval $[y_{t-1}, \tau]$ as support (over which it takes strictly positive values). For simplicity of exposition the errors are uniformly distributed between $-a$ and a .

What we wrote means that whenever the “inner” random walk should happen to cross the threshold τ it will actually do it just with a probability $(1-p)$. With a probability- p instead it will be a number drawn between its previous state, y_{t-1} , and the threshold (this is the job of the generic distribution- D).

It is easy to show that, given a $\delta < a$, whenever $a \leq \tau - y_{t-1}$ we have:

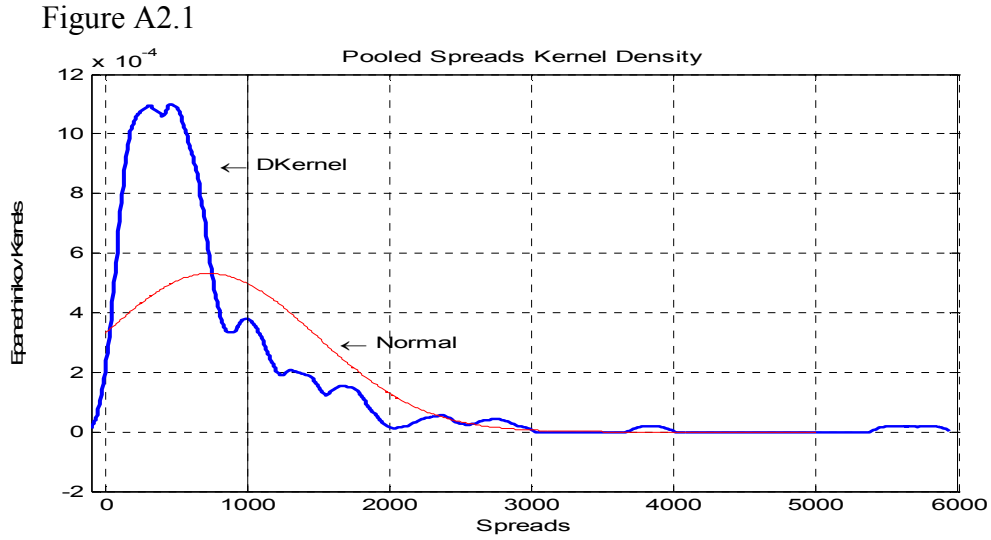
$$P(y_t \in I(y_{t-1}, \delta) / y_{t-1}) = \delta / a$$

Being y_{t-1} far away from the τ , the conditional probability of lying in a neighborhood of y_{t-1} is proportional to δ .

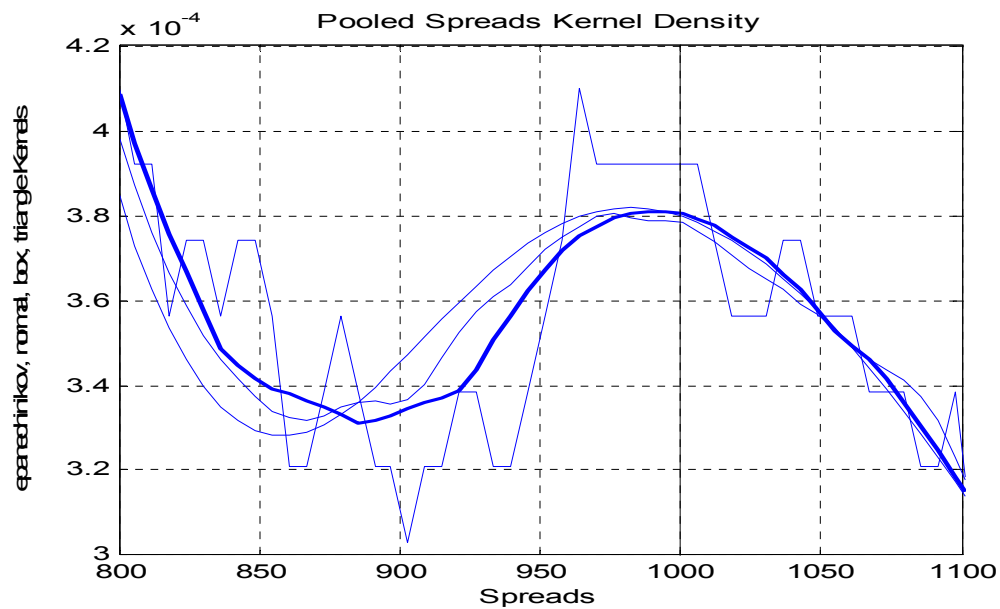
On the other hand whenever $a > \tau - y_{t-1}$ we have:

$$P(y_t \in I(y_{t-1}, \delta) / y_{t-1}) = \delta / a + pP(\varepsilon_t > \tau - y_{t-1})P(x_t \in [y_{t-1}, y_{t-1} + \delta]) > \delta / a$$

So, because by recurrence we should hit the threshold with probability one, sampling from the previous model will give a mode around the threshold.

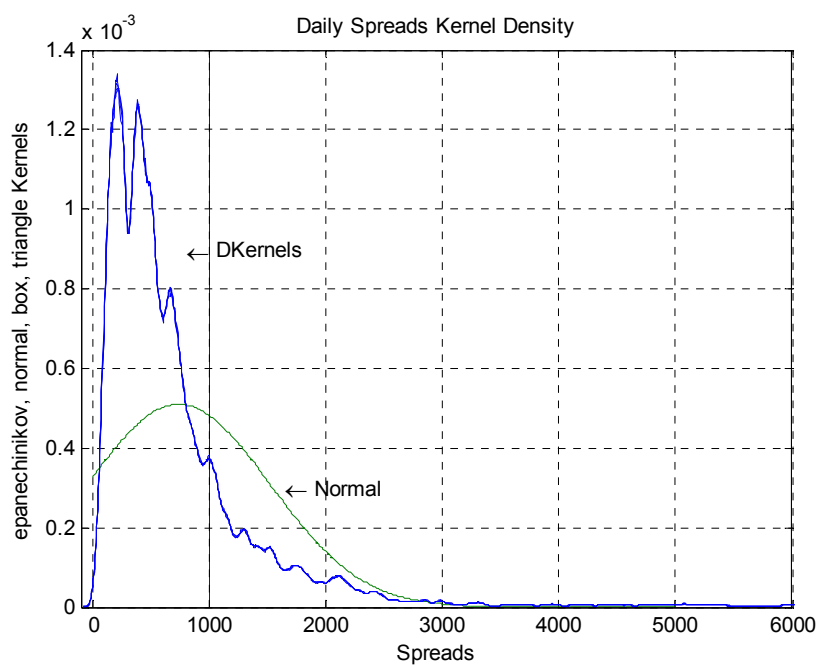


Clouser View and Robustness Analysis to Other Kernels

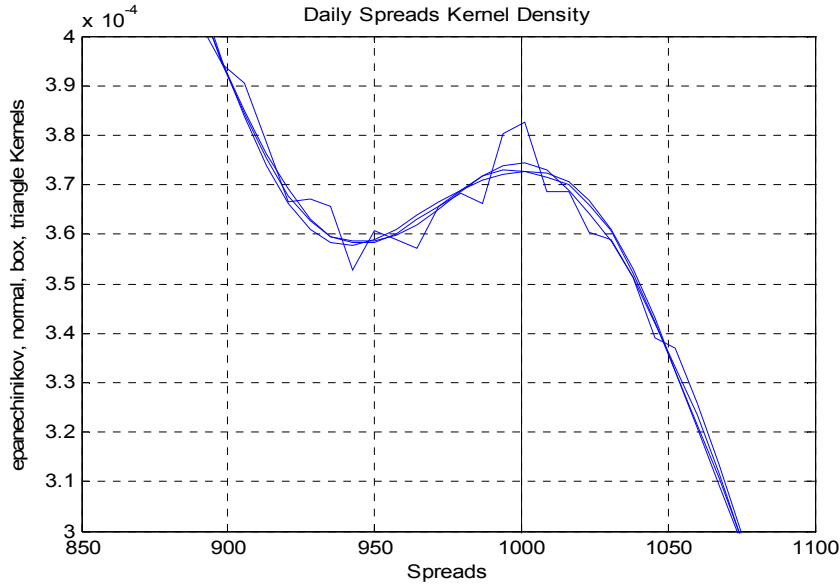


Source: Authors' calculations.

Figure A2.2: Daily



Closer View



Source: Authors' calculations.

III. THE METROPOLIS-HASTING ALGORITHM⁸

The task is to sample from a density function, $f(x)$, that is analytically unknown. In principle if we could find a candidate-generating density $q(x, y)$ such that $\int q(x, y) dy = 1$ for all x and satisfies the reversibility condition:

$$f(x)q(x, y) = f(y)q(y, x) \quad (0.1)$$

We can generate sample from $f(x)$ starting from any initial point x_0 using the following algorithm:

- (1) Choose an initial value x_0 let $i = 0$.
- (2) Generate x_i from $q(x_{i-1}, \cdot)$ $i = 1, 2, \dots$

Because condition (0.1) is difficult to meet the Metropolis-Hasting algorithm use a clever way to balance $q(x, y)$ based on the following

Lemma:

⁸ The Metropolis-Hastings algorithm is a powerful Markov Chain Monte Carlo (MCMC) method to simulate multivariate distributions. It was developed by Metropolis, Rosenbluth, Rosenbluth, Teller, and Teller in 1953 but its applications to statistics were not been explored till 1993.

Define

$$\alpha(x, y) = \min \left\{ 1, \frac{f(y)q(y, x)}{f(x)q(x, y)} \right\} \quad (0.2)$$

then

$$q_{mh} = q(x, y)\alpha(x, y) \quad (0.3)$$

satisfies the reversibility condition

$$f(x)q_{mh}(x, y) = f(y)q_{mh}(y, x) \quad (0.4)$$

Given the above, the Metropolis-Hasting algorithm is such that:

for j=1 to N

draw x^* from $q(x^*|x(j))$, draw $u \sim U(0,1)$

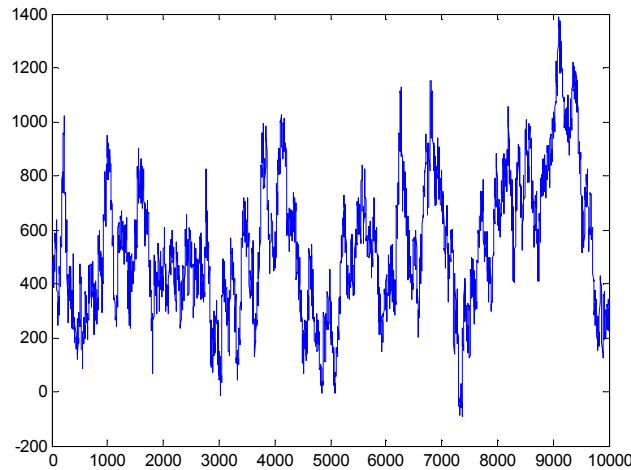
if $u < \min \{1, [q(x(j)|x^*)f(x^*)]/[q(x^*|x(j))f(x(j))]\}$

then $x(j+1)=x^*$

else $x(j+1)=x(j)$

return $\{x(1), \dots, x(N)\}$

Figure A3.1. Markov Chain Monte Carlo Convergence Checked: Sample Path.



Source: Authors' calculations.

In Figure A3.1, we show the path of our markov chain. Because we know where the mode is the initial burn in is not really necessary (however, the first 1,000 observation are thrown). In fact the Figure is among the ones for which sample convergence is considered achieved.

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