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Abstract

The financial crisis of the late 2000's highlighted the importance of strengthening risk management systems in financial markets. Consequently, an increasing interest in strategies to quantify risk under extreme scenarios has spawned. One of such techniques is CrashMetrics, a methodology for estimating the exposure of a portfolio to severe market movements. Using daily data, we find that CrashMetrics complements more traditional stress testing techniques, providing not only a stringent loss scenario, but one that is cemented on an observed market shock and on the estimated sensitivities of the change in portfolio value during periods of financial turmoil. Given that correlations between assets are stronger during a market crash, our findings indicate that financial institutions seem relatively more exposed to market risk under this methodology than using other market risk measures. Thus, results indicate that CrashMetrics provides vital information from a prudential perspective, alerting policymakers of significant individual or sector-specific exposures to market risk and thus, allowing preemptive action to be undertaken in a timely and efficient manner.

JEL classification: *G12, G21, G22, G23, G28, G32*
***Keywords*:** CrashMetrics, Market Risk, Stress Testing, Taylor Approximation.

Resumen

La crisis financiera de finales de la década pasada resaltó la importancia de fortalecer los sistemas de administración de riesgo en los mercados financieros. En consecuencia, se ha generado un creciente interés en metodologías para cuantificar riesgo bajo escenarios extremos. Una de estas técnicas es CrashMetrics, una metodología para estimar la exposición de un portafolio a movimientos pronunciados en el mercado. Utilizando información diaria, encontramos que CrashMetrics se constituye como un complemento idóneo a otras técnicas de *stress-testing* tradicionales, proveyendo no solo un escenario de pérdidas ácido, sino uno que está fundamentado en un choque de mercado observado y en las sensibilidades estimadas del cambio en el valor del portafolio durante periodos de estrés financiero. Adicionalmente, se encuentra que las instituciones financieras parecen estar relativamente más expuestas al riesgo de mercado bajo ésta metodología que bajo otras medidas de riesgo de mercado. Por tanto, los resultados sugieren que CrashMetrics provee información vital desde un punto de vista prudencial, alertando a los hacedores de política sobre exposiciones de riesgo significativas a nivel individual o sectorial, y permitiendo tomar las medidas preventivas de manera eficiente y oportuna.

Clasificación JEL: *G12, G21, G22, G23, G28, G32*
***Palabras clave*:** CrashMetrics, Riesgo de Mercado, *Stress Testing*, Aproximación de Taylor.

*The opinions contained herein are the sole responsibility of the authors and do not reflect those of Banco de la República or its Board of Governors. All errors and omissions remain our own.

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1. Introduction

The recent financial crisis underpinned the importance of strengthening risk management systems in financial markets. Specifically, it shed light on the dangers of over-relying on conventional measures of risk, such as VaR, to assess the potential exposure of market portfolios. Such measures, which provide acceptable risk estimations under normal market conditions, seem to fail miserably at the time when needed most: under a market crash. The reasons seem logical. On the one hand, VaR utilizes a variance-covariance structure that overstates the power of diversification (by estimating such parameters using all the available data), given that correlations during periods of financial turmoil are dangerously close to 1 between financial assets. Moreover, VaR tells us nothing about extreme market movements (i.e. the tails of the distribution), and so these must be analyzed separately.

Thus, an ever-increasing interest in other strategies to quantify risk under extreme scenarios has spawned. Regulators, policymakers and bankers alike have began to explore stress-testing techniques that can complement other traditional risk measures. One of such techniques is CrashMetrics (Wilmott (1998)). In its simplest form, CrashMetrics is a methodology for estimating the exposure of a portfolio to extreme market movements (i.e. worst-case scenarios). The methodology does not make any assumptions about the likelihood of the crash or its timing, and has no explicit dependence on volatility and correlation parameters. CrashMetrics assumes that during a crash all assets will move together, and thus tells us what is the worst possible loss that could happen in our portfolio under fire-sale conditions.

Even though CrashMetrics can be naturally extended to fixed income portfolios, as used here, it is originally thought as a measure of credit risk, where the change in the value of a portfolio of options is related to its underlying assets through the delta, gamma and theta. Unfortunately, there are no stock options in Colombia, and so instead of discarding the methodology altogether, we choose to extend its basic philosophy to the fixed income market. Therefore, the intention of the methodology explored in this paper is to provide an additional method for measuring market risk, as a complement of other tools such as VaR and CoVaR, and thus to enhance the stress-testing toolkit of policymakers and risk managers.

Using daily data for the period comprised between May, 2002 - December, 2011 on the duration and convexity of firm-specific public debt portfolios as well as the spot curve, we apply the CrashMetrics methodology to a total of 62 institutions (including credit intermediaries and non-bank financial institutions). We find that the methodology is an ideal complement to traditional stress testing techniques, providing not only a stringent loss scenario, but one that is cemented on an observed market shock and on the sensitivities of the change in portfolio value to said shock estimated with information from periods of financial turmoil. Moreover, our initial findings indicate that CrashMetrics supplies the highest valuation losses among the methodologies here considered. The latter is a result of the high concentration of financial institutions' portfolio in the middle-term of the yield curve, which is precisely were rates are more responsive to shocks in the benchmark asset (i.e the market). Finally, results suggest a high level of concentration in valuation losses in all types of financial institutions here considered, especially commercial banks and brokerage firms, were a small number of institutions garner a sizeable portion of total valuation losses.

Therefore, our initial findings indicate that the CrashMetrics methodology provides vital information from a prudential perspective, alerting policymakers of significant individual or sector-specific exposures to market risk. This would allow corrective action from the relevant authorities to be undertaken in a timely and efficient manner. It is also useful from an internal risk management standpoint, providing institutions with valuable information regarding their exposures at the tail of the distribution. In addition, the methodology also provides relevant information regarding the distinct sensitivities of interest rates along the term-structure of the yield curve. The latter is useful both in stress scenario-building and risk mitigation techniques. In other words, we strongly believe in the merits of including the methodology as part of the macroprudential stress testing toolkit of policymakers and risk management techniques of financial institutions, as it provides a natural complement to other, more traditional, measures of market risk.

The rest of this paper is organized as follows. Section 2 provides an overview of the CrashMetrics methodology. Section 3 illustrates the data used in applying the methodology to Colombia, while Section 4 presents the empirical application and key findings. Section 5 concludes.

2. The Methodology

Our interest lies in calculating the variation in the value of a portfolio given a significant change in the underlying assets (which we denote by $U_i \quad \forall\ i = 1, ..., N$). We know that there will be a relationship between the change in the value of the portfolio and the U_i's, which can be formally expressed as:

$$\Delta\Pi = F(\Delta U_1, \Delta U_2, ..., \Delta U_N) \tag{1}$$

where $\Delta\Pi$ is defined as the absolute change in the value of the portfolio (i.e. $\Pi_1 - \Pi_0$) and the ΔU_i's are the absolute changes in the underlying assets. The function $F(\cdot)$ generically represents (the sum of) all the formulae for each of the contracts in the portfolio.

Hence, the relevant question becomes how to define the ΔU_i's, given that each entity's portfolio will have many underlying assets (i.e. different yields in our case).

Fortunately, the CrashMetrics methodology has an intuitive and simple way of dealing with this dimensional problem, which we explain in more detail below.

2.1. The Multi-Asset/Single Index Model

The basic notion behind this model is that we can link all of the extreme movements in any one underlying asset in a portfolio to a single index or benchmark. The relative magnitude of such movements is captured by the so-called **crash coefficient** for each asset. Thus, if the benchmark index moves by x%, then the i-th underlying will move by $\kappa_i x$%. In estimating such a coefficient, we are only interested in relating **extreme** movements in the series, and so in calculating κ_i we only utilize the largest rises and falls in the benchmark index[1]. Hence, unlike the datasets of other methodologies used to estimate market risk (e.g. RiskMetrics[2]), the CrashMetrics methodology does not need constant updating, since it only utilizes extreme movements in the data and this are, by definition, rare events. Finally, note that the benchmark need not be an index comprised of the assets in the portfolio, but any representative quantity in the market.

[1] The criteria used to construct the **extreme** sample is discussed in Section 4.
[2] Morgan/Reuters (1996). RiskMetrics. Technical Document.

Once our crash coefficients are estimated, we need to define $F(\Delta U_1, \Delta U_2, ..., \Delta U_N)$ explicitly so as to relate the returns in the benchmark, which we denote by X, with the change in value of the portfolio. In other words, we wish to find a function such that:

$$F(\Delta U_i) = F(\kappa_i \cdot X) \tag{2}$$

And so the change in the value of the portfolio can be expressed as:

$$\Delta\Pi = F(\kappa_1 \cdot X, \kappa_2 \cdot X, ..., \kappa_N \cdot X) \tag{3}$$

For characterizing the functional form of $F(\cdot)$, we relate the returns of the benchmark asset with changes in the yield/spot curve (our underlying), and then translate such changes to the price of the bonds in the portfolio using a duration/convexity approximation (i.e. a Taylor expansion).

2.1.1. Taylor Expansion

Under this approach, the function $F(\cdot)$ is given by:

$$F(\cdot) = -\sum_{i=1}^{N} D_i \cdot W_i \cdot \Delta y_i + \frac{1}{2}\sum_{i=1}^{N} C_i \cdot W_i \cdot \Delta y_i^2 \tag{4}$$

And so the change in the value of the portfolio of each agent can be written as:

$$\Delta\Pi = -\sum_{i=1}^{N} D_i \cdot W_i \cdot \Delta y_i + \frac{1}{2}\sum_{i=1}^{N} C_i \cdot W_i \cdot \Delta y_i^2 \tag{5}$$

where Δy_i is the absolute change in the yield of bond i and D_i, C_i and W_i are the duration, convexity and current market value of the exposure to bond i in the portfolio, respectively. Next, we assume that the relation between the absolute change in the yield and the percentage change in the benchmark (i.e. X) can be expressed as:

$$\Delta y_i = \kappa_i \cdot X \tag{6}$$

And so the change in the value of the portfolio of each agent can be written as:

$$\Delta\Pi = -X\sum_{i=1}^{N} D_i \cdot W_i \cdot \kappa_i + \frac{1}{2}X^2\sum_{i=1}^{N} C_i \cdot W_i \cdot \kappa_i^2 \tag{7}$$

$$\Delta\Pi = -X \cdot D + \frac{1}{2}X^2 \cdot C \tag{8}$$

where C and D are defined as the **crash duration** and **crash convexity**, and represent a first-order and second-order exposure to the crash, respectively.

Finally, in order to calculate the *worst* portfolio change, one can use the historical distribution of the daily returns. Nonetheless, the Taylor approximation allows us to find an alternative analytical solution to the *worst* benchmark value. Formally, we can find X^{worst} by minimizing the portfolio change function. The latter yields:

$$\frac{\partial \Delta \Pi}{\partial X} \Rightarrow -D + X \cdot C = 0 \tag{9}$$

$$X^{worst} = \frac{D}{C} \tag{10}$$

which yields the following *worst* change in the value of the portfolio:

$$\Delta \Pi^{worst} = -\frac{D^2}{2C} \tag{11}$$

However, in our empirical application we choose to work only with the X^{worst} arising from the historical distribution of the benchmark's daily returns[3]. There are a couple of reasons for this. On the one hand, the analytical solution implies that each institution will have a unique X^{worst}, thus difficulting comparisons between different entities' loss calculations. Moreover, it is more realistic and practical, from a macroprudential perspective, to assume a uniform market shock affecting all entities when developing the stress scenario. Finally, aggregation of the losses resulting from the exercise becomes impractical, thus heavily reducing the usefulness from a macroprudential standpoint, where both individual and aggregate losses are crucial.

On a final note, notice that at no point in the methodology is there any consideration for the cross-correlations between assets. Indeed, we assume that, conditional on an extreme movement on the benchmark, all assets will move in conjunction. This is one of the fundamental assumptions underlining the CrashMetrics methodology; during a market crash, all assets fall together. In a nutshell, the methodology assumes perfect correlation between assets.

3. The Data

In carrying out our exercises, we use daily data for the period comprised between May, 2002 - December, 2011. Our dataset is comprised of the duration and convexity of firm-specific public debt portfolios as well as the spot curve. We use both credit intermediaries (31 commercial banks) and non-bank financial institutions (6 pension funds, 17 insurance companies and 8 brokerage firms[4]), for a total of 62 institutions[5]. We apply the CrashMetrics methodology at the firm-level (for the 62 institutions) and also for aggregated sectors, which additionally include commercial financing companies, upper-grade financial cooperatives and financial corporations in the credit institutions category, and trust companies in the non-banking segment.

All information related to the holdings of Government bonds and their idiosyncratic characteristics is from the Banco de la Republica's (Central Bank of Colombia) Securities Trading Registration System (DCV for its initials in Spanish). The spot curve is constructed at a daily frequency at the Banco de la República using the Nelson Siegel model (Nelson (1987)), and we use Government bonds Class B (i.e. TES-B)[6] in colombian pesos and UVRs (real value unit). We consider only the portion of these bonds

[3] The choice of X^{worst} is further discussed in Section 4 of this article.

[4] Given the substantial number of both insurance companies and brokerage firms, we use the "largest" life and general insurance companies and the "largest" brokerage firms. The criteria for "largest" was market-based, and included those institutions which due to the size of their portfolios, their trading volumes and/or overall connectivity in negotiation systems, are considered "important" to supervisors and other relevant market agents.

[5] As of December 2011, the total exposed amount of the public debt portfolio of these institutions represented 43.3% of total outstanding Government bonds.

[6] TES-B are Government securities which are traded in the secondary market.

that are tradable or available for sale (i.e. the exposed amount)[7], and all the bonds in our dataset are stripped, with each coupon being thus treated as an independent security. In other words, we work only with zero-coupon bonds.

Following RiskMetrics and similar to Arango et al. (2005) and Martinez & Uribe (2008), the cash flows of each security are mapped on risk factors to simplify the number of positions in the portfolio, assuming that those in the same maturity block face the same risk factor (Table 1).

Table 1: Maturity blocks from the mapping process

Months					Years									
0-1	1-3	3-6	6-9	9-12	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10

Once our database is organized in the 15 maturity blocks, the first step is to choose our benchmark, which will be related to each block through a regression analysis. In our case, the benchmark is a Government bonds index, called IDXTES, which summarizes the main characteristics of the public debt market in Colombia. This index, constructed by Reveiz & León (2008), includes fixed-rate bonds in colombian pesos, uses market capitalization in assigning the weights, contains only securities with a residual maturity longer than one year, and discards all bonds for which the time of issuance is no more than three months. We use the daily returns of the benchmark index in our exercises.

3.1. A Simplifying Caveat

Before proceeding into the details of the empirical application to the Colombian financial system, a clarifying simplification is in place. Note that the mapping into maturity blocks mentioned above, coupled with the fact that we are only working with zero-coupon bonds, effectively implies that we have simplified our asset space to 15 possible bonds in pesos and 15 in UVR. All bonds in the same maturity block will have the same price, yield, duration and convexity, and the amount outstanding for each intermediary will be represented by the sum of the total exposures included in the respective block. Our risk factors will simply be the spot rates of the average maturities of each of the 15 blocks.

Moreover, using zeroes simplifies our Taylor approximation exercise significantly, as the duration of each bond will be given by the time to maturity of the maturity block and the convexity will be this same time to maturity squared.

4. Empirical Application

As mentioned in Section 2, CrashMetrics evaluates the changes in the value of a portfolio during extreme market movements. In applying the methodology to fixed income portfolios, we develop an exercise for the identification of shocks that the portfolios would face when the whole market is in distress and consequently, the change in the value of the portfolios when the shocks occur.

The approach for determining the change in value of each entity's portfolio, as described before, is to assume a Taylor expansion. For this, we need to start with a regression to measure how changes in the

[7]In Colombia, investments can be classified as *i*) tradable, *ii*) available for sale and *iii*) held to maturity. Only the first two have to be marked-to-market and are therefore exposed to market risk.

benchmark's daily return (i.e. $X = r_{IDXTES_t}$) affect the absolute change of each block i's yield (i.e. $\Delta U_{i,t} = \Delta y_{block_{i,t}}$) :

$$\Delta y_{block_{i,t}} = \kappa_i r_{IDXTES_t} + e_{i,t} \tag{12}$$

It is important to highlight that the subscript i represents each maturity block (i.e. $i = 1, ..., 15$) and t refers to the date in which we are evaluating the relation between the returns of the benchmark and the change in yield. However, as CrashMetrics explores the relationship during periods of distress, t does not correspond to a continuous time series, but rather to the specific dates that we have identified as the best and worst returns.

The best and worst cases were selected using the 5^{th} and 95^{th} quantiles of the daily returns of the IDXTES series. The latter amount to 238 out of 2382 observations and primarily correspond to changes in price observed during 2002, 2006 and 2008. Although our high volatility sample includes observations for most years between 2002 and 2011, almost 50% occurred during the periods highlighted above, which have been indeed identified as moments of distress in the government bond market[8]. Daily returns during 2006 are the most frequent in our sample of worst cases, especially days during March-July. On the other hand, daily returns during 2002 (May-November) resulted as the most common for exceptionally high price increments. Daily returns during 2008 are part of our high volatility sample in both positive and negative cases, due to increased uncertainty as a consequence of the international financial crises.

Figure 1 shows the correlation coefficient between the changes of each block's yield and the returns of the benchmark, considering the best and worst cases and also for the whole sample. As we can see, in both cases (pesos and UVRs) the correlation coefficient initially increases (in absolute value) with maturity, reaches the highest point around block 10-12 and decreases again. The figure has almost the same shape for both samples, however, the correlation between the variables is much stronger during periods of high volatility.

Figure 2 presents the estimated coefficients for each block[9]. These coefficients have been obtained from a robust estimation which ensures that the error terms are homoscedastic and present no autocorrelation. Consistent with the correlation coefficients presented in Figure 1, the absolute value of the estimated coefficients initially increases with maturity, until around block 6 for pesos and block 12 for UVR's, and then decreases for the last maturity blocks. Moreover, the estimated coefficients are also significantly higher when we consider the best and worst returns only, which confirms the fact that the relationship between the change in yields and the benchmark's return is stronger during periods of high volatility.

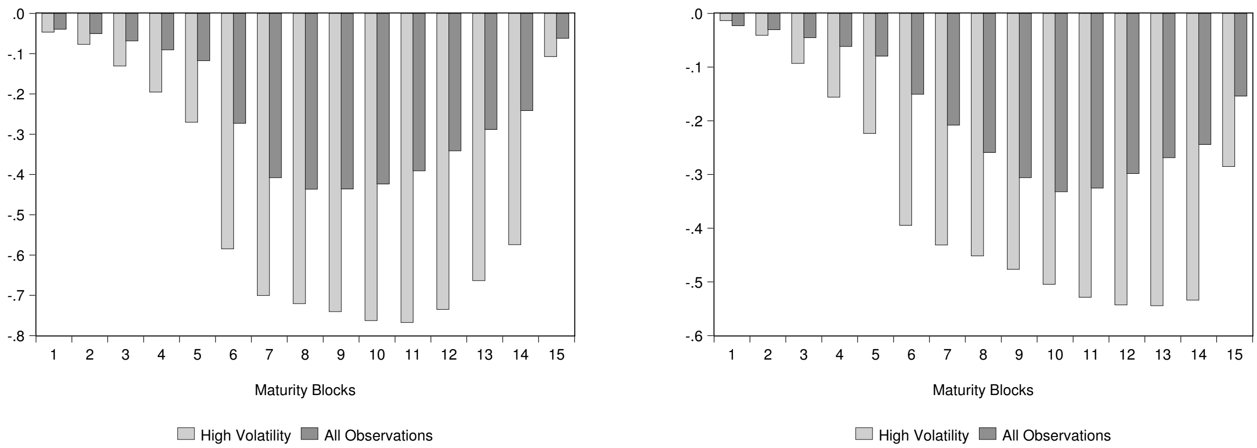
In what follows, we refer to these coefficients (i.e. high volatility) and the calculations that arise from their use as the CrashMetrics results. This is so as to differentiate them from those used to make comparisons, such as the results obtained when estimating the κ_i's using the entire sample and those

[8]See Gómez et al. (2011) for a more detailed discussion of these periods of turmoil in the Government bond market.

[9]Coefficient values along with their statistical significance can be found in Table 6 in Appendix A. Importantly, all coefficients are significant (albeit some at the 90% confidence level) when estimating the κ_i's using all available information. When using only the high volatility sample, all coefficients are significant except those pertaining to the shortest maturity block (0-1 month) for both pesos and UVRs, and that associated to the 1-3 month maturity block for UVRs.

Figure 1: Correlation Between Returns on the Benchmark and Changes in the TES-B Yield Curve

A. Pesos B. UVR

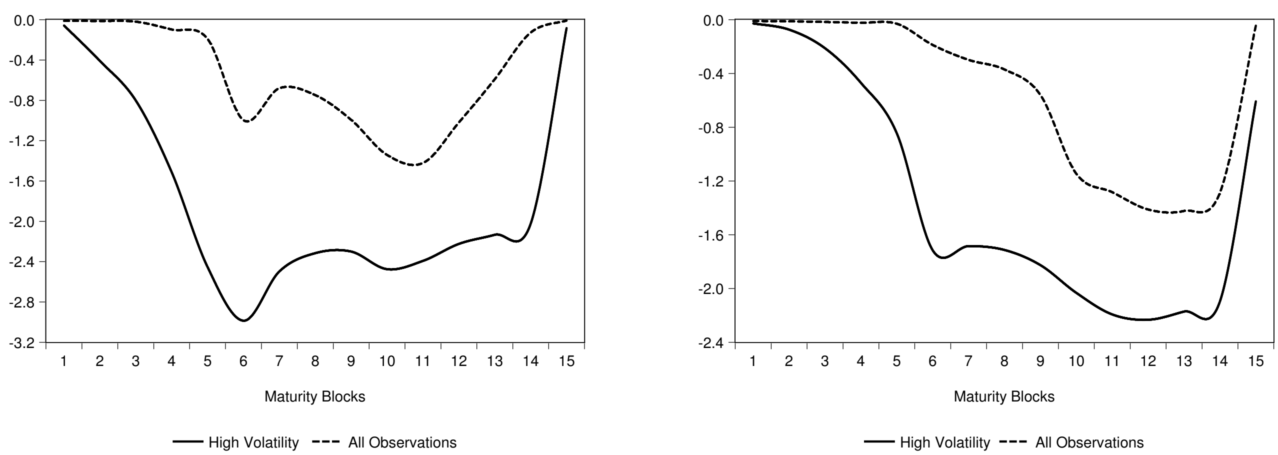


Source: DCV, Banco de la República. Own calculations.

from an alternative stress methodology, namely, the 200 basis points (bp) parallel shift in the yield curve as suggested by Basel II (see BIS (1996))[10,11].

Figure 2: Estimated Coefficients for Each Maturity Block

A. Pesos B. UVR



Source: DCV, Banco de la República. Own calculations.

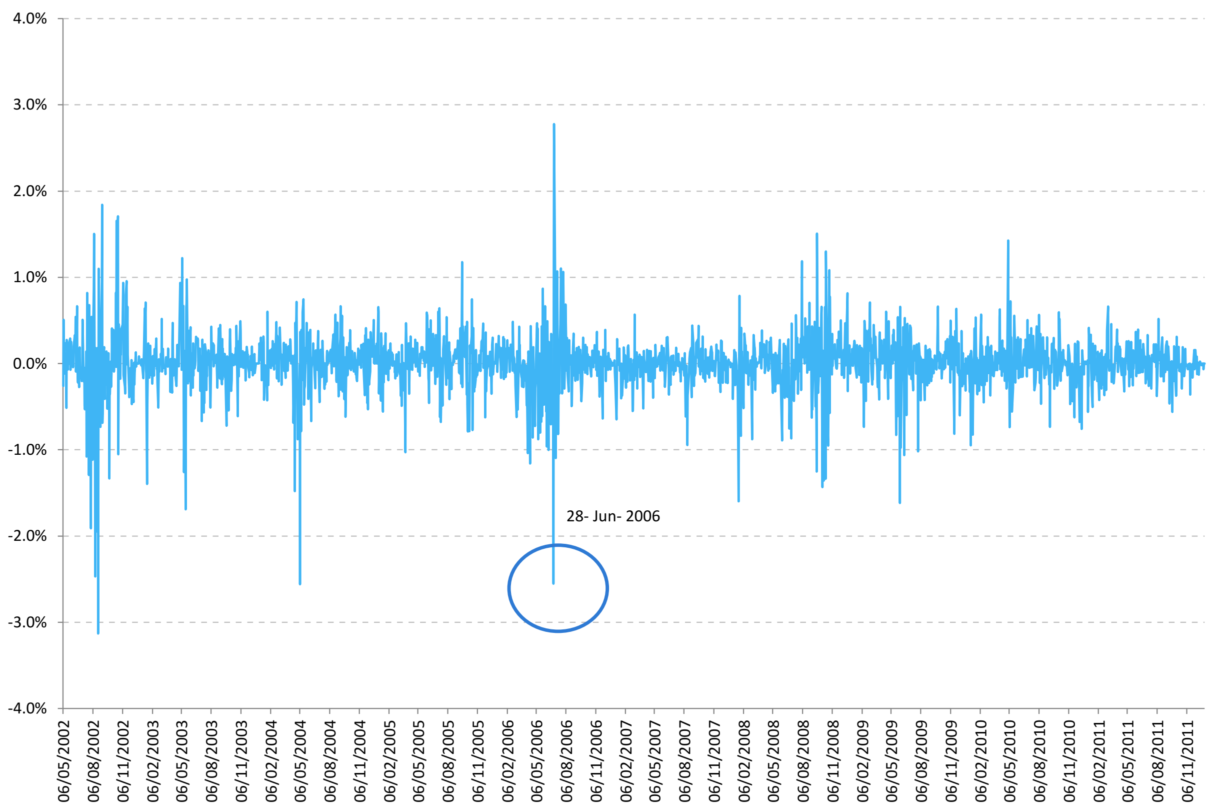
[10]In it simplest form, the methodology consists of pricing each bond with the last observed yield curve and then assuming a parallel shift of 200bp. The difference between the value of the assets under both scenarios, as a percent of total portfolio value, is defined as the risk measure.

[11]In Colombia we also calculate VaR for the same institutions considered here. However, in this paper we only include results from the parallel shift, as they provide a more stringent stress scenario with which to compare against.

4.1. Key Results

In assuming the size of X, we choose to work with the worst observed daily return of the last 6 years. This corresponds to a change of -2.55% in daily prices on June 28, 2006, coherent with a period of turmoil in public debt markets (i.e. $X^{worst} = -2.55\%$). The latter was a result of investors' expectations concerning the future path of monetary policy in the United States, which led them to liquidate their positions in emerging economies in the face of possible increments in foreign rates (Reporte de Estabilidad Financiera (2006)). A careful look at Figure 3 reveals that during 2002 a more pronounced fall in the benchmark was observed. However, the public debt market was still incipient during 2002, and so we chose to work with a shock in prices observed during a period where the market exhibited a level of depth akin to that observed and expected in coming years[12].

Figure 3: Daily Returns of the Benchmark
(IDXTES)



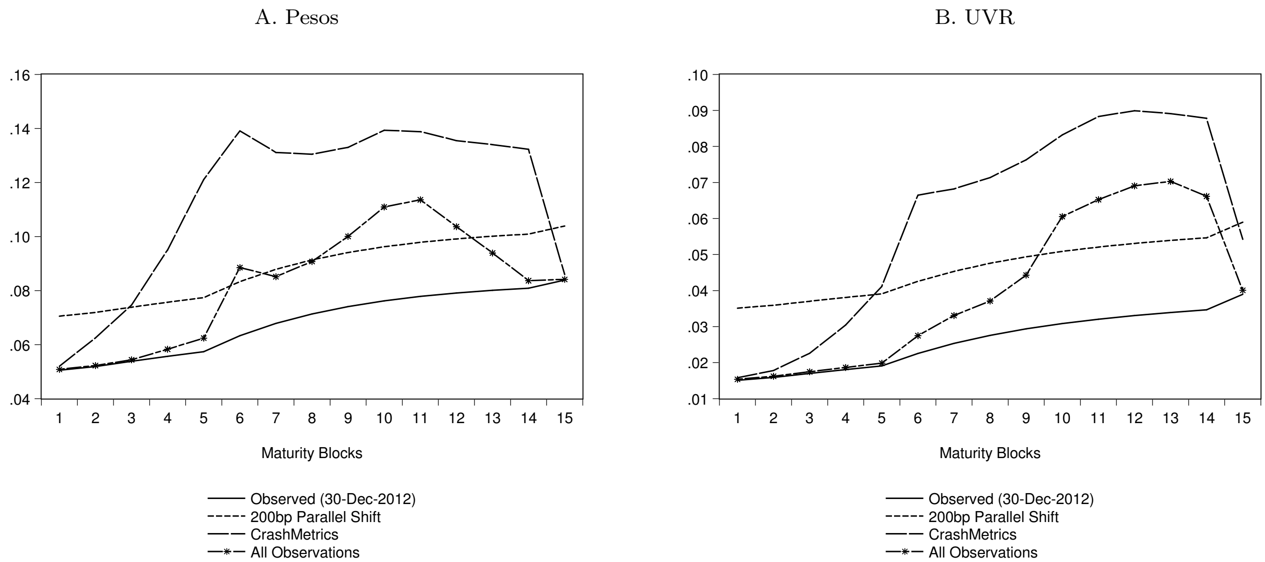
Source: DCV, Banco de la República.

Thus, with the estimated sensitivity of the yields to changes in the benchmark (i.e. the $\widehat{\kappa_i}$'s) and the size of X, we can approximate the change in the spot rate at each maturity block (i.e. $\Delta\widehat{y_i} = \widehat{\kappa_i} \cdot X$). Figure 4 depicts the observed spot curve (December 30, 2011) as well as those resulting from the 200bp parallel shift and from the -2,55% return on prices using both estimates of the κ_i's (i.e. only with high volatility returns and with all observations). As can be readily observed, the spot curve obtained using CrashMetrics is always above those from the other stress methodologies, except for the shortest stretch

[12]The total amount outstanding of government bonds in 2002 was just COP$50 billion (total credit was also equal to COP$50 billion). In 2006, the total amount outstanding had more than doubled to COP$115 billion (total credit, COP$98 billion).

of both the pesos and UVR curve, where the parallel shift results in higher rates. Moreover, the curve resulting from the 200bp parallel shift seems to be more stringent than that obtained estimating the κ_i's with all observations in the short and middle part of the curve. In effect, the former is always above the UVR curve from blocks 1-9, and is only less severe than the latter in the 9-12 maturity blocks of the peso curve.

FIGURE 4: TES Spot Curves



Source: DCV, Banco de la República. Own calculations.

Having obtained the changes in the relevant spot rates, we can approximate the *worst* variation in the value of each entity's (sector's) portfolio ($\Delta\Pi$) by using the Taylor expansion, where we also include the total exposure to each block (W_i) and the duration (D_i) and convexity (C_i), as follows:

$$\Delta\Pi^{worst} = X^{worst} \sum_{i=1}^{N} -D_i \cdot W_i \cdot \widehat{\kappa}_i + \frac{1}{2} X^{2^{worst}} \sum_{i=1}^{N} C_i \cdot W_i \cdot \widehat{\kappa}_i{}^2 \qquad (13)$$

Table 2 presents total valuation losses as a percentage of portfolio value[13]. When we assume a change of -2.55% in the value of the benchmark, under the CrashMetrics methodology, we find that the one-day valuation losses of the portfolio reach 13% of total exposure as of December 30, 2011 for commercial banks, 23.4% for pension fund managers, 19% for insurance companies and 8.6% for brokerage firms. Not surprisingly, credit establishments (i.e. commercial banks, financial corporations, commercial financing companies and upper-grade financial cooperatives) and non-banking financial institutions (i.e pension fund managers, trust companies, insurance companies and brokerage firms) all show a higher loss when applying the CrashMetrics methodology than when using the 200bp parallel shift suggested by Basel II or when applying the same return on the benchmark but utilizing the κ_i's estimated with all the observations in the sample.

[13]Valuation losses in millions of US dollars can be found in Table 4 in Appendix A.

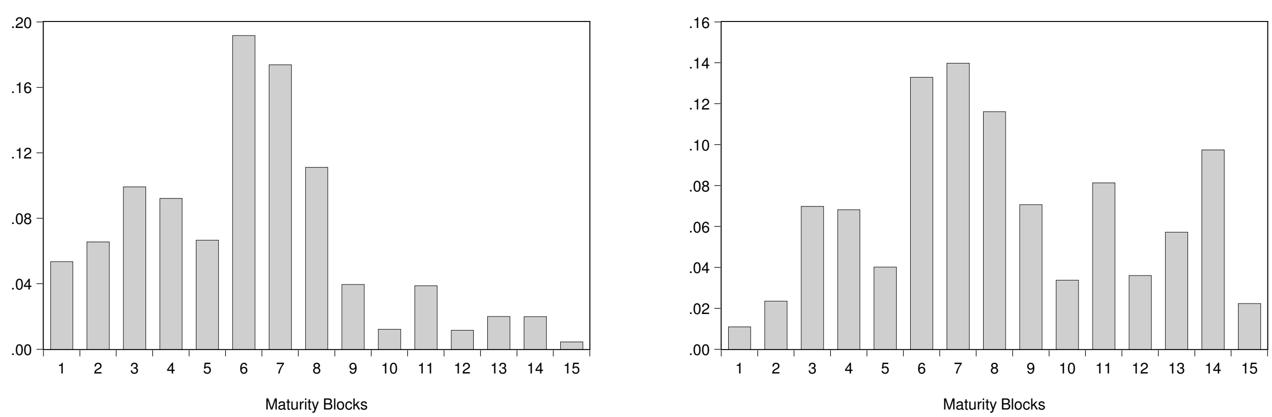
Table 2: Valuation Losses as a Percentage of Portfolio Value
(December 30, 2011)

	Shock		
Financial Institutions	**Basel II**	**Daily return on benchmark of -2.55%**	
	200bp Parallel Shift	CrashMetrics	All Observations
Commercial Banks	*4.9%*	*13.0%*	*4.7%*
Financial Corporations	*7.6%*	*18.2%*	*6.5%*
Commercial Financing Companies	*2.8%*	*8.1%*	*2.6%*
Upper-grade Financial Cooperatives	*2.6%*	*7.7%*	*2.2%*
Pension Fund Managers	*12.2%*	*23.4%*	*9.7%*
Trust Companies	*6.9%*	*16.5%*	*6.2%*
Insurance Companies	*8.8%*	*19.0%*	*8.0%*
Brokerage Firms	*3.5%*	*8.6%*	*2.6%*

As mentioned above, CrashMetrics provides the harshest loss scenario between the methodologies here considered. This is a direct result of the high concentration of financial institutions' portfolio in the middle-term of the yield curve, both in pesos and UVRs, which is precisely were rates are more responsive to shocks in the benchmark asset. As can be seen in Figure 5, both credit establishments and non-bank financial institutions seem to be heavily concentrated in TES-pesos in the middle-term of the spot curve, where the difference between the rates resulting from the CrashMetrics shock and those from the parallel shift are more pronounced. The argument is analogous for TES-UVR (see Figure 6). Nevertheless, it is important to note that, while losses for credit establishments arise almost exclusively from their TES-pesos positions, they seem to be more for evenly distributed between pesos and UVRs for non-banks. The latter is due to a significant difference in the relative weights of the portfolio in terms of currency. While credit establishments hold an average 4.1% of their total portfolio in TES-UVR, this participation reaches 35.7% for non-bank financial institutions[14].

Figure 5: Holdings of TES - pesos by Maturity Block
(Average Intermediary)

A. Credit Establishments B. Non-Bank Financial Institutions

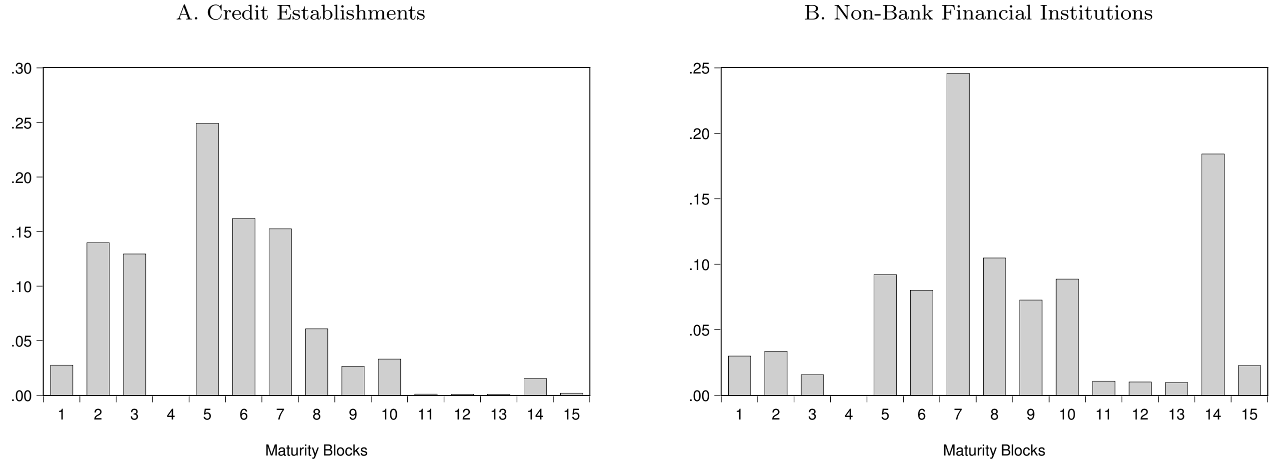


Source: DCV, Banco de la República.

[14]The composition of the portfolio by currency for all financial institutions can be found in Table 5 in Appendix A.

Figure 6: Holdings of TES - UVR by Maturity Block

(Average Intermediary)



Source: DCV, Banco de la República.

Analyzing valuation losses at a firm-specific level also gives rise to interesting insights. Table 3 presents the loss arising from each stress scenario considered as a percentage of the total loss from the CrashMetrics exercise for each type of financial institution. In order to synthesize the relevant information, we only include the institutions that, on aggregate, represent more than 50% of total losses for the sector. As can be seen, these are 4 commercial banks (50%), 2 pension funds (55.1%), 3 insurance companies (53.3%) and 1 brokerage firm (52.9%)[15]. These results suggest a high level of concentration in valuation losses in all types of financial institutions here considered, especially in brokerage firms and commercial banks, were a small number of institutions, relative to the size of the sector, amass a significant portion of total valuation losses. On a final note, these disaggregate results also provide vital information from a prudential perspective, as they can alert policymakers of significant individual exposures to market risk. The latter would allow preemptive action to be undertaken in a focalized and efficient manner.

Hence, our results suggest that implementing CrashMetrics as an alternative stress methodology seems justified. First, contrary to the Basel Committee's 200bp parallel shift, the shock is not entirely hypothetical, but rather grounded on the historical distribution of the benchmark asset. Secondly, the estimation of the sensitivity parameters (i.e. the $\widehat{\kappa_i}$'s) guarantees that the *stressed* yield curve correctly incorporates the distinct sensitivities of spot rates at different maturities, rather than assuming a homogeneous response to a market shock throughout the entire term structure of the curve. Additionally, the CrashMetrics methodology, by utilizing only the highest and lowest returns in the dataset, guarantees an estimation of the sensitivity parameters that effectively captures the statistical relationship that arises during times of market turmoil (when correlations between assets dramatically increase), thus providing a better risk measure than that obtained estimating the κ_i's using all available information. Last but not least, the methodology provides the most acid valuation loss scenario, which coupled with the factores mentioned above, makes it an ideal stress testing tool for macroprudential, supervisory and internal risk management purposes.

[15]In our sample, there are a total of 31 commercial banks, 6 pension fund managers, 17 insurance companies and 8 brokerage firms. Hence, the number of institutions that accumulate more than 50% of total losses represent 12.9%, 33.3%, 17.6% and 12.5% of the total number of institutions for each sector, respectively.

Table 3: Valuation Losses as a Percentage of Total Sector Losses
(December 30, 2011)

		Shock		
		Basel II	**Daily return on benchmark of -2.55%**	
Financial Institutions	#	200bp Parallel Shift	CrashMetrics	All Observations
Commercial Banks	1	*8.11%*	*18.89%*	*7.67%*
	2	*4.93%*	*13.60%*	*4.57%*
	3	*2.88%*	*8.55%*	*2.72%*
	4	*3.05%*	*8.26%*	*3.06%*
Pension Fund Managers	1	*15.80%*	*28.47%*	*10.50%*
	2	*13.15%*	*26.67%*	*12.12%*
Insurance Companies	1	*13.37%*	*31.49%*	*12.25%*
	2	*5.97%*	*11.07%*	*5.87%*
	3	*5.43%*	*10.71%*	*5.18%*
Brokerage Firms	1	*33.89%*	*52.87%*	*17.50%*

5. Concluding Remarks

In this paper, we have provided an alternative measure of market risk for financial institutions. The main contribution from the proposed methodology lies on exploiting the fact that the relationship between the returns of the assets in a portfolio and those of the market is stronger under periods of financial turmoil in comparison to normal times. Thus, by definition, the change in the value of the portfolio resultant from a shock to the market under such circumstances will differ from those regularly assumed in stress-testing exercises.

CrashMetrics is a methodology that first estimates the relationship between the assets in a portfolio and the market during times of distress, without any assumption about the likelihood of a crash or its timing, and with no explicit dependence on volatility and correlation parameters. Rather, it assumes that during a crash all assets will move together, and thus tells us what is the worst possible loss that could happen in our portfolio under fire-sale conditions. This measure is, together with other methodologies such as VaR and CoVaR, an important tool for policymakers, regulators and financial institutions in quantifying the losses that any fixed income portfolio will face when the whole market is in distress.

It is also relevant to note that CrashMetrics presents several advantages in comparison to other methodologies. First, it does not rely on many assumptions that could deviate the exercise from reality (e.g. distribution of returns, covariance structure, among others). Moreover, it allows us to account for the losses in a portfolio when there are extreme movements in the market, which makes the methodology an excellent tool for identifying the response of such portfolios in worst-case scenarios. Additionally, it does not require to be updated constantly, since once the relation between the assets and the market is established, the only additional work is to update the composition of the portfolios with the latest information available. Last but not least, CrashMetrics allows us to approximate the change in the term-structure of interest rates in a less arbitrary manner than assuming a parallel shift.

Results show that with the CrashMetrics methodology we find higher valuation losses for all sectors and for individual entities when compared to those attained assuming the 200bp shift in the yield curve proposed by Basel II. Given the strong correlation between yields at different maturities and market returns, especially during times of financial distress, the resulting changes in interest rates are generally above 200bp, and consequently, the losses experienced by the institutions are also above those from the

Basel shock. In addition, since we have calculated the losses for each sector and institution separately, we have been able to identify the financial institutions that experience the greatest losses for each sector as well as the high concentration in valuation losses that exists, mainly in brokerage firms and commercial banks. Both results represent important findings for financial regulators, supervisors and risk managers alike.

All in all, we strongly encourage the adoption of CrashMetrics as an integral part of the macroprudential stress-testing toolkit. Not only does the methodology provide interesting insights as to the exposure of financial institutions to market risk, but additionally, exploits the distinct sensitivities of the term structure of the yield curve to a market-wide shock, making the stress scenario less hypothetical and more informative for policymakers.

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Appendix A

Table 4: Valuation Losses in Millions of USD
(December 30, 2011)

	Shock		
	Basel II	**Daily return on benchmark of -2.55%**	
Financial Institutions	200bp Parallel Shift	CrashMetrics	All Observations
Commercial Banks	*531.5*	*1395.3*	*499.8*
Financial Corporations	*25.7*	*61.6*	*21.9*
Commercial Financing Companies	*4.0*	*11.8*	*3.8*
Upper-grade Financial Cooperatives	*0.2*	*0.6*	*0.2*
Pension Fund Managers	*2428.3*	*4665.9*	*1928.8*
Trust Companies	*1077.4*	*2573.7*	*965.0*
Insurance Companies	*211.8*	*458.5*	*193.4*
Brokerage Firms	*15.2*	*37.1*	*11.3*

Table 5: Composition of the Portfolio by Currency
(December 30, 2011)

Financial Institutions	**Pesos**	**UVR**
Commercial Banks	*89.3%*	*10.7%*
Financial Corporations	*97.4%*	*2.6%*
Commercial Financing Companies	*98.2%*	*1.8%*
Upper-grade Financial Cooperatives	*98.7%*	*1.3%*
Pension Fund Managers	*57.0%*	*43.0%*
Trust Companies	*84.7%*	*15.3%*
Insurance Companies	*52.3%*	*47.7%*
Brokerage Firms	*63.4%*	*36.6%*

Table 6: Regression Coefficients and Statistical Significance

	CrashMetrics				**All Observations**			
Maturity	Pesos		UVR		Pesos		UVR	
Block	Coefficient	P-Value	Coefficient	P-Value	Coefficient	P-Value	Coefficient	P-Value
0-1	-0.06	*0.47*	-0.03	*0.75*	-0.01**	*0.04*	-0.01***	*0.07*
1-3	-0.41*	*0.00*	-0.07	*0.45*	-0.01**	*0.02*	-0.01***	*0.06*
3-6	-0.8*	*0.00*	-0.21***	*0.09*	-0.02*	*0.00*	-0.02**	*0.03*
6-9	-1.51*	*0.00*	-0.47*	*0.00*	-0.1*	*0.00*	-0.02**	*0.02*
9-12	-2.45*	*0.00*	-0.85*	*0.00*	-0.19*	*0.00*	-0.03*	*0.01*
1-2	-2.99*	*0.00*	-1.72*	*0.00*	-1*	*0.00*	-0.19*	*0.00*
2-3	-2.5*	*0.00*	-1.69*	*0.00*	-0.68*	*0.00*	-0.3*	*0.00*
3-4	-2.32*	*0.00*	-1.71*	*0.00*	-0.75*	*0.00*	-0.37*	*0.00*
4-5	-2.3*	*0.00*	-1.83*	*0.00*	-1*	*0.00*	-0.56*	*0.00*
5-6	-2.48*	*0.00*	-2.03*	*0.00*	-1.34*	*0.00*	-1.15*	*0.00*
6-7	-2.39*	*0.00*	-2.19*	*0.00*	-1.42*	*0.00*	-1.28*	*0.00*
7-8	-2.23*	*0.00*	-2.23*	*0.00*	-1.02*	*0.00*	-1.41*	*0.00*
8-9	-2.13*	*0.00*	-2.17*	*0.00*	-0.59*	*0.00*	-1.42*	*0.00*
9-10	-2.02*	*0.00*	-2.09*	*0.00*	-0.13*	*0.00*	-1.29*	*0.00*
>10	-0.08***	*0.06*	-0.61*	*0.00*	-0.01*	*0.01*	-0.04*	*0.00*

* Significant at the 99% confidence level, ** Significant at the 95% confidence level, *** Significant at the 90% confidence level