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Premiums in the Sovereign CDS Market

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Ce document de recherche a été rédigée par :

Hitesh Doshi, University of Houston
Kris Jacobs, University of Houston
Carlos Zurita, University of Houston

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Economic and Financial Determinants of Credit Risk
Premiums in the Sovereign CDS Market*

Hitesh Doshi       Kris Jacobs       Carlos Zurita
University of Houston

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Abstract
We specify and estimate no-arbitrage models for sovereign CDS contracts by assuming that the country’s default intensity depends on observable economic and financial indicators. We estimate these models using a sample of twenty-eight countries, three CDS maturities, and over a decade of daily data. The models provide a good fit. The impact of the economic and financial variables on spreads is consistent with economic intuition. Spreads increase as a function of stock market and exchange rate volatility, but decrease as a function of interest rates and stock market returns. The magnitudes of these impacts vary substantially across countries and over time. Estimated risk premiums are also highly time-varying and peak during the 2008 financial crisis for nearly all countries. For European countries, the risk premiums are also high during the Eurozone debt crisis. In periods of market stress and high CDS spreads, the increase in market risk premiums is even larger than the increase in default probabilities. The cross-sectional variation in risk premiums across countries is high, also in non-crisis periods.

JEL Classification: G12

Keywords: credit default swap; sovereign risk; risk premiums; economic determinants; financial crisis.

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1 Introduction

Corporate and sovereign credit default swap (CDS) markets have expanded in size over the last decade, and modeling CDS spreads has therefore become more important both from a risk management and a portfolio management perspective. Moreover, a decade ago the relevance of sovereign risk seemed limited to emerging economies in Latin America and Asia, but following the U.S. debt downgrade in August 2011 and the Eurozone debt crisis, the study of sovereign risk has suddenly taken center stage. The determinants of sovereign credit spreads and the sources of the differences in spread levels between countries are thus a topic of considerable interest.

Following the increased availability of reliable CDS data over the last few years, the empirical literature on corporate CDS spreads has grown rapidly. The literature on sovereign CDS spreads has also developed but not as rapidly. From an analytical perspective, there is an important difference between sovereign and corporate CDS markets. Whereas there is consensus that variables such as interest rates, asset or equity volatility, and leverage should matter for corporate CDS spreads, following the logic of structural models such as Merton (1974), no such simple encompassing theory is available for sovereign CDS. The economics literature of course has a rich history of highlighting macroeconomic factors that are likely to influence sovereign default and sovereign credit risk, such as debt-to-GDP ratios and the terms of trade, but these are largely empirical discussions, and identifying parsimonious sets of variables that are prime candidates for explaining sovereign CDS spreads is not straightforward.

This paper contributes to the expanding literature on sovereign credit risk, and sovereign CDS in particular. The recent literature contains two very different approaches to analyze sovereign CDS. Several studies use so-called reduced-form models of credit risk, see for example Pan and Singleton (2008) and Longstaff, Pan, Pedersen, and Singleton (2011). These models originate in the term-structure literature and start by specifying a default intensity that depends on a number of latent factors or state variables. Given the specification of the default intensity, the CDS spread can be obtained as a function of the same latent factors. The advantage of this approach is that one can increase the number of factors and choose the appropriate statistical specification to achieve a good fit. These models are typically estimated using different CDS

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2 See for instance Pan and Singleton (2008), Longstaff, Pan, Pedersen and Singleton (2011), Ang and Longstaff (2013), Augustin (2012), Benzoni, Collin-Dufresne, Goldstein, and Helwege (2011), and Dieckmann and Plank (2012) for recent studies of sovereign CDS. See also Duffie, Pedersen, and Singleton (2003), and Hilscher and Nosbusch (2010) for recent studies of sovereign debt.
maturities, and absence of arbitrage is imposed to ensure pricing consistency across maturities. This also allows for estimation of the price of risk and risk premiums.

Other studies analyze sovereign CDS spreads by regressing the spreads on (macro) economic and financial determinants of credit spreads. The advantage of this approach compared to reduced form models with latent factors is that it provides more intuition on the economic determinants of sovereign default. The disadvantage of the regression approach is that it does not provide as good a fit as the reduced-form latent models, and the regressions are estimated for each maturity separately so that there is no pricing consistency across maturities. Furthermore, estimated CDS spreads can be negative. Longstaff, Pan, Pedersen, and Singleton (2011) use linear regression to determine the relative importance of global and local factors in sovereign credit spreads. Dieckmann and Plank (2012) provide an exhaustive analysis of potential determinants of sovereign CDS spreads using linear regression.

This paper combines the advantages of both approaches. We use the framework of Doshi, Ericsson, Jacobs, and Turnbull (2013), who value corporate CDS in a reduced-form framework with intensities that are functions of observable covariates. This approach combines the advantages of linear regressions on observable covariates and the reduced-form approach. It readily provides economic intuition, but additionally the pricing is consistent across maturities, and risk premiums are obtained as a by-product of the estimation. Moreover, we specify the country’s default intensity as a quadratic function of observable economic and financial indicators, guaranteeing positive default intensities at all times. To the best of our knowledge, ours is the first attempt at modeling sovereign risk premia with observable covariates within a no-arbitrage framework.

Just as in the case of linear regressions, the selection of observable covariates is not straightforward. There is no consensus theory to guide the specification search, and economic intuition suggests a large number of variables that ought to influence sovereign default probabilities. However, parsimony ought to be a guiding principle, because for this type of model, the numerical optimization becomes more time-consuming and less reliable when the number of parameters increases. We select a parsimonious benchmark model with four covariates based on the explanatory power of the observable variables. A substantial part of the variation in CDS spread can be explained by global factors such as the VIX, and therefore we use global factors as well as country-specific factors.

Our preferred benchmark model contains four determinants of the countries’ default intensities: the U.S. interest rate, the VIX stock market volatility index, the one-year trailing return on the country’s stock market index, and the implied exchange rate volatility for the country’s currency. We estimate this model using a sample of twenty-eight countries. For each country we have over a decade’s worth of daily data, and we use the 1-year, 5-year, and 10-year tenors in
The impact of the economic and financial variables on spreads varies substantially across countries and over time, and is consistent with economic intuition. In the benchmark model, spreads increase as a function of stock market and exchange rate volatility, but decrease as a function of interest rates and stock market returns. Estimated risk premiums are highly time-varying and peak during the 2008 financial crisis for nearly all countries. For Eurozone countries the risk premiums are also high during the Eurozone debt crisis. This means that in periods of market stress and high CDS spreads, the increase in market risk aversion is even larger than the increase in default probabilities. Outside of the financial crisis, the variation in risk premiums across countries is also very large. Some of this variation is driven by different exposures to global factors, and some of it is country-specific. We document an interesting relation between the term-structure slopes in the CDS spreads and the credit risk premiums. In the 2008 crisis these slopes are clearly inversely related, but this is not the case pre- and post-crisis.

We also report on two more richly specified models, which include the one year local swap rate and the terms of trade. These models improve the fit but not dramatically so. Importantly, they provide similar economic intuition regarding the size and time variation in risk premiums and the impact of observable covariates on spreads.

The paper proceeds as follows. Section 2 outlines the model. Section 3 briefly summarizes the data and the estimation method. Section 4 presents a case study for two countries, Poland and Mexico, to show that the risk premiums and the sensitivities obtained from the model are intuitively plausible. Section 5 discusses the empirical results, with particular attention for risk premiums and common trends across the countries in the sample. Section 6 discusses alternative model specifications and robustness exercises. Section 7 documents the correlations between CDS spreads and risk premiums across different geographical regions. Section 8 concludes.

2 The Model

In this section, we describe the model used for CDS valuation. We work in discrete time and assume that the observable macroeconomic and financial factors are described by autoregressive processes. We also specify the market prices of risk.

2.1 Credit Default Swap Valuation

We use the quadratic framework of Doshi, Ericsson, Jacobs, and Turnbull (2013), who value corporate CDS based on the dynamics of observable covariates. The resulting models are easier
to estimate than models with latent dynamics because there is no need to filter latent state variables from CDS prices.\footnote{See Gourieroux, Monfort, and Polimenis (2006) for discrete-time default models. See Lando (1994, 1998) for models of default based on observable covariates. See Bekaert, Cho, and Moreno (2006) and Ang and Piazzesi (2003) for term structure models with observables within discrete-time affine Gaussian frameworks.} A stopping time has an intensity process \( \lambda(t) \). Given no default up to time \( t \), the probability of no default over the next interval is \( \exp(-\lambda(t)) \). The probability for an obligor surviving until at least time \( h \) is given by

\[
P_t[\tau > t + h] = E_t \left[ \exp \left( - \sum_{j=0}^{h-1} \lambda_{t+j} \right) \right],
\]

where \( \tau \) denotes the time of default. The default intensity of each country is assumed to be a quadratic function of common factors that affect all countries, denoted by \( X_{k,t}^w \), and country-specific factors denoted by \( X_{k,t}^c \)

\[
\lambda_t = \left( \alpha_0 + \sum_{k=1}^{n} \alpha_k^w X_{k,t}^w + \sum_{k=1}^{m} \alpha_k^c X_{k,t}^c \right)^2,
\]

where \( n \) is the number of common factors and \( m \) the number of country-specific covariates. The advantage of a quadratic specification over a Gaussian specification is that the intensity function is strictly positive. Defining \( q = n + m \) and stacking \( X_t^w \) and \( X_t^c \) in the \( q \) by 1 vector \( X_t \), we can write

\[
\lambda_t = \gamma_0 + \gamma_1 X_t + X_t^\prime \Omega X_t,
\]

We assume that the covariates \( X_t \) are described by the following dynamics under the risk-neutral measure,

\[
X_t = \mu + \rho X_{t-1} + \Sigma e_t,
\]

where \( e_t \sim N(0, I) \), \( \mu \) is a \( (q, 1) \) vector, and \( \rho \) and \( \Sigma \) are \( (q, q) \) matrices that we assume to be diagonal for simplicity.

Consider the payments by the CDS protection buyer, who typically makes an initial payment and a series of quarterly payments. In our CDS sample, we are provided with the spread and the initial payment is zero, so we ignore it in the pricing. Let \( S \) denote the CDS spread. The protection buyer promises to make payments \( S \Delta \) each quarter, conditional on no default by the reference obligor, where \( \Delta \) is the time between payment dates. If a credit event occurs, the protection buyer receives a payment from the protection seller and the contract terminates. The
present value of the payments by the protection buyer is

\[ PB_t = E_t \left[ S \Delta \sum_{j=1}^{h} 1_{(\tau > t + j)} B(t, t + j) \right], \tag{2.5} \]

where \( 1 \) denotes the indicator function and \( B(t, t + j) \) is the riskless discount rate, which is assumed to be deterministic. Doshi, Ericsson, Jacobs, and Turnbull (2013) show that

\[ B(t, t + j) E_t[1_{(\tau > t + j)}] = B(t, t + j) \times \exp(F_j + G_j X_t + X_j H_j X_t), \tag{2.6} \]

where the coefficients \( F_j, G_j, \) and \( H_j \) are derived recursively. The protection seller will make a payment of \((1 - R)\) per dollar of notional, where \( R \) is the recovery rate, if a default event occurs. We assume that if a default event occurs during the interval \((t + j - 1, t + j)\), payment by the protection seller is made at the end of the interval. The present value of the promised payment by the protection seller is

\[ PS_t = E_t \left[ (1 - R) \sum_{j=1}^{h} 1_{(t + j - 1 < \tau \leq t + j)} B(t, t + j) \right]. \]

Assuming that the recovery rate is known and constant,\(^4\) this gives

\[ PS_t = (1 - R) \left( E_t \left[ \sum_{j=1}^{h} 1_{(\tau > t + j - 1)} B(t, t + j) \right] - E_t \left[ \sum_{j=1}^{h} 1_{(\tau > t + j)} B(t, t + j) \right] \right), \tag{2.7} \]

where both expectations on the right side are of the form (2.6). The spread of the CDS is set such that

\[ PB_t = PS_t. \tag{2.8} \]

### 2.2 The Market Prices of Risk

Section 2.1 introduces the pricing model under the risk-neutral measure \( Q \). We now specify the market prices of risk. To change from the risk-neutral measure to the physical measure, we

\(^4\)The assumption of a constant recovery rate can be relaxed. We experimented with stochastic recovery rates but found that the resulting model is subject to serious econometric identification issues, confirming the findings of Pan and Singleton (2008).
specify the Radon–Nikodym derivative to take the form

\[ \frac{\Delta P}{\Delta Q} = \frac{\exp(-\Lambda_{t-1} e_t)}{E_{t-1}[\exp(-\Lambda_{t-1} e_t)]}, \]  

(2.9)

where \( \Lambda_t \) is a \( q \times 1 \) vector, with \( q \) the number of factors that are priced. Given this assumption and the risk-neutral dynamic (2.4), the dynamics of the state variables \( X_t \) under the physical measure are given by

\[ X_t = \mu + \rho X_{t-1} + \Sigma e_t - \Sigma \Lambda_{t-1}. \]  

(2.10)

We assume time-varying prices of risk that are a linear function of the state variables:\(^5\)

\[ \Lambda_t = \lambda_0 + \lambda_1 X_t, \]  

(2.11)

where \( \lambda_0 \) is an \( N \times 1 \) vector and \( \lambda_1 \) is an \( N \times N \) matrix. The dynamics of the state variables under the physical measure can therefore be written as

\[ X_t = \mu^P + \rho^P X_{t-1} + \Sigma e_t, \]  

(2.12)

where \( \mu^P \) and \( \rho^P \) are given by

\[ \mu^P = \mu - \Sigma \lambda_0 \]  

(2.13)

\[ \rho^P = \rho - \Sigma \lambda_1. \]

### 3 Data and Estimation Method

We first discuss the data and the specification search we used to decide on a benchmark model. Subsequently, we briefly discuss the estimation method.

#### 3.1 Data

The data consists of daily sovereign CDS spreads for a set of twenty-eight countries for the period January 2, 2001 to June 29, 2012, and is obtained from Markit. We use 1-, 5-, and 10-year tenors in the estimation.

We estimate the model for each country separately, but in order to save space we often depict

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\(^5\)See Ang and Piazzesi (2003), Ang et al. (2011), and Dai, Le, and Singleton (2010) for other studies that make this assumption.
results that are averaged within regions. We report on three regions. The Latin American region in our sample consists of five countries: Brazil, Chile, Colombia, Mexico, and Peru. The Eurozone region includes ten countries: Austria, Belgium, Finland, France, Germany, Ireland, Italy, Portugal, Slovenia, and Spain. The Asian region includes six countries: Hong Kong, Japan, Malaysia, Philippines, South Korea, and Thailand. There are seven countries in our sample that are not part of any of these three regions: the Czech Republic, Israel, Poland, Russia, South Africa, Turkey, and the United Kingdom. In total we report on twenty-eight countries, which are determined by data availability. Our sample period has 2999 business days. We require at least 75% of the 2999 observations on the CDS data and the covariates to be available for a country to be included.

We used linear regression to select covariates with high incremental explanatory power for CDS spreads. Our specification search included the following daily covariates: the level of interest rates measured by the 10 year U.S. Treasury bond yield, the S&P 500 implied volatility index (VIX), the 1-year trailing country-specific stock return measured by the Morgan Stanley Composite Index (MSCI), the 3-month foreign exchange rate implied volatility, the 1-year trailing return on the S&P 500 index, the spread between the three month T-bill and the Libor with the same maturity, the 1-year local denominated interest rate swap, the Citi terms of trade index, the 1-year trailing return on the CRB commodity futures price index, the 1-year trailing return on the U.S. Dollar Index (DXY), the 1-year trailing return on the oil price measured by the West Texas Intermediate first futures contract (WTI), the U.S. economic policy uncertainty index obtained from Nicholas Bloom’s website (EPU), the 1-year trailing return on the country’s foreign exchange rate, and CDS liquidity measured by the bid-ask spread.\(^6\) Several studies use bank CDS data as a potential covariate for sovereign CDS spreads in developed countries (see Acharya, Drechsler and Schnabl (2014) and references therein). Our scope of analysis is worldwide and therefore we are restricted by availability of banking sector data from emerging markets. We also investigated other covariates that are available at the monthly and quarterly frequencies. These covariates include the country’s international reserves, as well as its trade balance, industrial production, and debt-to-GDP ratio. All covariates data were obtained from Bloomberg.

Based on measures of fit for the linear regressions, we chose a benchmark model with four covariates, which are all available at the daily frequency. Two covariates are common across the entire set of countries, and two covariates are specific to each country. The common or global covariates are the 10-year U.S. Treasury bond yield and the VIX index. The country-specific or

\(^6\)See Monfort and Renne (2013), Bai, Julliard, and Yuan (2012), and Schwarz (2014) for analyses of liquidity in European sovereign debt and CDS markets.
local covariates are the 1-year trailing return of the Morgan Stanley Composite Index and the 3-month foreign exchange implied volatility. We also estimated two extensions to the benchmark model: these models also use the 1-year local denominated interest rate swap and the Citi terms of trade index. Note that for the Eurozone countries, the foreign exchange implied volatility, the 1-year interest rate swap, and the terms of trade index are identical.

Figure 1 shows the time-series evolution of the covariates. We report the cross-sectional average for the entire set of twenty-eight countries. The 2008 financial crisis is clearly visible with peaks in the VIX and the average exchange rate volatility in 2008. The drop in stock markets in the financial crisis is also clearly visible, and the crisis also shows up in the time series for the average terms of trade. The 2008 crisis is less visible in the fixed-income variables. U.S. interest rates in Panel A clearly drop in 2008-2009, but they continue their decline through the end of the sample.

Another event that emerges from Figure 1 is the period following the bursting of the internet stock market bubble at the beginning of our sample. The corresponding decline in worldwide stock markets and the increase in the VIX are clearly visible from Panels C and B respectively.

Panel A of Figure 2 contains the time path of the 5-year CDS spreads averaged over all twenty-eight countries. Panels B, C, and D present the average time path of the CDS spreads for three regions. Whereas in Panel A there is a clear peak around the credit crisis in 2008, this is not the case for all regions. In the Eurozone countries in Panel B, spreads decreased in 2009, just as in the other regions, but then they increased again fueled by concerns regarding the fiscal solvency of Greece, Italy, Ireland, Portugal and Spain. The Latin American countries experienced a period of major uncertainty between 2003 and 2005, when Brazil elected a new president and doubts developed about monetary policy and increasing inflation. Asian countries also experienced substantial uncertainty in 2003, but spreads did not reach the levels of the 2008 financial crisis.

In summary, based on the patterns in Figure 1 and Panel A of Figure 2, we anticipate a positive relationship between spreads and the VIX, as well as between the spreads and exchange rate volatility. We anticipate a negative relationship between spreads and stock market returns, as well as between the terms of trade variable and spreads. For the U.S. ten-year yield, Figure 1 suggests a negative relationship with overall average spreads in Panel A of Figure 2 which is more low-frequency in nature than the relationship between volatility and spreads. However, a comparison of the U.S. ten-year yield in Panel A of Figure 1 with the spreads in different regions in Panels B, C, and D of Figure 2 suggests that the strength of the overall negative relation will

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7We compute the averages only if there are at least four countries in a given region with available data. Therefore, the time paths for the Latin American and Asian countries start later.
differ across regions. The local swap rate in Panel E reflects a massive easing of monetary policy across the world following the credit crisis.

Because of space constraints, we do not report time paths of spreads and covariates for individual countries. Table 1 reports sample averages and standard deviations for each country. Columns 2 and 3 report the descriptive statistics on the CDS spreads for the five year maturity for each country, and columns 4 to 11 report the descriptive statistics on the country-specific covariates. There are substantial cross-sectional differences in the first and second moments of spreads and covariates.

### 3.2 Estimation Method

We estimate the models for each country separately. Because we observe the time-series of covariates, in a first step we estimate the dynamics of the covariates under the physical measure. The observable macroeconomic and financial variables are described by the AR(1) process in (2.12). Based on the normality assumption for the AR(1) innovation, it is straightforward to write the resulting likelihood function in order to estimate the physical dynamics.

Subsequently, in a second step we estimate the dynamics of the covariates under the risk-neutral measure and the loadings on the covariates using the credit default swap spreads, by minimizing the root-mean-squared-error (RMSE) based on the 1-, 5-, and 10-year maturities, using equal weights for the three maturities. Given the assumptions on the prices of risk, the standard deviations of the innovations are identical under the physical and risk-neutral measures. In the second estimation step, we therefore fix them at the values obtained in the first step. Following market convention and existing studies on sovereign CDS (see for example Pan and Singleton (2008)), we assume a constant recovery rate of 25% in estimation.

### 4 Country-Specific Results

Before we discuss the empirical findings for all 28 countries, we first provide a more detailed discussion for two countries in the sample, Poland and Mexico. Table 2 indicates that the RMSE for the no-arbitrage model is 51 basis points for Mexico for the contract with five year maturity, which has an average spread of 142 basis points. For Poland the RMSE is 29 basis points, while the average spread is 84 basis points. This suggests that the model adequately explains the time-variation in the CDS spreads of these two countries.

Panel A of Figure 3 depicts the credit spread and the credit risk premium for the five-year
contract for Poland.\footnote{Intuitively the credit risk premium is the part of the credit spread that is due to risk aversion. We explain the computation of the credit risk premium in more detail in Section 5.4 below.} Poland experienced a period of uncertainty in the first half of 2003, when the final phase of the European integration referendum was at stake. This is reflected in higher credit spreads. Eventually, the referendum was approved and the country subsequently joined the European Union following the ratification of the 2003 Treaty of Accession. A very calm period followed up till the start of the credit crisis. The 2008 crisis is reflected in much higher spreads. Toward the end of the sample, the high spreads reflect the turmoil in the Eurozone countries. Even though Poland is not part of the Eurozone, it is strongly affected through its trading partners.

The credit risk premium for Poland in Panel A varies significantly over time. It is even more reflective of the economic reality than the spreads themselves. It is low in the early part of the sample before 2003 and peaks around March 2003. It gradually declines from mid-2003 onwards and reaches its minimum around mid-2007. It increases substantially from mid-2007 onwards with the onset of the financial crisis and reaches its peak of 4.24 in late 2008 after the defaults of Lehman Brothers and Washington Mutual. It subsequently declines until early 2010, after which it again starts rising following the Eurozone debt crisis. Overall, the conclusion from Panel A is that the estimated credit risk premium is intuitively plausible and increases in bad times.

Panel C of Figure 3 presents the sensitivity, or delta, of the Polish five-year spreads with respect to U.S. interest rates. The delta with respect to U.S. interest rates is negative throughout the sample, which is consistent with the economic intuition mentioned earlier. It is stable and around -20 basis points on average before the 2008 financial crisis. It drops to around -82 basis points during the financial crisis. It also drops substantially during the Eurozone debt crisis from mid-2010 onwards. The time-series average of the deltas is -32 basis points. For comparison, consider the constant interest rate delta from a linear regression model, which is -46 basis points in our sample.

Panel D presents the deltas with respect to the VIX. Consistent with economic intuition, it is positive. Panels E and F present the deltas with respect to the stock return and exchange rate volatility respectively. Both these deltas have signs consistent with economic intuition. Both deltas are substantially larger during the 2008 financial crisis.

Panel B of Figure 3 presents the credit spread and the credit risk premium for Mexico. The spreads reflect Mexico’s ties to the events experienced in the Americas, especially around 2002. Mexico’s vicinity to the U.S. makes the nation more susceptible than any other country in the sample to events occurring in the U.S. In 2001 and 2002, Mexico’s partners, both to the North and the South, experienced extreme negative events. The U.S. economy was in the
aftermath of a collapsing stock market bubble, and experienced the terrorist attacks in September 2001. Argentina declared default in December 2001, and Brazil, the major country in the Latin American region, was about to elect a former union leader in 2002, and the prospects regarding monetary and fiscal policy were unclear. In addition, in 2001 the Mexican state-owned oil enterprise PEMEX, one of the main sources of income for the Mexican government, was involved in a major scandal involving illegal funding of political parties. These events are reflected in high spreads in 2002-2003. After this turbulent time, the country experienced a calm period up until the beginning of the credit crisis in 2007.

The credit risk premium for Mexico is also positive throughout the sample. It increases in periods of turmoil, such as 2008 and 2002-2003. Panels C to F present the deltas with respect to all four covariates. Overall, the deltas have economically plausible signs and are largest during the financial crisis. The positive delta with respect to U.S. interest rates is perhaps surprising. We find positive interest rate deltas for several emerging economies, and we discuss this in more detail below.

Overall, the results for the two countries strongly suggest that our estimated deltas and risk premiums are consistent with economic intuition. In Section 5, we report results for all twenty-eight countries in our sample.

5 Empirical Results

In this section, we estimate the no-arbitrage model for all countries in our sample using the benchmark parsimonious specification, with four covariates: the level of U.S. interest rates measured using the 10 year Treasury yield, the S&P 500 volatility index (VIX), the one-year trailing returns on the MSCI country index, and the foreign exchange implied volatility. We refer to this parsimonious specification as the benchmark specification.

We chose this benchmark model after an extensive specification analysis using linear regressions. We selected variables that provided substantial incremental explanatory power. Our specification search favored a parsimonious model, in the sense that other variables are available that are relevant in a univariate context, but they do not increase explanatory power much when the benchmark covariates are included. This specification is also consistent with the recent literature that convincingly demonstrates a substantial global component to sovereign credit risk. Our benchmark specification includes two country-specific variables and two variables that are common to all countries. We report on other (richer) specifications of the covariates in Section 6, and compare the implications of those models with the benchmark model.

The top four panels of Figure 1 show the time paths for the four covariates in the benchmark
model. Panel A contains the U.S. 10-year Treasury yield, which steadily decreased over the sample period. Panel B shows the VIX, which substantially varies over the sample and peaks during the financial crisis. Panels C and D contain averages of country-specific variables. Note that the average stock market return in Panel C is clearly highly negatively correlated with the VIX in Panel B, presumably because it is highly positively correlated with the S&P500. This illustrates that in our sample we have a substantial systemic component to sovereign risk that is also present in the country-specific covariates. Panel D shows that average exchange rate volatility is also highly related to the VIX and the stock market index. Of course there is substantial country-specific variation in the stock market index and exchange rate volatility which is not apparent from Figure 1.

5.1 Parameter Estimates

Table 3 presents the distribution of the parameter estimates across all countries. For each parameter, the table provides information about the mean, median, standard deviations, and percentiles ranging from 2.5% to 97.5%. Panel A presents the distribution of the covariate loadings. The loadings on the level of U.S. interest rates and the MSCI index are mostly negative. The loadings on the VIX and exchange rate volatility are mostly positive. Since the default intensity is a quadratic function of the covariates, it is difficult to interpret the impact of the covariates based on the sign of the loadings. In Section 5.3, we compute the numerical deltas of the CDS spreads with respect to each covariate to provide more intuition for the impact of the covariates on the term structure of CDS spreads.

Panels B to F present the distribution of the parameters characterizing the covariate dynamics under the risk-neutral and physical measures. Remember that the off-diagonal elements of $\rho$ and $\Sigma$ in (2.4) are assumed to be zero. All covariates are highly persistent under both the risk-neutral and physical measures. The risk-neutral dynamic for the level of the U.S. Treasury yield is mostly explosive. For all covariates, the range of the persistence parameter $\rho$ is relatively tighter under the physical measure compared to the risk-neutral measure. This suggests that the market price of risk associated with this parameter varies a lot across countries. The distribution of the intercept $\mu$ of the autoregressive process also differs substantially under the risk-neutral and physical measure, suggesting that these covariates carry large risk premiums. For example, for the exchange rate volatility, the percentile range under the physical measure is between 0.032 and 0.232, while it is between -0.688 and 0.132 under the risk-neutral measure.
5.2 Model Fit

The third column in Table 2 presents the root mean squared error (RMSE) in basis points for the five year maturity contract for each country in our sample. The table does not report RMSEs for other maturities, but the conclusions are similar. We also report the averages for the three geographical regions. For comparison, the fifth column also reports the goodness of fit measure for the linear regression

\[ S_t = \gamma + \beta X_t + \varepsilon_t. \]  

(5.1)

The RMSEs for the five-year contract are similar for the no-arbitrage model and the simple regression model. The no-arbitrage model performs well in capturing the variation in spreads for the Latin American and Asian countries. Table 2 indicates that the ratio of the average RMSE to average spreads for Latin American countries is 49%; for the Asian countries it is 37%. The model has more difficulty to capture the variation in the spreads of the Eurozone countries. The ratio of average RMSE to average spreads for Eurozone countries is almost 100%. However, there is clearly a lot of variation within regions. For instance, the ratio is around 50% for Finland, while for Portugal the fit is very poor.

Panel A of Figure 2 provides additional perspective on model fit by presenting the time-series of the cross-sectional averages of the spreads across all countries for the no-arbitrage model and the regression model, together with the average market spreads, again using the 5-year tenor. The no-arbitrage model generally performs well in capturing the level and the variation in spreads except between 2005 and 2007, when its prediction is too high. The linear regression model performs better between 2005 and 2007, but predicts negative spreads in 2001. Panel B of Figure 2 presents the same information for the Eurozone countries. For these countries, the no-arbitrage model is unable to capture the level of spreads before the financial crisis of 2008. The linear regression model performs worse however, because it generates large negative fitted spreads before the financial crisis. The fit of the no-arbitrage model and the linear regression model during and after the financial crisis is similar and fairly good. Figure 2 suggests that the relatively poor model fit for many Eurozone countries is due to the large increase in Eurozone spreads after 2008, which can be thought of as a structural break. We address this issue in more detail in Section 6.2.

Panels C and D of Figure 2 graph the average model and market spreads for Latin American and Asian countries respectively. For both regions, the no-arbitrage model is able to capture the substantial rise in spreads during the 2008 financial crisis. While the fit is good throughout the

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9Note that the regression model is estimated one maturity at a time, whereas the no-arbitrage model is estimated using the entire term structure of CDS spreads.
sample of Asian countries, for the Latin American countries the model tends to underestimate spreads in 2003 and 2004. This time period coincides with the Argentinian debt crisis and political uncertainty in Brazil.

Overall, the fit of the no-arbitrage model across all countries is reasonable for our purpose. Our main objective with the benchmark model is to use a parsimonious model to provide economic intuition by studying the impact of the covariates on the term structure of spreads and the associated risk premiums. In Section 6, we consider alternative covariate specifications that are more richly parameterized and provide better fit, and we compare estimated risk premiums from different specifications.

5.3 Economic Determinants of Credit Spreads

We now turn to a detailed study of the quantitative impact of covariates on CDS spreads. Note that the loadings $\alpha$ in equation (2.2) are not directly interpretable because the default intensity is quadratic in the state variables. We therefore focus on the numerical derivatives (deltas) of the credit spreads with respect to changes in the covariates. These deltas also make it easier to compare the results of the no-arbitrage specification and the regression approach, because in the no-arbitrage specification it is the default intensity (2.2) that is specified as a function of the covariates, whereas for the regression (5.1) it is the credit spread.

5.3.1 Cross-Sectional Variation in Deltas

Columns 12 to 15 of Table 1 report, for each country, the time-series average of the sensitivities or deltas of the five year maturity spreads with respect to the covariates. All deltas reported in the table represent the change in spreads for a one unit change in the covariate. The unit of all four covariates is percentage points. The delta of the spreads with respect to U.S. Treasury yield is mostly negative, which can be seen from the time paths in Figure 2 and Panel A of Figure 1. The negative delta is also consistent with economic intuition. In bad economic times, when credit spreads are high, interest rates are low, partly because the Federal Reserve generally maintains a low interest rate environment in order to spur growth. On average across countries and time, a one percent (100 basis points) increase in yields results in a 19 basis points decrease in spreads.

The delta with respect to the U.S. interest rate environment is lowest for Portugal and Ireland, two countries which experienced substantial distress during our sample. The delta is positive for several emerging economies: Brazil, Colombia, Mexico, Peru, the Philippines, and Turkey. One potential explanation for the positive sign for these countries is as follows. A decrease in
U.S. Treasury rates may result in investors looking for yield elsewhere, which may increase the demand for bonds of developing countries and result in a reduction in spreads for these countries. Another potential explanation for the positive delta is that the financial crisis (initially) did not affect the emerging economies as much as the more developed economies. Note that the often-cited flight-to-quality effect predicts the opposite pattern: when there is turmoil in emerging markets, characterized by falling stock markets and higher sovereign CDS spreads, additional capital flows to the U.S., and to the U.S. Treasury market in particular, leading to lower interest rates.

We expect an increase in spreads when U.S. stock market volatility, as measured by the VIX, increases. There is no formal theory to support this prior. However, the Merton (1974) model predicts a positive relation between stock market volatility and corporate credit spreads, and it is not unreasonable to expect this to carry over to sovereign spreads. Consistent with our intuition, the average sensitivity of the spreads with respect to VIX is positive for all countries except Brazil, Portugal, and Spain. On average across countries and time, a one percent increase in VIX, for instance from 20% to 21%, results in a 0.35 basis points increase in spreads. Colombia has the largest sensitivity with respect to the VIX, followed by Mexico, and Latin American countries have on average higher sensitivity to VIX. For many Eurozone countries, the VIX delta is close to zero. Longstaff, Pan, Pedersen, and Singleton (2011) find that the VIX explains sovereign credit spreads, but their sample does not contain European countries.

For the country-specific covariates, we expect an increase in spreads when the stock market in a given country performs poorly, and an increase in spreads when the exchange rate is more volatile. Column 14 of Table 1 shows that the impact of the MSCI returns is indeed mostly negative. On average, a one percent decrease in yearly returns results in a 0.41 basis points increase in spreads. Local stock market conditions have the largest negative impact on the spreads of Asian countries and the least impact on the spreads of Eurozone countries. Finally, consistent with our intuition, spreads increase by 2 basis points on average with a one percent increase in exchange rate volatility (see column 15 of Table 1). The impact of the exchange rate volatility is mostly positive across all countries. Brazil and Ireland have among the largest deltas to exchange rate volatility. Interestingly, the Eurozone countries have larger exchange rate volatility deltas than the Asian countries.

5.3.2 Time-Series Variation in Deltas

Figure 4 reports the average time path of the deltas for different covariates. The figures present the time path for the overall cross-sectional average and the time path for the cross-sectional
average for different geographical regions, all for the five-year contract. For comparison, each panel also presents the average estimated delta from the linear regression model, indicated by the solid line. The first row presents the average delta of spreads with respect to the U.S. Treasury yield level across all countries and for different geographical regions. The linear regression model estimates the average delta with respect to U.S. interest rates at approximately -48 basis points, whereas the estimate from the no-arbitrage model is substantially smaller on average. More importantly, the no-arbitrage model allows for substantial time-variation in interest rate deltas. The deltas become more negative during the 2008 financial crisis as well as during the Eurozone debt crisis from mid-2011 to mid-2012. We obtain similar time-series patterns in deltas for the Eurozone and Asian countries. For Asian countries, the interest rate delta is positive on average at the beginning of the sample. For Latin American countries, the interest rate delta is positive throughout our sample. It increases in the later part of 2008 and drifts downwards from then on. This result is partly driven by Brazil, which has a large positive delta with respect to U.S. interest rates in our sample.

The second row reports the deltas with respect to the VIX for different geographical regions, as well as the overall average. The time-series pattern of the deltas is largely similar across Latin America and Asia. For the Eurozone countries the deltas decrease towards the end of the sample. Note that the (small) negative average delta for the Eurozone countries is partly driven by Portugal and Spain which have large negative deltas with respect to VIX.

The third row reports the deltas with respect to the MSCI index. The overall average and the averages by region are all negative and drop substantially during the financial crisis of 2008. For the Asian countries, there is a large drop in the average delta around 2003, while in case of Europe the delta also drops substantially in the later part of the sample during the Eurozone debt crisis.

The final row reports the deltas with respect to exchange rate volatility. The overall average and the averages by region are positive and increase during the financial crisis of 2008. For Europe the deltas also increase in the later part of the sample between 2011 and 2012.

In summary, the deltas for all covariates have signs largely consistent with economic intuition. The time-variation in deltas estimated using the no-arbitrage approach is substantial, and mostly conforms to our intuition given the changes in economic conditions over the sample.

5.3.3 The Term Structure of the Deltas

We also computed the term structures of the deltas, which captures how the covariates affect spreads of different maturities. To save space, we do not report the figures, which can be
summarized as follows: the term structure is upward sloping for U.S. interest rates, downward sloping for the VIX and stock returns, and hump shaped for exchange rate volatility.

5.3.4 The Impact of Covariates on Model Spreads

Figure A.1 plots model spreads for the five-year maturity for different values of the covariates. We compute the spreads for each country individually using the estimated parameters, changing the covariates one at a time while fixing other covariates at their time-series average. The figures present the averages across all sample countries and the three geographical regions. Panel A shows that on average, spreads decrease with U.S. yields. The pattern for Asian and Eurozone countries is downward sloping, whereas for Latin American countries spreads monotonically increases with interest rates.

Panel B shows that model spreads increase with increases in the VIX, except for Europe, but we know from Figure 4 that the Eurozone spreads do not respond much to changes in the VIX. Higher values of the VIX indicate increased uncertainty, and therefore the positive relation is plausible. Panel C presents model spreads as a function of stock market returns. Spreads decrease as the return on the MSCI country index rises for all geographical regions. Panel D of Figure A.1 shows that model spreads increase with foreign exchange volatility for all regions. The intuition for this finding is similar to the intuition used for the pattern for the VIX.

5.4 Risk Premiums

For each country in our sample, at each point in time we first compute the model implied spreads under the pricing (Q) measure. We then change the probability measure and compute the model implied spreads under the physical measure P. The credit risk premium is defined as the ratio of the difference between the Q and P spreads over the P spreads \( \frac{CDS_Q - CDS_P}{CDS_P} \). Note that by construction this risk premium only captures the risk associated with the variation in default probabilities. Our definition of the P spreads follows Pan and Singleton (2008).\(^\text{10}\)

5.4.1 Time Series Evidence

We report time series of the average credit risk premium computed using all countries, as well as the time series for geographical regions. We use the contract with five-year maturity.

Figure 5 present the resulting time series. Average risk premiums are positive at each point in time for all regions. The average risk premium across all countries in Panel A varies between a

\(^{10}\)The estimates under the P measure are not the same as estimates from historical default data. See Pan and Singleton (2008) and especially Jarrow, Lando, and Yu (2005) for a more detailed discussion.
minimum of 0.30 and a maximum of 2.92. Risk premiums are largest for Latin America, followed by Asia and Europe. On average over the sample, the ratio is equal to 2.25 for Latin America, 1.46 for Asia and 0.45 for Europe. The risk premium rises substantially during the financial crisis of 2008 for all geographical regions. The Eurozone risk premium also rises substantially during the Eurozone debt crisis from mid-2010 onwards. The increase in risk premiums is relatively smaller for other geographical regions during the Eurozone debt crisis. Remarkably, even following the large increase in Eurozone risk premiums following 2008, at the end of the sample the average Eurozone risk premium is still lower than the risk premium in Latin American and Asian countries.

Consider the time-series relation between credit risk premiums (in Figure 5) and the spreads (in Figure 2). Spreads and credit risk premiums seem to be positively related. This is largely due to the sharp increase in spreads and risk premiums in the financial crisis, but this positive relation can also be observed in other crises that are not worldwide, such as in Asian countries at the beginning of the sample, and in Europe toward the end of the sample.

### 5.4.2 The Cross-Section of Credit Risk Premiums

The positive time-series relation between spreads and credit risk premiums documented in Section 5.4.1 seems very intuitive, as we expect risk aversion and risk premiums to increase in crises. This underlying intuition is evident in Pan and Singleton’s (2008) discussion of sovereign risk, for instance.

When thinking about the cross-section of credit risk premiums, it is useful to consider the stylized facts in the cross-section of corporate credit risk. When measuring credit risk premiums in percentage terms or ratios, this literature contains robust evidence that credit risk premiums are larger for relatively safer bonds. Indeed, default probabilities alone explain a very small percentage of the spread of AAA-rated corporate bonds, but a relatively higher part of the spread of lower-rated bonds.\(^\text{11}\) We now investigate the patterns in the cross-section of sovereign credit risk premiums.

Column 7 of Table 2 lists the average credit risk premium for all countries. There is substantial cross-sectional variation in the credit risk premium across countries. Average credit risk premiums are positive for all countries, except for Ireland and Portugal. This may be surprising, but note that the credit risk premium is determined by both the $P$ and $Q$ spreads, and that this result is simply due to a high $P$-spread for both countries. Note that the average credit risk premium for other Eurozone countries with high credit spreads, such as Italy and Spain, is

\(^{11}\)See for instance Huang and Huang (2012) and Elton, Gruber, Agrawal, and Mann (2001).
positive, but very small. A comparison of the average credit risk premiums in column 7 of Table 2 with the average credit spreads in column 2 indicates that the relationship between spreads and credit risk premiums is complex.

To provide some insight into the complex relationship between credit risk premiums and various measures of risk, Table 2 also reports average P-spreads \((\text{CDS}^P)\), average Q-spreads \((\text{CDS}^Q)\), and average credit ratings for all countries. Consider the relation between credit risk premiums and credit ratings, which is depicted in Figure 6. At each point in time, we map a country’s credit rating into a numerical scale and then take the average. Different geographical regions are indicated by different colors, black for Asia, grey for Latin America, and white for Europe. The first conclusion is that within each of these three regions, there is one country with a credit risk premium that is substantially higher than the other countries in the region. In Asia this is Japan, in Europe it is Germany, and in Latin America it is Chile. These countries also have the highest credit ratings in their respective regions, and can be thought of as safe havens for each of the regions. Excluding these safe havens from the sample, the relation between credit risk premiums and ratings is negative within Asia and within Latin America, which suggests that credit risk premiums and credit spreads are positively correlated. In Europe, a different result obtains, and credit risk premiums and ratings seem positively correlated.

Figure 6 suggests that the cross-sectional relation between credit risk premiums and credit spreads is complex partly because the cross-sectional relation between physical default probabilities and credit risk premiums is complex. Excluding the three safe-haven countries, Figure 6 suggests a positive relation between physical default probabilities and CRPs in two of the three regions, i.e. higher rated countries have lower CRPs. When including the safe havens or when considering all countries together, this result is much less clear, and not nearly as strong as the positive relation evident from the time series of credit risk premiums and credit spreads discussed above.

5.4.3 Risk Premium Deltas

We can compute the sensitivity (delta) of the risk premium with respect to the covariates, which may differ from the delta of the spread with respect to the covariates, reported in Figure 4. To save space, we report these deltas in Figure A.2 and we provide a brief discussion. The signs for the risk premium deltas are very similar to the signs for the spread deltas. The sign is positive for exchange rate volatility and the VIX, and mostly negative for U.S. interest rates and stock market returns. The notable exception is the Latin American countries’, for which spreads and risk premia are positively affected by interest rates in our sample.
The differences between Figures A.2 and 4 are more pronounced when inspecting the time series patterns. Consider the VIX in the second row. Eurozone risk premia are not affected by changes in the VIX, similar to the spreads in Figure 4. For the case of all countries in the first column and the Latin American countries in the third column, the pattern is similar to the one in Figure 4, with a sharp peak in the financial crisis. However, the pattern for the Asian countries is very different. In Figure 4, the model spread delta for the VIX drops off after the financial crisis, but the delta for the risk premium stays at a high level afterward, indicating that the Q-deltas and P-deltas are very different for this region.

For the stock market deltas in row 3, the time pattern of the deltas in Figure A.2 looks very similar for the Latin American countries, but entirely different for Asia and Europe. For interest rates and exchange rate volatility, the patterns look different than the ones in Figure 4 for all regions.

We conclude that when the covariates change over time, their impact on model spreads and risk premiums has the same sign, but the time-series patterns for risk premiums and spreads are very different.

5.5 The Term Structure of Spreads and Risk Premiums

Panel A of Figure 7 presents the time series of the average term structure slope for the credit risk premium, averaged over all countries in the sample. Panels B, C, and D present results for the geographical regions. For comparison we also provide the slope of the CDS spreads. The slopes are defined as the difference between the spread or credit risk premium for the 10-year maturity and the 1-year maturity. Intuitively, short-term spreads that are larger than long-term spreads suggest that the country is highly distressed. An example in our sample is the Eurozone in 2011-2012, when the CDS slope is -40 basis points on average across countries. For the entire sample in Panel A, CDS slopes are always positive, but CDS slopes dramatically decrease in the financial crisis in 2008, from 80 basis points to 25 basis points.

How does the slope of the credit risk premiums compare with the slope of the CDS spreads? The answer is complex. During the 2008 financial crisis, the slope of the credit risk premium rises when the slope of the CDS spread drops. During the crisis, default probabilities and spreads increase, but there is a larger increase in physical relative to risk-neutral default probabilities at shorter horizons while there is a relatively larger increase in risk-neutral compared to physical default probabilities at longer horizons.

This pattern obtains for the overall average in Panel A, but it is most pronounced during 2008 for Latin American and Asian countries in Panels C and D. For the Eurozone countries,
we observe this negative relation during the Eurozone debt crisis from mid-2010 onwards. We conclude that in periods of market stress, the slope of the CDS spreads and the credit risk premiums are negatively related.

Panel E of Figure 7 provides additional evidence on this relation. We present a scatter plot of the CDS slope and credit risk premium slope, generated by pooling the daily data from all countries in our sample. We separate the scatter plot into three periods: before the financial crisis of 2008 (April 2001 to March 2008), during the financial crisis (April 2008 to July 2011), and post-crisis (August 2011 to June 2012). A very clear and interesting pattern emerges from the plot: before the financial crisis, the credit risk premium slope is roughly constant, and it does not depend on the CDS slope; after the financial crisis, the credit risk premium slope again does not change very much with changes in the CDS slope, but the CRP is at a higher level compared to the pre-crisis period. The credit risk premium slope captures the difference in the price of a dollar in bad states of the world for long and short horizons, and it seems that the relative price of this risk for long and short horizons is now priced differently than before the crisis. During the crisis, the negative relation between the CDS slope and the credit risk premium slope evident from Panel A can be clearly seen in Panel E.

6 Robustness Analysis

All empirical results discussed so far are based on the benchmark specification with four covariates: U.S. interest rates, the VIX, the MSCI country index return, and exchange rate volatility. In this section, we first compare the credit risk premiums obtained from the benchmark covariate specification with alternative covariate specifications. We then analyze the impact of structural breaks.

6.1 Alternative Covariate Specifications

Figure 8 compares the credit risk premium from the benchmark model with two alternative, more richly parameterized, covariate specifications. Model 2 augments the benchmark covariates with the one year local swap rate. Model 3 includes the covariates from the benchmark specification, the one year local swap rate and the terms of trade. We decided on these two covariates based on the results of an extensive specification search using linear regression.

We estimate these two richer specifications for each country in our sample. The fit of these two models is better than that of the benchmark model but not significantly so. We therefore focus on the risk premiums. Panel A shows the comparison of the average credit risk premium across
all countries obtained from each of the specifications. The key observation from the figure is that the level and the dynamics of the credit risk premium are similar across all three specifications. Panels B to D show the comparison of the credit risk premium for all three specifications for different geographical regions. These graphs also show that the dynamics are fairly similar across the three specifications for all regions. There are of course some differences in the levels of the credit risk premiums, but the time-series correlation of the paths is very high.

The consistency of the estimated risk premiums across model specifications is an important advantage of the use of observable covariates in no-arbitrage models. We investigated risk premiums in no-arbitrage models with latent factors, and we found that models with very similar fit often yielded dramatically different risk premiums. This is perhaps not surprising because it is well known that a similar fit can be obtained with very different latent state variables. These results are available on request.

6.2 Structural Breaks

The time series of the spreads in Figure 2, and the economic and financial turmoil in the sample period more in general, suggest that both the covariates and the CDS spreads may be characterized by one or more structural breaks. Characterizing these breaks is not the focus of this study, but they are of interest to us to the extent that they affect our inference on the impact of economic covariates on credit spreads and risk premiums.

Judging from the model fit in Figure 2 and Table 2, the largest impact of structural breaks may be for the Eurozone countries, where the sample can be split up in a low spread environment in the first half of the sample and a high spread environment in the second half of the sample. When fitting the overall sample with our benchmark model, the result is that model spreads are dramatically higher than market spreads in the first half of the sample. Inspection of the average credit risk premia by country in Table 2 indicates that the credit risk premia are small or negative for several Eurozone countries, and this may be due to model misspecification.

Rather than estimating a more complex regime-switching model that could potentially capture the structural breaks with a single set of parameters, we instead split up the sample for the Eurozone countries and estimate the model twice. The first subsample is from January 2, 2001 to March 31, 2008. The second subsample is from April 1, 2008 to June 29, 2012. The resulting model fit and credit risk premiums are reported in columns 4 and 8 of Table 2. As expected, the resulting model fit is superior to the one for the benchmark model. The average credit risk premiums are higher for all countries but two (Austria and Finland), and in some cases they are much higher. We also investigated how splitting the sample affects the estimates.
of the deltas and the other economic conclusions for the Eurozone countries. While there are numerous differences for individual countries, as expected, our main conclusions regarding the determinants of credit spreads and credit risk premia are not affected.

7 Sovereign Credit Correlations

We now examine the correlation between CDS spreads and risk premiums. Both the global factors and the country-specific factors carry risk premiums in our model, which enables the model to capture differences in dependence between spreads and risk premiums, as well as regional differences in these patterns.

Figure 9 depicts the correlations between CDS spreads and risk premiums for different combinations of regions. At each point in time, we compute the rolling pairwise correlations between the countries of any two regions using data from the past two years.\textsuperscript{12} We show the correlation averaged over all possible pairs. For example, we have ten Eurozone countries in our sample and five Latin American countries. This leads to 50 possible pairs between these two regions. The graph for the correlation between the Eurozone and Latin America represents the average of these 50 pairs. Panels A and C report the correlations computed using the levels of CDS spreads and risk premiums across regions. Panel B and D instead use changes in spreads and risk premiums. We report results based on differences as well as levels because correlations based on levels may be subject to econometric problems. The correlations between the Eurozone and Latin America are represented by the dotted line. The dashed line depicts the Eurozone-Asia correlations and the solid line the Latin America-Asia correlations.\textsuperscript{13}

There are notable differences between the results for the levels of spreads and risk premiums (left panels) and the results based on differences (right panels). Most importantly, the correlations based on levels are characterized by larger fluctuations over time. However, a number of conclusions are common to the levels and differences results. First, both CDS spreads and risk premiums have become more highly correlated during our sample period. This is mainly due to a substantial increase in correlations during the financial crisis. Starting in 2008, the correlation between spreads and risk premiums increases substantially for all regions, consistent with the intuition that the financial crisis resulted in a global systematic event. Panel C also suggests that the increase in the spread correlations in Panel A during the financial crisis is at least partly

\textsuperscript{12}Results obtained using more sophisticated dynamic conditional correlation techniques are very similar.

\textsuperscript{13}The pairwise correlation between any two countries is computed if there is at least one year of data available for both countries in the past two years. We require at least four countries in each region to compute the average correlation.
due to the increase in risk premium associated with a global event.

Second, the evolution of spread and risk premium correlations during the Eurozone debt crisis is more complex. Overall the correlations between spreads and risk premiums decline during the Eurozone debt crisis, but the results differ across regions. For the levels of spreads and risk premiums (left panels), it can clearly be seen that the decline is large for the Eurozone-Asia and Latin America-Eurozone cases. This is consistent with the intuition that the crisis mainly affected the spreads and risk premiums for the Eurozone countries, but did not significantly impact the risk premiums in the other two regions. As a result, the spreads and risk premiums for the other two regions did not move together with the Eurozone risk premium, and this resulted in a reduction of the correlations. However, when computing correlations based on differences (right panel), this conclusion is not quite as obvious.

Third, Figure 9 provides insight in the sources of credit spread correlations. As mentioned before, both risk premium and spread correlations increase over the sample. However, spread correlations increase in the financial crisis in 2008, and decrease afterward, whereas the increase in risk premium occurs more steadily throughout the sample. We therefore conclude that the early part of the sample is characterized by increased correlation between economic fundamentals, whereas the latter part of the sample is characterized by an increase in global risk aversion.

8 Conclusion

We specify no-arbitrage models for the valuation of sovereign CDS contracts. The country’s default intensity is assumed to be a quadratic function of observable economic and financial indicators, guaranteeing positive default intensities at all times. We select a parsimonious benchmark model that contains four determinants of the countries’ default intensities: the U.S. interest rate, the VIX stock market volatility index, the one-year trailing return on the country’s stock market index, and the implied exchange rate volatility for the country’s currency.

We estimate this model using a sample of twenty-eight countries. For each country we have over a decade’s worth of daily data, and we use the 1-year, 5-year, and 10-year tenors in estimation. The benchmark model provides a satisfactory fit. We also report on two more richly specified models, which include the one year local swap rate and the terms of trade. These models have similar implications regarding the size of risk premiums and their time-variation, and the sign of the deltas of spreads with respect to the observable covariates.

The impact of the economic and financial variables on spreads varies substantially across countries and over time, but is consistent with economic intuition. In the benchmark model, spreads increase as a function of stock market and exchange rate volatility, but decrease as a
function of interest rates and stock market returns. Estimated risk premiums are highly time-varying and peak during the 2008 financial crisis for nearly all countries. For Eurozone countries, risk premiums are also high during the Eurozone debt crisis. It seems that during periods of market stress, market risk aversion increases by more than default probabilities. The variation in risk premiums across countries is very large, also outside of crisis periods, and some of this variation is driven by regional factors. The correlation between credit spreads as well as credit risk premiums increased over our sample period. To the best of our knowledge, we are the first to study sovereign risk premia using a no-arbitrage framework with observable covariates.

Several extensions of our analysis are possible. It is possible to further improve in-sample fit by adding economic and financial variables, but in our opinion this is not a priority. Reduced-form models with latent factors are much better suited for this task. Instead, the model has much more promise for investigating the effects of specific economic and financial variables. In this paper, we have limited ourselves to economic and financial data that are available daily, partly to avoid econometric complications. Combining low-frequency macroeconomic variables such as inflation and GDP growth with daily CDS data might provide interesting additional insights. Allowing for stochastic recovery rates could be an interesting extension, but this substantially complicates the resulting estimation problem. A more in-depth investigation of the relative strengths and weaknesses of models with latents and observables, for instance in identifying risk premiums, would also be interesting.
References


Notes to Figure: We plot the time series of the ten-year US Treasury bond yield, the VIX index, the average of the MSCI one-year trailing returns across all twenty-eight countries, the average of the three-month foreign exchange implied volatility, the average of the one-year constant maturity local swap rate, and the average of the terms of trade index. The first two covariates are common to all countries.
Figure 2: Model and Market Spreads

Notes to Figure: Panel A plots the CDS spreads (dotted line), the no-arbitrage (NA) model spreads (dashed line), and the fitted OLS spreads (solid line) averaged over the entire set of twenty-eight countries. Panel B only uses the countries in the Eurozone. Panel C only uses the Latin American countries, and Panel D only uses the Asian countries. For all regions, the average is computed only if we have at least four countries with available data.
Notes to Figure: We plot CDS spreads (in basis points), credit risk premiums (CRPs), and deltas for Poland and Mexico. Panels A and B show the credit risk premium and the CDS spread. Panels C, D, E, and F plot the deltas of model spreads with respect to changes in the ten-year U.S. Treasury bond yield (UST), the VIX, the one-year trailing stock return index (MSCI), and the three-month foreign exchange implied volatility (FXIV). The deltas represent the change in spreads for a one unit change in the covariate. The unit of all covariates is percentage points.
Notes to Figure: We plot the sensitivity or delta (in basis points) of the credit spreads to changes in the covariates. The deltas represent the change in spreads for a one unit change in the covariate. The unit of all covariates is percentage points. Panels A, B, C, and D plot the UST delta averaged over all countries, the Eurozone, Latin American, and Asian countries respectively. Panels E, F, G, and H plot the VIX delta for the same groups of countries. Panels I, J, K, and L plot the MSCI delta for all countries, the Eurozone, Latin American, and Asian countries respectively. Panels M, N, O, and P plot the FVIX delta for the same groups of countries.
Notes to Figure: We plot the time series of credit risk premiums (CRPs) for the entire set of twenty-eight countries, the Eurozone, the Latin American, and Asian countries in panels A, B, C, and D respectively.
Notes to Figure: We plot Credit Risk Premiums and Credit Ratings for countries within the Eurozone (white squares), Latin America (grey squares), and Asia (black squares). The credit ratings are from Fitch (foreign currency rating). We convert credit ratings to a numerical scale using a linear scale (AAA is 18 and B is 4).
Notes to Figure: Panels A, B, C, and D plot the difference between the ten-year and one-year credit risk premium (CRP), and between the ten-year and one-year CDS spreads (in basis points) for the entire set of countries, the Eurozone countries, the Latin American countries, and the Asian countries respectively. The left axis refers to the CDS spread slope, in basis points (solid line). The right axis refers to the CRP slope (dotted line). Panel E plots the CRP and CDS slopes’ average across countries, for different periods. Each circle denotes one day. The first period starts in April 2001 and ends in March 2008. The second period starts in April 2008 and ends in August 2011. The third period starts in September 2011 and ends in June 2012. The vertical axis measures the CRP slope, and the horizontal axis measures the CDS spread slope (in basis points).
Figure 8: Credit Risk Premiums for Different Models

Panel A: All Countries
Panel B: Eurozone Countries
Panel C: Latin American Countries
Panel D: Asian Countries

Notes to Figure: The dotted line shows the credit risk premium obtained from the benchmark model specification, referred to as model 1, which includes the following covariates: the ten-year U.S. Treasury bond yield (UST), the VIX, the one-year trailing stock return index (MSCI), and the three-month foreign exchange implied volatility (FXIV). The solid line shows the credit risk premium obtained from model 2, which includes the same covariates as the benchmark model, as well as the one-year constant maturity local swap (SWA). The dashed line shows the credit risk premium obtained from model 3, which includes the covariates from model 2, as well as the terms of trade (TOT). Panels A, B, C, and D report on the entire set of twenty-eight countries, the Eurozone countries, the Latin American countries, and the Asian countries respectively.
Notes to Figure: Using a rolling window of 500 trading days, we plot correlations for CDS spreads and credit risk premiums. The dotted lines show the correlations between the Eurozone countries and the Latin American countries. The dashed lines show the correlations between the Eurozone countries and the Asian countries. The solid lines show the correlations between the Latin American countries and the Asian countries. Panel A plots correlations for CDS spread levels. Panel B plots correlations for CDS spread differences. Panel C plots correlations for CRP levels. Panel D plots correlations for CRP differences.
Table 1: Descriptive Statistics

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Notes to Table: For each country, we report descriptive statistics for five-year CDS spreads and country-specific covariates. MSCI refers to the one-year trailing stock return index, FXIV refers to the three-month foreign exchange implied volatility, SWA refers to the one-year constant maturity local swap rate, and TOT refers to the terms of trade index. We report the sensitivities ( deltas) to the four covariates in the benchmark model. The deltas represent the change in spreads for a one unit change in the covariate. A delta of 0.00 indicates a very small positive number. The unit of all covariates except TOT is percentage points.
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Notes to Table: For each country, we report the average CDS spread, along with the average credit risk premiums, the RMSE, the CDS model spreads under the P measure and the Q measure, and the credit rating. We report on the no-arbitrage model and the OLS regression. We convert the credit rating from Fitch into a number, where AAA is 18 and B is 4, and compute the country average. Modelbr. and CRPbr refer to the model fit and CRP with a structural break in April 2008.
Table 3: Parameter Estimates

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Notes to Table: We report the cross-sectional distribution of the model parameters across countries for the four covariates: the ten-year U.S. Treasury bond yield (UST), the VIX index, the country’s one-year trailing stock return index (MSCI), and the three-month foreign exchange implied volatility (FXIV). Panel A reports the intensity loadings. Panel B reports the standard deviation. Panel C reports the persistence under the Q measure. Panel D reports the intercept under the Q measure. Panel E reports the persistence under the P measure. Panel F reports the intercept under the P measure.
Figure A.1: Model Spreads for Different Values of Covariates

Notes to Figure: For different groups of countries, panels A, B, C, and D plot the model spreads ($CDS^Q$) in basis points as a function of UST, VIX, MSCI, and FXIV respectively.
Notes to Figure: We plot the sensitivity or delta of the credit risk premiums to changes in the covariates. Panels A, B, C, and D plot the UST delta averaged over all countries, the Eurozone, Latin American, and Asian countries respectively. Panels E, F, G, and H plot the VIX delta for the same groups of countries. Panels I, J, K, and L plot the MSCI delta for all countries, the Eurozone, Latin American, and Asian countries respectively. Panels M, N, O, and P plot the FVIX delta for the same groups of countries.