The Pricing of Investment Grade Credit Risk during the Financial Crisis

Joshua D. Coval, Jakub W. Jurek, and Erik Stafford*

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Abstract

This paper uses a structural model to investigate the pricing of investment grade credit risk during the financial crisis. Our analysis suggests that the dramatic recent widening of credit spreads is highly consistent with the decline in the equity market, the increase in its long-term volatility, and an improved investor appreciation of the risks embedded in structured products. In contrast to the main argument in favor of using government funds to help purchase structured credit securities, we find little evidence that suggests these markets are experiencing fire sales.

PRELIMINARY AND INCOMPLETE.

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*Coval: Harvard Business School; *jcoval@hbs.edu*. Jurek: Bendheim Center for Finance, Princeton University; *jjurek@princeton.edu*. Stafford: Harvard Business School; *estafford@hbs.edu*. We thank Stephen Blythe, Ken Froot, Bob Merton, André Perold, and David Scharfstein for valuable comments and discussions.

1 Introduction

This paper investigates the pricing of investment grade corporate credit during the financial crisis from the perspective of a structural risk model. A crisis is typically characterized by an unexpected large drop in asset prices. A crucial question for both investors and policymakers is to what extent the drop in asset prices reflects news about economic fundamentals and how much is attributable to increased market frictions created by disruptions in the financial system. The challenge, of course, is that both are likely to be important contributors to the price decline.

To empirically address this challenge, we utilize a structural risk model to consistently link the pricing of stocks, credit securities, and credit derivatives. We seek to understand the key drivers of the dramatic repricing of credit securities in general, and structured credit securities in particular, that has occurred over the past two years. As an example, consider the 7-10 tranche of the major credit index of investment grade US corporations (CDX.NA.IG). From January 2007 to December 2008, the tranche saw its spread increase from 14 basis points to 8.12%. Given that this tranche was initially priced as a AAA-rated security, the enormous spread increase has led many to conclude that we are witnessing fire sales in credit markets.[1]

On March 23, 2009, the Treasury announced that the TALF plan will commit up to $1 trillion to purchase legacy structured credit products. The government's view is that a disappearance of liquidity has caused credit market prices to no longer reflect fundamentals:[2]

> An initial fundamental shock associated with the bursting of the housing bubble and deteriorating economic conditions generated losses for leveraged investors including banks ... The resulting need to reduce risk triggered a wide-scale deleveraging in these markets and led to fire sales ... [The Public-Private Investment Program] should facilitate price discovery and should help, over time, to reduce the excessive liquidity discounts embedded in current legacy asset prices.

The main objective of this paper is to determine whether fire sales are required to explain prices currently observed in credit markets. Other potential sources of repricing include a correction of *ex ante* mispricing due to incorrect forecasts of expected losses (i.e. incorrect ratings), a correction of *ex ante* mispricing arising from a failure of investors to charge for systematic risk, and rational change in prices reflective of a change in fundamentals. A key distinction between the fire sale view and the other possibilities is that only the fire sale view requires that current prices are incorrect. And given that fundamentals have changed dramatically during the past 2 years, and that *ex ante* mispricing was likely present in many of the structured credit markets, the conclusion that the large spread changes are evidence of fire sales is, at best, a premature one.[3]

The focus of our analysis is on investment grade corporate credit risk. The investment grade setting offers two attractive features as a setting for studying the pricing of credit securities during

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[1] Although the index tranches are not formally rated, a typical bespoke (or custom) investment-grade portfolio would receive a AAA rating on its 7-10 tranche.

[2] Public-Private Investment Program White Paper, US Treasury, March 23, 2009.

[3] See Coval, Jurek, and Stafford (2009a and 2009b), Brennan et al. (2009), Benmelech and Dlugosz (2009).

the financial crisis. First, in contrast to several other credit markets including ABS and subprime, it is not obvious that *ex ante* assessments of expected losses, such as ratings, were severely incorrect in the investment grade corporate universe. This puts less burden on any pricing model to capture large shifts in the state-contingent cash flows anticipated by investors. Second, because the underlying assets are claims on the same cash flows as those of US equity investors, constructing a mapping to states that equity investors care about is quite feasible. In contrast, properly pricing claims on pools of mortgage-backed securities requires an accurate mapping of real estate values and mortgage default rates to economic conditions (Rajan, Seru, and Vig (2009)).

Our results suggest changes in fundamentals, as reflected in the equity market, account for a large portion of the repricing of credit that has occurred. In particular, the dramatic increase in the price of low cashflow states can account for most, if not all, of the rise in credit spreads for cash bonds. The spreads on credit default swaps, which currently trade at a large and negative basis relative to the underlying bonds, appear too low relative to risk-matched alternatives in the equity market.

We also find that the repricing of the investment grade structured credit securities suggests a correction of an *ex ante* failure of investors to appropriately charge for systematic risk. Prior to the crisis, Coval, Jurek, and Stafford (2009b) argued that investors did not appreciate the systematic risk exposures of these securities and provided evidence that credit protection on the senior tranches of the investment grade CDX was underpriced (i.e. spreads were too low), while protection on the junior most tranche was overpriced. During the crisis, all of the tranches have converged towards the prices predicted by the structural framework. Junior tranches, with relatively low systematic to total risks, experienced declines in the price of protection relative to the model. Senior tranches, with high systematic to total risk, saw the price of protection climb rapidly relative to the model. This pattern of convergence in tranche prices is confirmed by analyzing trading strategies that purchase underpriced (sell overpriced) tranche credit protection and hedge by selling (purchasing) protection synthetically in the equity index option market. In each tranche, the strategy earns economically impressive returns, including the equity tranche, which suggests that the majority of the repricing for the tranches of investment grade securitizations is coming from an increased charge for systematic risk as opposed to a lesser assessment of conditional payoffs.

2 A Structural Approach to Valuing Credit Securities

This paper follows the modified Merton-CAPM framework employed in Coval, Jurek, and Stafford (2009b). The intuition behind this approach is to construct payoffs to credit securities (e.g. bonds, collateralized debt obligation tranches, etc.) contingent on the realization of the economic state, as measured by the contemporaneous market return, and then value these payoffs by applying state-prices extracted from equity index options (Breeden and Litzenberger (1978)). To construct state-contingent payoffs for credit securities we assume asset returns in Merton's (1974) structural model satisfy a CAPM relationship. This allows us to specify firm asset values as a function of the equity market return as well as an idiosyncratic, firm-specific return. Since bond payoffs are determined by the terminal asset value, we can then compute payoffs of bond portfolios and derivatives written thereon using a large portfolio limiting argument, or via simulation. The final step is to simply scale the mean conditional payoffs by state prices and integrate across the states to obtain the corresponding asset prices.

2.1 State Prices

As in Coval, Jurek, and Stafford (2009b), the state prices we use come from over-the-counter S&P 500 index option quotes from a major investment bank. The quotes are for constant maturities in one-year increments. Since our focus is on on-the-run 5-year credit default swap indices, we use the 5-year implied volatility quotes to construct 5-year state prices. The quotes are provided in increments of 5% and range from 70% to 130% moneyness, which we then interpolate and extrapolate using a hyperbolic-tangent function.[4] This parametric form is smooth, produces strictly positive implied volatilities, and has controllable behavior in the tails. To fit the proposed implied volatility specification we minimize the sum of squared (percentage) pricing errors across the thirteen European options for which we observe prices. This procedure allows us to extrapolate the implied volatility on the entire grid of log moneyness values, m_τ, and compute a complete set of Arrow-Debreu state prices from:

$$q(m_\tau) = \frac{\partial^2 C^{BS}}{\partial K^2} + \frac{d\sigma}{dK} \cdot \left(2 \cdot \frac{\partial^2 C^{BS}}{\partial K \partial \sigma} + \frac{\partial^2 C^{BS}}{\partial \sigma^2} \cdot \frac{d\sigma}{dK} \right) + \frac{d^2\sigma}{dK^2} \cdot \frac{\partial C^{BS}}{\partial \sigma} \bigg|_{m_\tau = \ln \frac{K}{F_{t,\tau}}} \tag{1}$$

which is the analog of the Breeden and Litzenberger (1978) result in the presence of a volatility smile.

Our quotes can be compared to the implied volatilities of exchange-traded index options. Specifically, in Figure 1, we plot, as a function of moneyness, the implied volatilities of the exchange-traded options as well as our over-the-counter volatility quotes. The plot covers the most recent period for which we have exchange-traded option quotes – September 2008. We plot exchange-traded options that, as of September 2008, have 9, 15, 21, and 27 months remaining until expiration. We also plot the over-the-counter option quotes for 2, 3, 4, and 5 years to maturity. The figure verifies that the implied volatilities for the two-year OTC quotes closely match those of the longest-dated exchange traded options as of September 2008 – those with 21 and 27 months to maturity. As maturity increases, the volatility skew begins to flatten in the exchange-traded options – a common feature of the implied volatility surface. This flattening continues in the OTC contracts, as the maturity extends out to 3, 4, and 5 years. The exchange-traded options also suggest that any functional form that extrapolates the OTC volatilities to moneyness levels below 0.7 should maintain the skew that is present at the quoted levels. At a minimum, there appears to be no evidence that volatilities decline or even flatten as the moneyness level declines below 0.7. Consequently, our

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[4] The moneyness values are computed by scaling strike prices, K, by the contemporaneous forward price for the corresponding maturity.

use of a hyperbolic tangent functional form to fit the implied volatilities represents a conservative assessment of the pricing of adverse economic states.

2.2 State-contingent Payoffs to Credit Securities

In order to obtain bond payoffs conditional on the realization of the market return, suitable for use in a state-contingent valuation method, Coval, Jurek, and Stafford (2009b) modify Merton's (1974) model by imposing a factor structure on the asset returns. Specifically, they assume that asset returns are driven by a combination of a possibly non-Gaussian market factor, $\tilde{Z}_m$, and a Gaussian idiosyncratic shock, $\tilde{Z}_{i,\varepsilon}$, such that:

$$\ln \tilde{A}_{i,T} - \ln A_{i,t} = \left(r_f + \lambda_a - \frac{\sigma_a^2}{2} \right) \cdot \tau + \beta_a \sigma_m \cdot \sqrt{\tau} \cdot \tilde{Z}_m + \sigma_\varepsilon \cdot \sqrt{\tau} \cdot \tilde{Z}_{i,\varepsilon}$$

where: r_f denotes the riskless rate, λ_a is the asset risk premium, β_a is the asset CAPM beta and σ_ε is the idiosyncratic asset volatility. When combined with a CAPM pricing restriction, the conditional probability of a firm i defaulting on its debt given the realization of the common market factor is given by:

$$p_i^D(m_\tau) = \text{Prob}\left[\tilde{A}_{i,T}(m_\tau) < D \right] = \Phi\left[-\eta(m_\tau) \right]$$

where:

$$\eta(m_\tau) = \frac{\ln \frac{D}{A_{i,t}} - (r_f \cdot \tau + \beta_a \cdot m_\tau)}{\sigma_\epsilon \sqrt{T}}$$

and m_τ is the logarithm of the ratio of the terminal market index level, M_T, to the time t futures price, $M_t \cdot \exp((r_f - \delta_m) \cdot \tau)$. The random state-contingent loss on a large homogenous portfolio – expressed as a fraction of the par value of the underlying bonds – is then shown to converge by the law of large numbers to:

$$\tilde{L}_p\left(m_\tau\right) \rightarrow \left(1 - (1 - \nu) \cdot \frac{A_t}{D} \cdot \exp\left(r_f \tau + \beta_a m_\tau + \frac{1}{2}\sqrt{\tau}\sigma_\varepsilon^2 \right) \cdot \frac{\Phi\left[-\eta(m_\tau) - \sigma_\varepsilon \sqrt{\tau} \right]}{\Phi\left[-\eta(m_\tau) \right]} \right) \cdot p^D(m_\tau)$$

where ν is the fraction of assets lost to bankruptcy costs (Leland (1994), Cremers, Driessen and Maenhout (2007)). As is readily seen, the portfolio loss is determined by the triple of parameters describing the underlying firms: the asset beta, β_a, the initial debt-to-asset ratio, $\frac{D}{A_t}$, and the idiosyncratic volatility of assets, σ_ϵ, and contemporaneous market parameters.

To compute the state-contingent payoffs of derivative securities, whose payoffs are linked to losses on the underlying bond portfolio one simply needs to apply the contract terms state-by-state. For example, tranches of collateralized debt obligations (CDOs) can be thought of as call spreads on the portfolio loss, such that the loss on the $[X, Y]$ tranche – as a fraction of the tranche notional – is given by:

$$\tilde{L}_{[X,Y]}\left(m_\tau\right) = \frac{1}{Y - X} \cdot \left(\max(\tilde{L}_p\left(m_\tau\right) - X, 0) - \max(\tilde{L}_p\left(m_\tau\right) - Y, 0) \right)$$

In general, the mean state-contingent payoffs necessary for valuation cannot be computed analytically given the non-linearity of the tranche contract terms, potentially requiring simulation. However, as shown in Coval, Jurek, and Stafford (2009b), the large homogenous portfolio assumption provides a very accurate approximation to the simulation method (for $N = 100$) for computing the mean state-contingent payoffs by simply replacing the random portfolio loss, $\tilde{L}_p\left(m_\tau\right)$, with its limiting value, (**??**). The present value of the losses on the underlying portfolio and its derivatives can then be computed by integrating the expected state-contingent loss against the state-prices, $q(m_\tau)$ and discounting the sum at the risk-free rate.

Aside from valuation we will also be interested in analyzing the expected loss rates on the underlying portfolio and its derivatives. To compute the unconditional expected loss for a particular security under the risk-neutral measure, $E_\tau^Q\left[\tilde{L}\right]$, we integrate its state-contingent loss against the risk-neutral probabilities, $\pi^Q\left(m_\tau\right) = e^{r_f \cdot \tau} \cdot q(m_\tau)$. Moreover, since the expected payoff on a security is equal to one minus the expected loss, it is easy to see that the risk-neutral loss rate, l_τ^Q, simply corresponds to the security's yield spread:

$$l_\tau^Q \quad = \quad -\frac{1}{\tau} \cdot \ln\left(1 - E_\tau^Q\left[\tilde{L}\right]\right) \tag{2}$$

Finally, to obtain the corresponding loss rate under the objective measure, l_τ^P, we compute the unconditional expected loss, $E_\tau^P\left[\tilde{L}\right]$, using an auxiliary assumption that the distribution of (log) market returns under the objective measure is Gaussian with an annualized risk premium $\lambda_m = 5\%$ and volatility given by the contemporaneous implied volatility of 5-year equity index options. To avoid confusion, in the remainder of the paper when we refer to a *loss rate* we have in mind the objective loss rate, l_τ^P, and reserve the term *yield spread* for the risk-neutral loss rate, l_τ^Q.

2.3 The Price of Protection and Counterparty Risk

An investor who sells protection on a portfolio of bonds commits to paying out the amounts lost in the event of default to the protection buyer in exchange for receiving a sequence of insurance premium payments. In practice, these payments are generally a combination of an *up-front* payment received at contract initiation and a periodic payment paid on the remaining notional over the life of the contract, or *running spread*. We refer to the combined value of the up-front payment and the running spread as the price of protection. At inception, the insurance contract – or credit default swap (CDS) – is priced such that price of protection exactly equals the present value of the anticipated losses, such that no money exchanges hands. Using state prices extracted from the equity index options and the state-contingent portfolio loss function in (**??**), the present value of protection can be computed as:

$$\mathrm{PV}_\tau(\text{protection}) = \int_{-\infty}^{\infty} \tilde{L}_p(m_\tau) \cdot q(m_\tau) \cdot dm_\tau$$

In order to express this value as a running spread for comparison with empirical data, we make an auxiliary assumption that the expected outstanding portfolio notional declines at a constant rate, reaching $1 - E_T^Q\left[\tilde{L}_p\right]$ at maturity, and that the running spread, s, is paid continuously. The rate at which the outstanding portfolio notional declines is obtained from, (2), by fixing the time-to-maturity at its maximum value, T, and is denoted by l_T^Q. The running spread, s, is then set such that the present value of the premium payments equals the present value of the expected losses:

$$\begin{aligned} \text{PV}_\tau(\text{premium}) &= \int_s^T s \cdot e^{-l_T^Q \cdot u} \cdot e^{-r_f \cdot (u-s)} \cdot du \\ &= s \cdot e^{-r_f \cdot \tau} \cdot \frac{\left(1 - E_T^Q\left[\tilde{L}\right]\right)}{r_f + l_T^Q} \cdot \left(e^{(r_f + l_T^Q)\cdot \tau} - 1\right) \end{aligned} \tag{3}$$

If s is expressed in basis points, the term that follows has the interpretation of the risky present value of one basis point, or RPV01. We will make use of the model RPV01 to convert running spreads observed in the data into present values, enabling comparisons of the price of protection across securities and markets. Analogous computations can be carried out for tranches by replacing the portfolio notional and expected losses with the tranche notional and tranche expected losses, resulting in estimates of the price of protection for insuring tranche losses.

In actual capital markets, the price of protection can also be affected by concerns regarding the ability of the counterparty to make the promised protection payments, (**??**), covering losses realized on the reference entity. The structural model enables us to analyze this effect quantitatively by modeling the state-contingent likelihood of counterparty default in relation to the realized loss. This is made particularly tractable by the feature that after conditioning on the realization of the common factor, m_τ, all defaults are independent. If the state-contingent probability of a counterparty defaulting is given by, $p_D(m_\tau)$, and the counterparty only makes a fraction, $1 - \xi$, of the promised payment in the event of default, the present value of the protection leg becomes:

$$\begin{aligned} \text{PV}_\tau^*(\text{protection}) &= \int_{-\infty}^{\infty} \Big((1-\xi) \cdot \tilde{L}_p(m_\tau) \cdot p_D(m_\tau) + \tilde{L}_p(m_\tau) \cdot (1 - p_D(m_\tau))\Big) \cdot q(m_\tau) \cdot dm_\tau \\ &= \text{PV}_\tau(\text{protection}) - \xi \cdot \int_{-\infty}^{\infty} \tilde{L}_p(m_\tau) \cdot p_D(m_\tau) \cdot q(m_\tau) \cdot dm_\tau \end{aligned} \tag{4}$$

Intuitively, if there is a chance that the counterparty defaults on its obligation to cover the realized losses on the reference security, the present value of the protection declines relative to the “no counterparty risk” case. The magnitude of this effect rises with ξ, which measures the proportional losses on the obligation due to counterparty failure. Regulatory regimes with stringent two-way market-to-market procedures will generally be characterized by low values of ξ, as the ongoing payments eliminate the the effect of a counterparty default.

2.4 Robustness

The modified Merton-CAPM model priced bonds fairly easily during the pre-crisis period. Parameters exhibited stability and the model's ability to explain weekly yield spread movements was on par with that of most reduced-form specifications. However, two new and potentially important considerations arise in the pricing of credit securities during the financial crisis using a structural model.

First, a key assumption of the Merton-CAPM model is that changes in firm asset values are linear in the equity market return. Although it is fairly standard to assume that the beta of a firm's assets is invariant to its degree of leverage (e.g. M&M II), if the equity market is used as the single risk factor, the representative firm's asset beta cannot be constant. In particular, as the equity index nears zero and leverage nears 100%, large percent changes in the market will have little impact on the total value of firm assets, since most of it is claimed by debt. And so while the assumption of constant asset betas is a reasonable one when the average leverage is low (i.e. the stock market is healthy), when the market declines severely, the asset beta may begin to decline in a non-trivial way from the perspective of a structural model.

A second key feature of the financial crisis is the dramatic increase in default risk experienced by a number of financial firms. During the fall of 2008, spreads on financial firms increased to almost 1000 basis points. To the extent that these firms represent the major counterparties to the contracts that underlie the CDX and its tranches, counterparty risk represents a potentially important consideration in any attempt to value these securities during the crisis. One might expect these risks to be particularly pronounced in the so-called "super-senior" tranches of CDOs, since they only default in states of the world when distress is widespread. Indeed, prior to the crisis, several practitioners mentioned to us that this was a key challenge in pricing and interpreting spreads on the super-senior tranches.

On the other hand, there are at least two factors that may limit the degree of the counterparty risk in the CDX and its tranches. First, for any non-AAA rated counterparty, two-way marking-to-market is a standard feature of most over-the-counter swap contracts. So the counterparty risk will only show up to the extent that both the reference entity and the counterparty experience simultaneous jumps-to-default. However, since this will typically occur in fairly expensive states of the world, the effect on valuations may still be non-trivial.

A second factor that may limit the impact of counterparty risk on our valuations is if the long-dated option prices used to obtain state prices also contain counterparty risk. In particular, the over-the-counter equity index option quotes used to identify state prices may be artificially depressed - particularly for deeply out-of-the-money states - if the counterparty is not expected to deliver all of its payments in those states of the world. To investigate this possibility, one can compare the long-dated over-the-counter quotes to the exchange-traded implied volatilities, where counterparty risk is expected to be considerably lower if not negligible. As discussed above, Figure 1 demonstrates that two-year OTC volatilities coincide almost perfectly with those of the 21 and 27-month exchange traded options. This suggests that, at least at the two-year horizon in September 2008, the over-the-counter quotes were not biased downward to reflect an additional degree of counterparty risk in these contracts. Put differently, the market does not appear to be pricing the long-dated volatility quotes with a significant degree of counterparty risk.

3 Credit Spreads

At the start of 2009, investment-grade bonds were trading at their highest spreads in the post-war era, surging from 33 to 432 basis points in just two years. A key premise behind the government's actions at the time was a view that credit markets had seized up, and that intervention was required to return liquidity to these markets and restore appropriate spreads.[5]

Of course, this period was also fairly unprecedented for equities, which witnessed a dramatic revaluation of their own. By early 2009, the S&P was more than 40% off its peak reached in October 2007 and the VIX index of short-term implied volatility had remained consistently above 38% since September 30, 2008. During the first two months of 2009, the VIX has averaged 45%, a level never experienced even once prior to October 2008. Perhaps even more remarkable was the substantial and permanent increase in long-dated volatilities. Typically, increases in short-term volatility are expected to decay rapidly, and have muted effects on longer-dated implied volatilities. In contrast, the financial crisis brought about roughly a doubling of *five-year* implied volatility by October 2008 to a level of 35% from which there has been only modest retreat.

Table 1 presents a summary of various capital market measures around several key dates of the financial crisis. As Panel B of the table makes clear, the crisis in the investment grade corporate credit market began in 2007, as the CDX spread increased 145% over the year and the credit spread on cash bonds increased 270% over the year. Meanwhile, the S&P 500 index was essentially flat in 2007. This superficially gives the appearance that the credit and equity markets were not well integrated at the beginning of the crisis. However, it is important to note that the implied volatility of S&P 500 index options increased dramatically over the year. In particular, the VIX index nearly doubled and the implied volatility of 5-year at-the-money options increased 35%. The second year of the crisis, 2008, produced another round of large increases in investment grade corporate credit spreads and volatility measures. In addition, the S&P 500 index dropped nearly 40% over the year and 5-year US Treasury yields fell in half.

The structural framework allows us to ask whether the historically unprecedented movements in these two markets were consistent with one another. Since risky debt is essentially short a put option on assets, a decline in the value of assets and increase in their volatility both predict a significant widening of spreads. The structural model allows us to determine whether the spread increases experienced in credit markets were consistent with movements in the equity market and its volatility.

If equity markets rule out the observed spread increase, this means that the two markets are

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[5] "More capital injections and guarantees may become necessary to ensure stability and the normalization of credit markets," Ben Bernanke, New York Times, January 13, 2009.

not integrated and potentially assets being marked at observed credit spreads are being severely misvalued. On the other hand, if the dramatic widening in credit spreads is consistent with the behavior of equity prices, this means that credit markets cannot be viewed as any more mispriced than equity. It also suggests that policies that attempt to prop up credit markets are essentially requiring (or assuming) that equity prices respond in a commensurate way.

Another key feature of credit markets during the fall of 2008 was a dramatic widening of the so-called "basis" – or difference in yields – between the CDX and its underlying bonds. This gap, which averaged negative 30 basis points prior to the fall and has averaged negative 164 basis points since, has been interpreted as evidence of a significant liquidity premium paid by investors in the CDX. This premium was likely magnified throughout the crisis as funding requirements of the trade to arbitrage this spread became more severe. An alternative possibility, which we investigate below, is that the CDX swaps suffer from counterparty risk that became of progressively greater concern to investors this fall. Although our structural model makes no formal distinction between the cash and swap markets, to the extent that we calibrate to one market or the other, liquidity premia will only be captured indirectly, through adjustments in the model parameters.

3.1 Forecasting credit spreads

Our first exercise is to see whether the structural model can replicate the widening of credit spreads that has occurred since the onset of the crisis. In particular, we ask whether the decline in the stock market and the increase in volatility are sufficient to produce the observed widening of spreads. The specific forecasting exercise proceeds as follows. We calibrate the model parameters as of a certain date. We then forecast daily CDX spreads using updated information on the level of the S&P 500 index, the riskfree rate, and index option prices. We update the model parameters by assuming that asset returns obey the CAPM causing the debt-to-asset ratio to shift and that asset betas evolve such that the model-implied equity beta remains constant at one. In this way, any spread changes are solely a consequence of changes in the level and volatility of the stock market. It is worth noting that this approach ignores any changes in the nature of the underlying assets. To the extent that firms attempt to reduce their debt outstanding or substitute safe for risky assets during the crisis period, the structural model will produce spreads that exceed those observed in the market.

One dimension along which this exercise is underspecified is the evolution of idiosyncratic volatility. If idiosyncratic volatility is held constant, constant model parameters will pin down the conditional payoff function across the sample. If idiosyncratic volatility is allowed to vary, the conditional payoff function will move as well. Ideally, five-year idiosyncratic volatility swaps would be used to guide our calibration. Unfortunately, we have little available in this regard. Estimates of realized CDX firm idiosyncratic volatility during the crisis suggest that it also increased significantly during this period. Therefore, a natural alternative to holding idiosyncratic volatility constant is to assume that it evolves in proportion to market volatility.

Figure 2 presents the cash bond, CDX, and model-implied yield spreads during the crisis.

We present four distinct calibrations, matching the CDX or cash bond spread on the following dates: January 2007, July 2007, January 2008, and July 2008. Figure 2 presents the proportional idiosyncratic volatility case, and Figure 3 presents the constant idiosyncratic volatility case. Due to the absence of a meaningful spread differential, or basis, between the credit default swap markets in either January or July 2007 our model is able to simultaneously match the CDX and bond spreads. For the remaining calibration dates, we must choose to either calibrate the model to the CDX (second row) or the cash bonds (third row). Crucially, by rolling the model parameters forward from the calibration date the structural model enables us to produce out-of-sample forecasts of credit spreads through the end of our sample in January 2009.

When the model is calibrated to 2007 credit spreads – far in advance of the ongoing credit crisis – and the firms' idiosyncratic volatility is scaled in proportion to the five-year option implied market volatility, the model-implied credit spreads track the actual credit spreads fairly closely throughout 2007, despite the fact that the stock market starts and ends the year at roughly the same level. This is driven by the large increase in the price of insuring poor economic states in the index options market. As the forecasts continue into 2008, the model-implied spreads end the year in line with the spreads of investment-grade cash bonds (Figure 2; first row). This provides evidence that the pricing of bonds is integrated with the pricing of equities, and casts doubt on claims that credit markets are in the midst of a "fire sale," causing prices to depart from "hold-to-maturity" values.

When the model is calibrated in 2008 to spreads of *synthetic* securities, such as the CDX, the results remain qualitatively unchanged. Both the January and July 2008 calibrations suggest that the CDX spread is surprisingly low relative to the model-implied credit spread – a fact we examine in greater detail in a later section – which itself straddles the actual observed value for the bond spread. Analogous out-of-sample pricing exercises based on parameters calibrated to cash securities in January or July of 2008 (third row) produce even more striking results, suggesting that the cash securities are close to fair, or possibly even expensive.

To examine the robustness of these results, in Figure 3 we perform the same out-of-sample experiments but holding the idiosyncratic asset volatility fixed at its initially calibrated value. In this more conservative case, the model-implied spreads based on calibrations performed in 2007, lie between the spreads on the cash and synthetic securities observed in 2009, and are perhaps somewhat more in line with spreads on the CDX. The 2008 calibrations (bottom two rows), whether based on cash or synthetic spreads, projects credit spreads in January 2009 that either match or exceed the level of the CDX, and in three of the four cases are within 50 basis points of the spreads on the cash bonds. To investigate the source of the repricing that has occurred in the bonds, it is useful to study the evolution of conditional payoffs implied by the model parameters. In Figure 5, we plot on each roll date, the payoffs of the representative bond conditional on the value of the market at maturity. For purposes of comparison, the value of the market is normalized to one on each roll date. The plot reveals that the conditional payoffs implied by CDX prices and a structural framework have evolved considerably during the past year. Series 5-8 exhibit fairly consistent state-contingent payoffs. Series 9, which began at the end of September 2007, has somewhat elevated state-contingent payoffs. This is because although the CDX spreads had recovered from the quant-crisis of the summer, returning to roughly 50 basis points, 5-year stock market volatility, which had not exceeded 20% since 2003, was now at 23.5%. By the end of March 2008, the payoffs for Series 10 were now, for all but deeply out-of-the-money states, well below the others. The widening of spreads to 197 basis points implied lower conditional payoffs given that stock market level and volatility were both essentially flat. This suggests that the credit quality of the CDX, which is reconstituted on the roll dates to remain at a constant level in the on-the-run series, had materially deteriorated following the failure of Bear Stearns.

One way to see this is by examining loss rates through time relative to yields, which are plotted in Figure 6. The implied loss rate began to increase considerably at the end of 2007, accelerated with the failure of Bear Stearns, and has remained elevated ever since. The ratio of yield spread to loss rate (credit risk ratio) through time, plotted in Panel B, has also declined since the fall of 2007, as a greater fraction of yield is now accounted for by expected losses. This pattern of a declining credit risk ratio as credit quality falls is a common feature of credit data.

3.2 Estimating the effect of counterparty risk

One possible explanation for the CDS-bond basis is the risk that the counterparty defaults jointly with the reference entity. In such a situation, the credit default protection fails to deliver precisely when it is promised, which reduces its value *ex ante*. The counterparty risk is essentially credit risk on the credit default swap.

We modify the structural credit model to account for the possibility of counterparty risk by assuming that the CDS counterparty has a similar state-contingent probability of defaulting as the representative firm in the CDX, (4), and that upon a joint default of the CDS and the counterparty, recovery is zero ($\xi = 1$). This is an extremely aggressive view that essentially assumes there is no marking-to-market of the CDS contract through time. Figure 4 shows the actual CDS-bond basis and the portion explained by this counterparty risk measure. Even with this very aggressive computation, we find limited support for counterparty risk as the main driver of the basis. In unreported results, we find that alternative recovery value assumptions, which recognize that at least some marking-to-market of the CDS is likely to occur, produce smaller effects.

Taken together, we conclude that the pricing of investment-grade corporate credit has largely been consistent with that of the equity market when viewed through the structural model. In other words, from the context of the structural model, there should be nothing particularly surprising about the severe widening of credit spreads in the investment grade CDX and the underlying cash bond credit spreads. Indeed the observed widening of the CDX spread is, if anything, somewhat low relative to what the structural model forecasts conditional on the market declining by 40% and its long-term volatility doubling. The out-of-sample results challenge the commonly advocated view that the pricing of credit securities has become distressed, and instead suggest that spreads on the synthetic securities are unusually low.

4 Credit Derivatives

In this section we examine the pricing of the structured credit derivatives, or tranches, referencing the Dow Jones North America Investment Grade Index (CDX NA.IG). As a first step in the analysis, the structural model is calibrated to match the spread of the underlying index on each day in the sample by selecting a triple of firm-parameters: the firm's debt-to-asset ratio, asset beta, and idiosyncratic volatility.[6] This is done by combining the state-contingent payoff function implied by the structural model with the equity index option implied state price density, and varying the model parameters until the model simultaneously matches the CDX spread, produces an equity beta of one and a pairwise firm return correlation of 0.20, as in Coval, Jurek, and Stafford (2009b). This allows us to produce a state-contingent payoff function for the CDX, to which we can apply the various tranche terms to calculate the corresponding tranche payoffs. The mean state-contingent tranche payoffs are then valued by applying the state prices, resulting in a time series of tranche spreads, or equivalently, prices of default protection.

Before proceeding with the analysis, it is useful to review how the world looked at the start of the crisis from the structural perspective. The investment-grade CDX spread had been stable at 40 basis points and then expanded to around 70 during the summer of 2007 (Figure 5; top panel), just prior to the inception of Series 9. The bottom panel of Figure 5 additionally plots the ratio of the CDX spread to the contemporaneous loss rate, or credit risk ratio, which measures the quantity of systematic risk in the CDX. At the same time, the junior most tranche (0-3) offered around twice the spread predicted by the structural framework, while all other tranches offered a fraction of what the model said they should. In short, the structural framework predicted a major relative repricing of CDX tranches and, to the extent that this mispricing was the key driver of the structured finance boom, the outright collapse in securitization may not be too unexpected.

4.1 Tranche pricing through the crisis

Credit models are often evaluated in terms of the difference between model and actual credit spread. Metrics such as root mean-squared error, for example, are used to evaluate the quality of fit. Because of the unprecedented change in underlying risks, the crisis poses some challenges in scaling the convergence in yields appropriately. In risk-adjusted terms, a security that is trading at 20 basis points that should be trading for 40 basis points is far more mispriced than one that is trading at 900 basis points but should be trading for 920. This problem is compounded by the fact that some tranches are quoted in terms of a running spread, while others offer combinations of an up-front payment and a running spread. To deal with these issues, we convert all spreads, running and upfront, into an all-in present value of credit protection. In this way, all tranches are compared to the model in terms of the full price of protection an investor is effectively paying.

Figure 6 shows the daily prices of credit protection for the various tranches available in the

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[6] For tractability, the maintained assumption of our calibration procedure is that the 125 firms in the CDX portfolio are homogenous.

market and those implied by the model. These prices have converged dramatically over the past 18 months. Figure 7 presents the percentage mispricing of the tranche prices from the model's perspective. These figures verify that tranche prices have converged dramatically to the predictions of the structural model over the past 18 months of the sample. Equity protection, which was 70% overpriced at the start of the crisis, is now fairly priced by the end of the sample of January 23, 2009 according to the model. Similarly, protection on the 7-10 tranche, which was 80% underpriced 18 months ago, is also now fairly priced. Protection on the 10-15 tranche has converged markedly but is still 20% too cheap. The 3-7 tranche protection has gone from 40-60% underpriced to 20-40% overpriced. The overpricing of 3-7 protection may be a consequence of the failure of our model to account for industry exposures. In particular, our model assumes firms are only correlated through the market factor. To the extent that a number of financial firms experienced a dramatic increase in their default risk during the crisis, the 3-7 tranche is where our failure to account for within-industry correlations will materialize. Of the five tranches, only the 15-30 tranche has not converged significantly to the model predicted price.

Another way to measure the model's ability to explain tranche prices is by measuring the quality of fit over time. Table 2 reports the root mean squared percentage error for each of the tranches. Specifically, we calculate the average squared percentage mispricing for protection on each tranche across each quarter of the sample and report the values in square-root terms. The table confirms the convergence of the figures. Errors in all but the 15-30 tranche converge dramatically and steadily across the quarters. The equity and 7-10 tranches lead the way, settling at 10-11% pricing errors at the end of the sample. The 3-7 and 10-15 tranches exhibit convergence but maintain errors of roughly 30%.

A final way to examine the pricing of credit risk is by calculating the ratio of yield spread to loss rate (credit risk ratio). Because senior tranches concentrate their losses in poor economic states, their risk premia should be high relative to similarly-rated corporate bonds, translating into a relatively high credit risk ratio.

Figure 8 displays scatter plots of the daily credit risk ratios against expected loss rates. The expected loss rates are calculated with the assumptions of a lognormal distribution for the terminal market value, a market risk premium of 5% per year, and volatility given by the daily at-the-money 5-year option implied volatility. The figures clearly show that the model "pricing function" has been remarkably stable through time. In other words, the scatter plot of daily credit risk ratios against loss rates maps out a very smooth curve with the expected steep slope for small loss rates. The credit market's "pricing function" appears to have changed through time. Early in the sample period, the junior tranche (0%-3%) earned a very large risk premium relative to the model, which has disappeared in the more recent period (beginning in October 2008). The other tranches started the sample period with small risk premia relative to the model, but with the exception of the most senior tranche, have all experienced an increase in their risk premia in the recent period. The repricing of the tranches is consistent with the notion that investors have come to better appreciate how the systematic risks are allocated across the various claims.

4.2 Evaluating the economic significance of tranche repricing

For an alternative perspective on the statistical and economic significance of the convergence in model and tranche prices, we investigate the returns to investment strategies that attempt to exploit the initial mispricing. If protection on a particular tranche appears underpriced according to the model, we purchase protection on the tranche and then sell it synthetically by constructing and selling the appropriate portfolio of index option contracts. Tranche protection that is overpriced is sold and then repurchased synthetically in the options market. The model is used to identify the specific portfolio of option contracts that replicates the conditional payoffs of the tranche. Because the portfolio of options that we own (or are short) changes daily as the profile of conditional payoffs evolves, we calculate the returns earned each day on the portfolio of options purchased (or sold) at the close of trading on the previous day. This return series is combined with the returns on the protection of the particular tranche to construct a hedged return series for protection on each tranche.

An attractive feature of this approach is that it allows us to isolate how the repricing is occurring. To the extent that the convergence is driven by changes in the model conditional payoffs – which are resulting in changes in the composition of the replicating portfolio – the trading strategy's performance will be unimpressive. This would occur if convergence were solely a consequence of our model having an ability to describe conditional payoffs that was improving with time. On the other hand, if convergence is occurring because the tranche is being repriced in the direction suggested by our model, the strategy should exhibit non-trivial performance.

An additional benefit of this perspective is that, to the extent that repricing is occurring in the direction predicted by the model, it allows us to gauge the extent to which the initial mispricing was a consequence of incorrect forecasts of default risks or incorrect pricing of those risks. If only the tranches with underpriced protection earn significant returns, this suggests that an underappreciation of default risks was primarily responsible for the initial mispricing. If, on the other hand, profits are earned selling the overpriced protection, given that the underlying credit risks have increased during the crisis period, this suggests that improved appreciation of the state dependence of tranche default risks is an important factor in the repricing.

Table 3 presents the returns to trading in the CDX tranches and index options according to the prescriptions of the structural model. We present each tranche separately as well as the returns on an equally-weighted portfolio of all five tranches and their corresponding index option portfolios. Although the returns can easily be improved if the weights are allowed to vary across the tranches and over time according to the degree of mispricing, we present results using equal and constant weights from the start of our sample (September 2005) and from July 2007 onward.

The trading performance is highly consistent with the convergence results presented above. Implemented at the start of the sample, the 0-3, 7-10, and 10-15 tranches all exhibit impressive returns and relatively modest risks. The 3-7 and 15-30 tranches earn returns that are less impressive economically and statistically, but still non-trivial. When combined, the five tranches deliver returns that are economically large and exhibit fairly modest risks. Interestingly, the skewness is positive for all but the equity tranche and particularly so for the portfolio, suggesting that much of the strategy's risk is coming from positive jumps in returns.

The second panel reports returns to strategies implemented at the start of July 2007. This date is selected because it immediately precedes the quant crisis and because it is also the time when concerns about the pricing of structured credit securities began to appear in the popular press.[7] Clearly, implementing the trading strategies immediately prior to the initial onset of the crisis improves performance considerably. Although risks do not change, average returns are roughly doubled, which is not surprising given that time period is roughly halved and most of the convergence remains.

Perhaps the most interesting result in Table 3 is the performance of the equity tranche. From July 2007 to January 2009, the underlying CDX spread increases from under 50 basis points to over 200. The price of \$1 of protection on the 0-3 tranche increases from roughly 0.40 to 0.80. Nevertheless, the return from selling protection on the equity tranche and purchasing it synthetically in the equity market is highly positive during this period. The positive return earned from selling the equity tranche is coming because it was overpriced *ex ante* and, importantly, in spite of the fact that the underlying portfolio's loss rate increased significantly *ex post*. This suggests that, at least in terms of the pricing of the CDX and its tranches, the market's *ex ante* underappreciation of default risk was modest relative to its failure to appreciate the state-dependence of various tranche risks. And the fact that convergence has largely occurred between the traded and model prices suggests that the market is now pricing the state-dependence of default properly.

5 Discussion

Policymakers are rapidly moving towards using TARP money to purchase toxic assets – primarily tranches of collateralized debt obligations (CDOs) – from banks, with the aim of supporting secondary markets and increasing bank lending. The key premise of current policies is that the prices for these assets have become artificially depressed by banks and other investors trying to unload their holdings in an illiquid market, such that they no longer reflect their true hold-to-maturity value. By purchasing or insuring a large quantity of bank assets, the government can restore liquidity to credit markets and solvency to the banking sector.

The analysis of this paper suggests that recent credit market prices are actually highly consistent with fundamentals. A structural framework confirms that bonds and credit derivatives should have experienced a significant repricing in 2008 as the economic outlook darkened and volatility increased. The analysis also confirms that severe mispricing existed in the structured credit tranches prior to the crisis and that a large part of the dramatic rise in spreads has been the elimination of this mispricing.

If prices currently coming out of credit markets are actually correct, and not reflecting fire sales, this has several important implications. First, correct prices in the secondary market for these assets

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[7] See, for example, "How Street Rode the Risk Ledge and Fell Over," Wall Street Journal, August 7, 2007

essentially imply that many major US banks are now legitimately insolvent. This insolvency can no longer be viewed as an artifact of bank assets being marked to artificially depressed prices coming out of an illiquid market. It means that bank assets are being fairly priced at valuations that sum to less than bank liabilities. In turn, any positive valuation assigned by shareholders to their equity claim arises solely from their anticipation of value transfer from firm debtholders or resource transfers from US taxpayers.

Second, if current market prices are fair, any taxpayer dollars allocated to supporting these markets will simply transfer wealth to the current owners of these securities. To the extent that these assets reside in banks that are now insolvent, the owners are essentially the bondholders of these banks. The reason their bonds are currently trading far below par is that the assets backing up their claim are just not worth enough (nor expected to become worth enough when their bonds mature) to repay them. And so while they will be cheered by any government overpayment for the toxic assets backing up their claims, their happiness will be at the taxpayer's expense since – to the extent that current prices are fair – they will be receiving more than fair value for their investments. Similarly, using government resources to support these markets by insuring assets against further losses amounts to providing insurance at premia that are significantly below what is fair for the risks that the US taxpayer will now bear.

Third, the market for securitized claims is not going to operate the same way it did in the past. Investors in these assets are setting prices in the secondary market that reflect both the high expected losses of the securities and the highly systematic nature of these expected losses. And while the pricing of these securities is dramatically different from the way it was a year or two ago, this is because it was wrong then, not now. Efforts to restart this market are focused on resuming the flawed pricing of the past, when there was no charge for risk and investors relied on the accuracy of ratings. Investors have learned from their mistakes and now seem to be pricing these securities in accordance with their true risks.

6 Conclusion

This paper has investigated the pricing of investment grade credit risk during the financial crisis. Many analysts appear to be looking at large recent price changes and concluding that we must be witnessing distressed pricing and widespread market failure. This conclusion is based on intuition that fails to appreciate the extreme nonlinearity in the risks of credit securities, especially those manufactured by securitization (i.e. CDO tranches). Our analysis suggests that the dramatic recent widening of credit spreads is highly consistent with the decline in the equity market, the increase in its volatility, and an improved investor appreciation of the risks embedded in these securities. From this perspective, policies that attempt to prevent a widespread mark-down in the value of credit-sensitive assets are likely to only delay – and perhaps even worsen – the day of reckoning.

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Figure 1
Exchange-traded and Over-the-counter S&P Volatilities

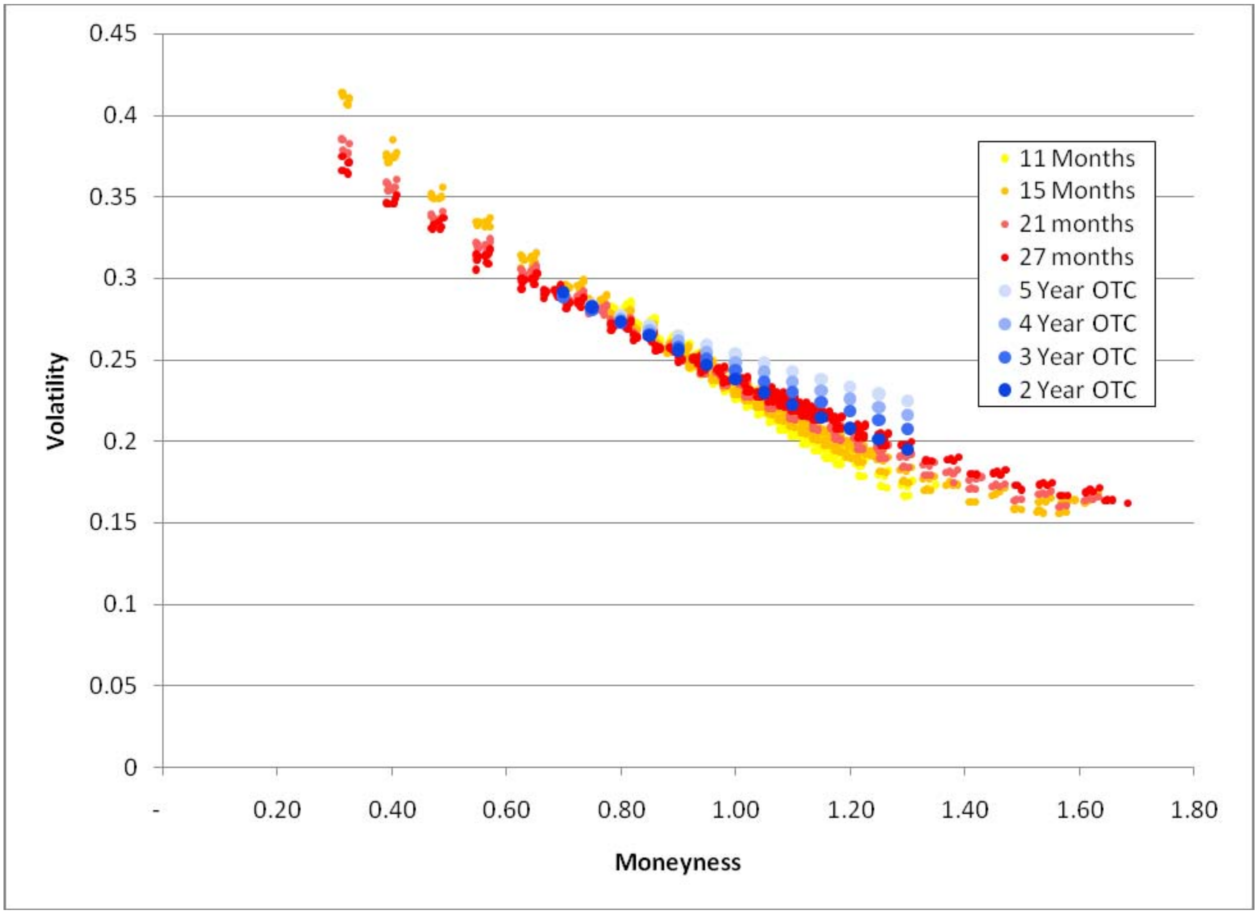

Figure 1 plots closing implied volatilities of exchange-traded S&P 500 option contracts and quotes on over-the-counter long-dated S&P 500 options from September 2, 2008 through September 10, 2008. Strike prices are plotted on the x-axis as a fraction of the index value.

Figure 2
Time Series of Credit Spreads
(Idiosyncratic Volatility assumed proportional to ATM Volatility)

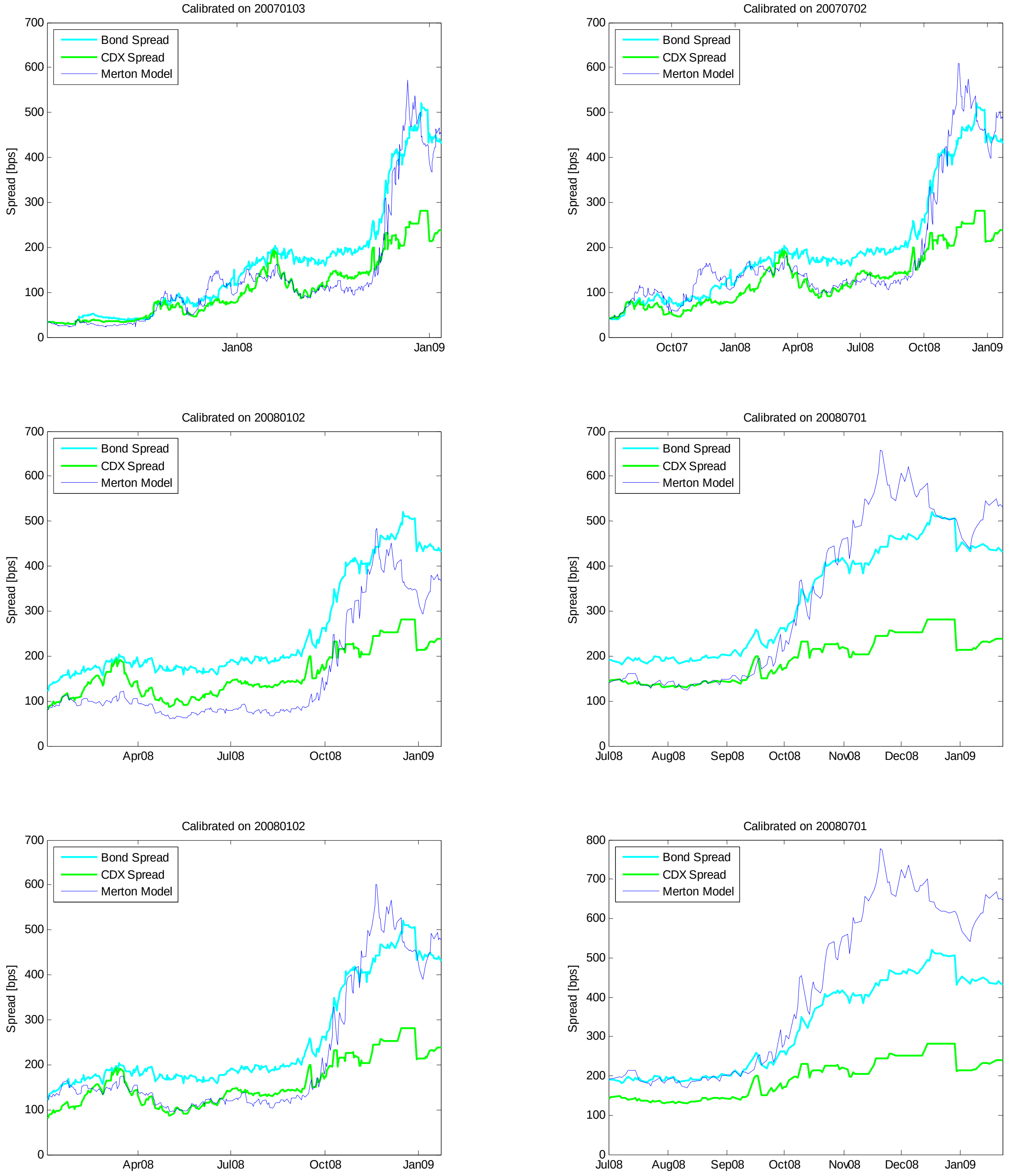

Figure 2 plots the predicted yield spreads against actual cash and CDX spreads by calibrating the model parameters to either the CDX or cash markets and then updating predicted yield on the basis of the level and volatility of the equity market. Idiosyncratic volatility is modeled as proportional to at-the-money volatility.

Figure 3
Time Series of Credit Spreads
(Idiosyncratic Volatility fixed on Calibrated Value)

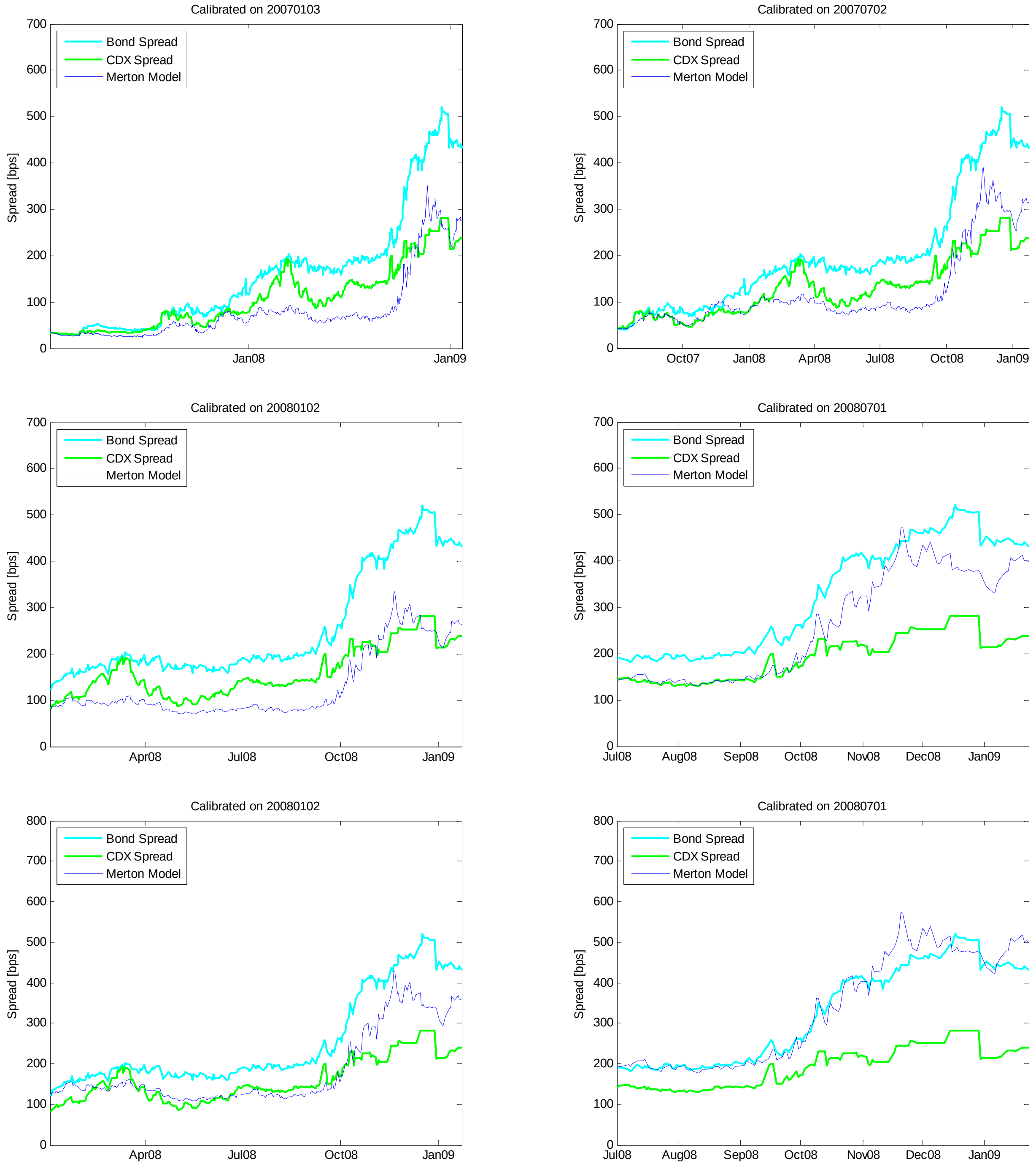

Figure 3 plots the predicted yield spreads against actual cash and CDX spreads by calibrating the model parameters to either the CDX or cash markets and then updating predicted yield on the basis of the level and volatility of the equity market. Idiosyncratic volatility is assumed to remain constant at the calibrated level.

Figure 4
The CDS-Bond Basis

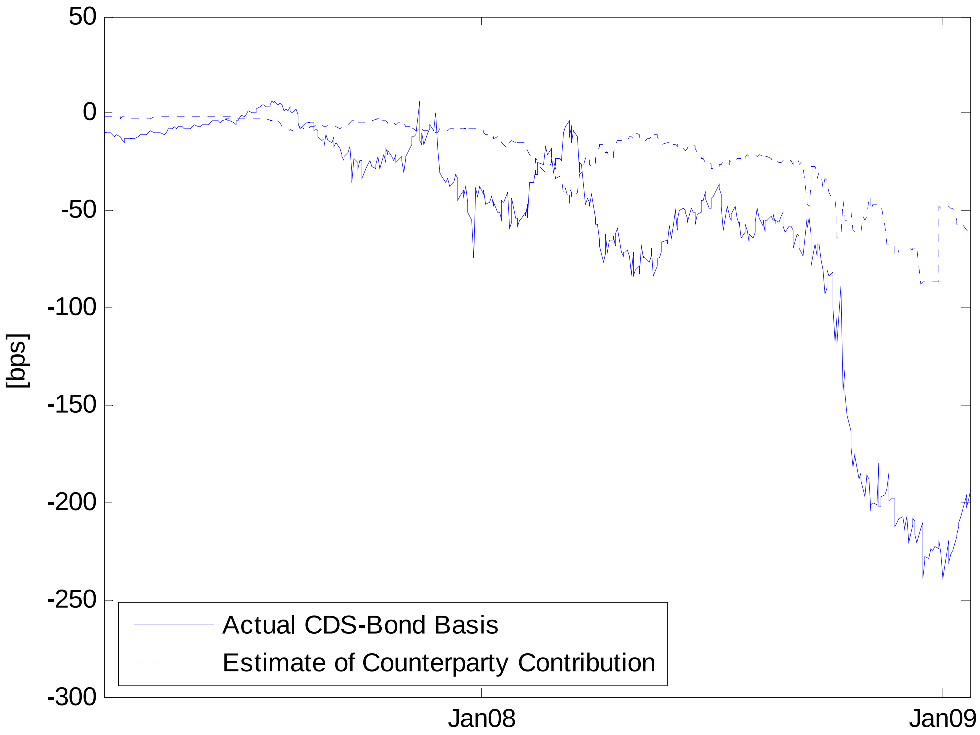

Figure 4 plots the CDS-Bond basis through against the adjustment in basis predicted by a structural model that allows for counterparty default on the CDS contract. The CDS counterparty is modeled as the representative firm in the CDX universe and, conditional on the joint default of the CDS contract and the counterparty, the CDS recovery rate is assumed to be zero.

Table 5
Calibrated State-Contingent Payoffs

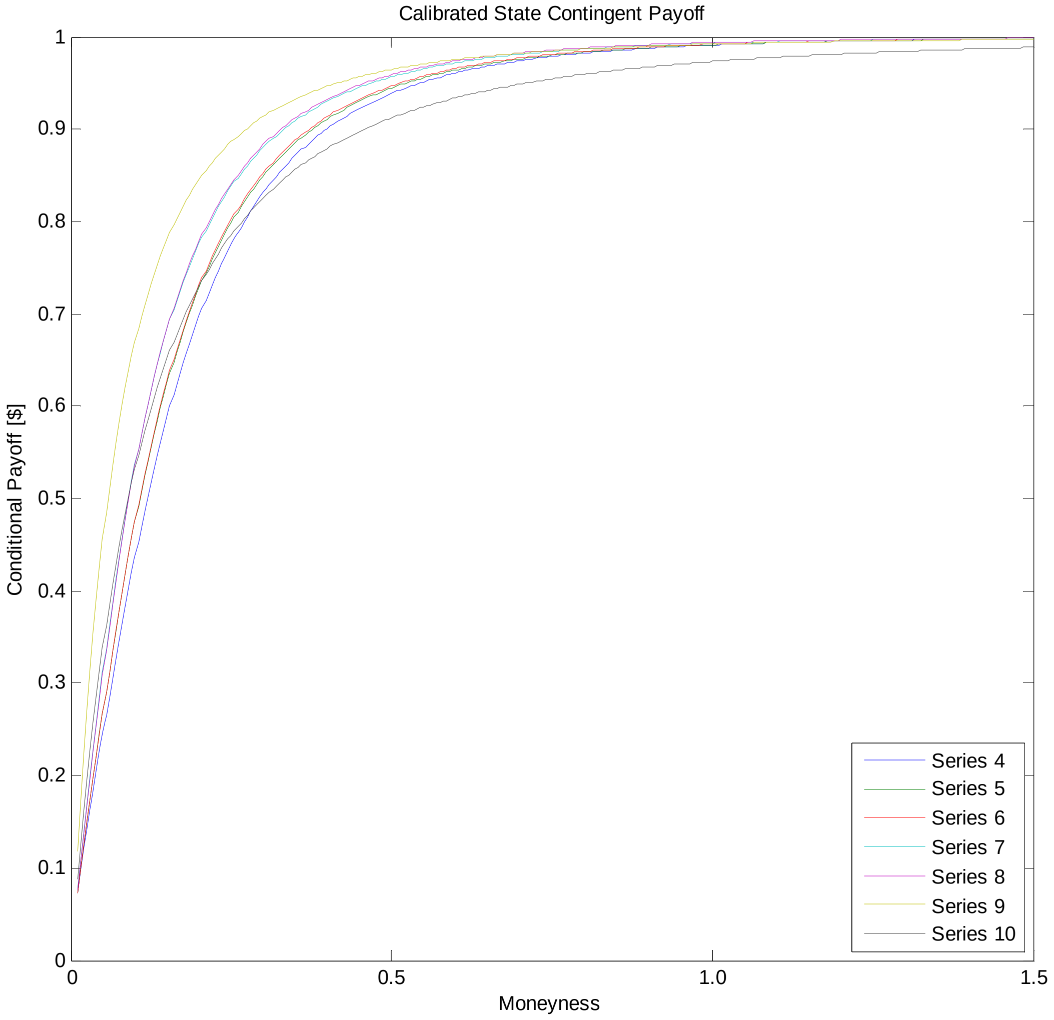

Figure 5 plots conditional payoffs implied by the structural model on each of the CDX index roll dates. The market's terminal level is reported relative to its value on the roll date (i.e. in moneyness terms).

Figure 6
Credit Risk Ratio

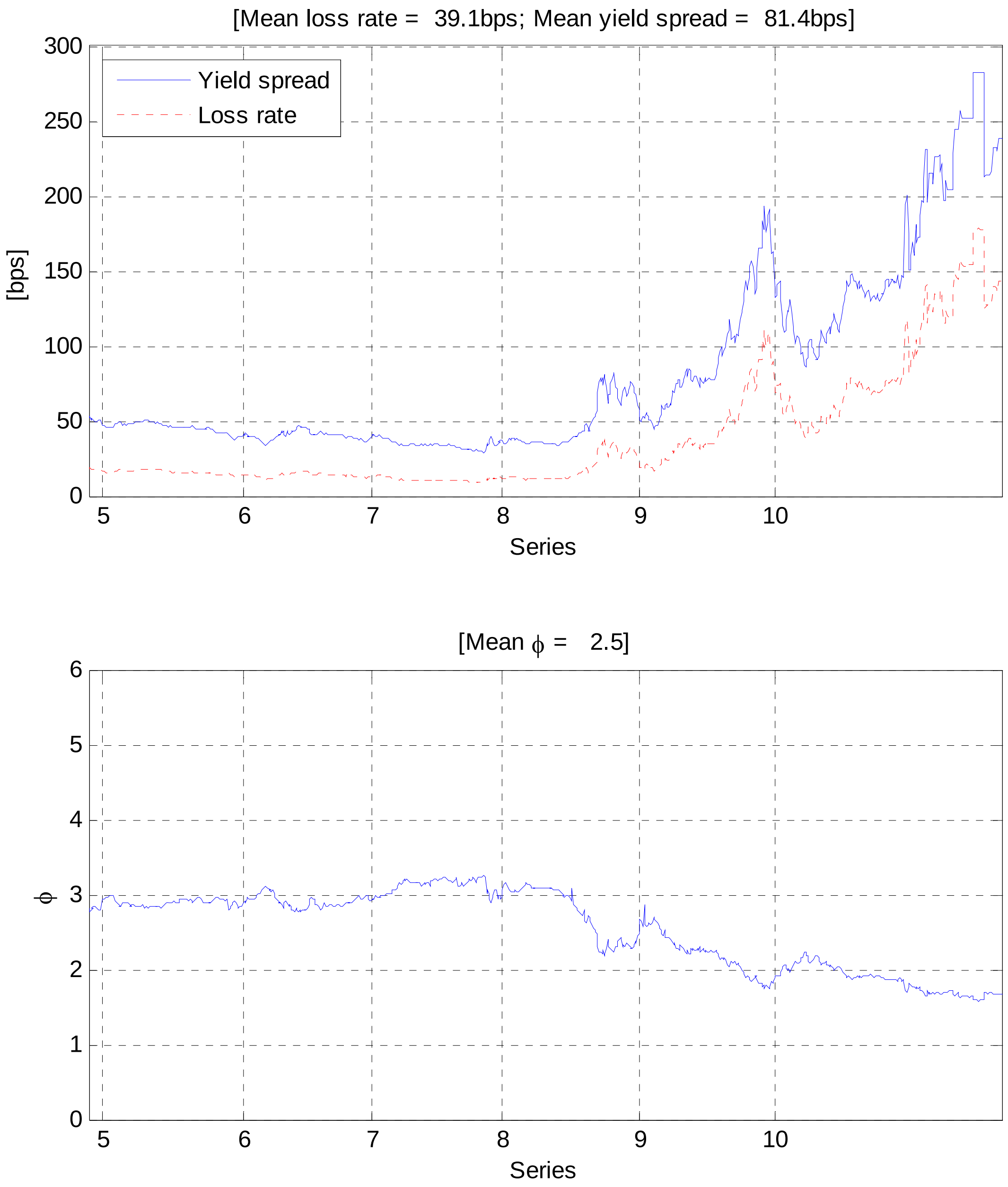

Figure 6 plots the yield spread and the expected loss rate on the CDX through time. Panel A reports the two series separately and panel B reports their ratio.

Figure 7
The Price of Credit Protection

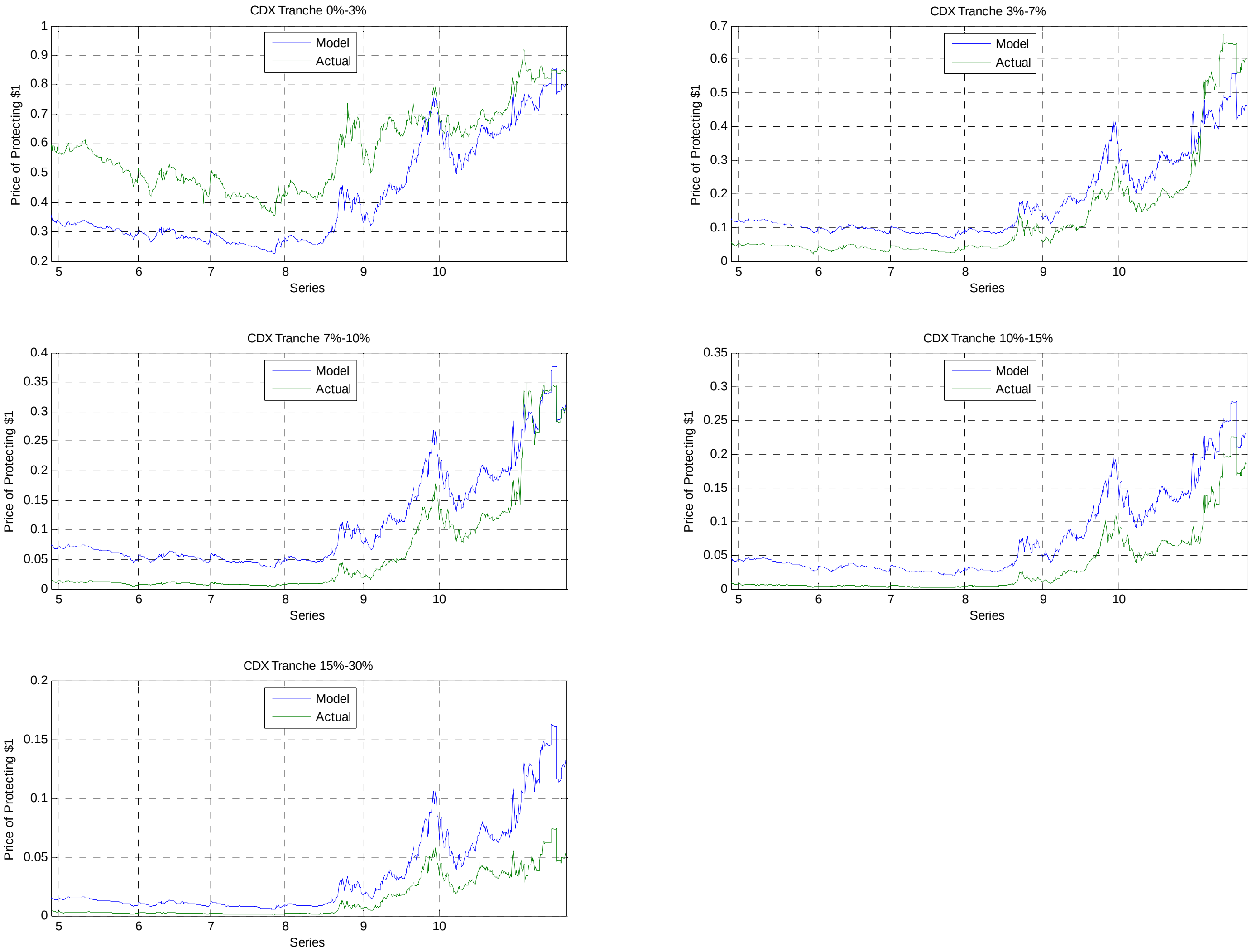

Figure 7 plots actual and model price of protection on each of the CDX tranches through time.

Figure 8
Percentage Mispricing Relative to Model

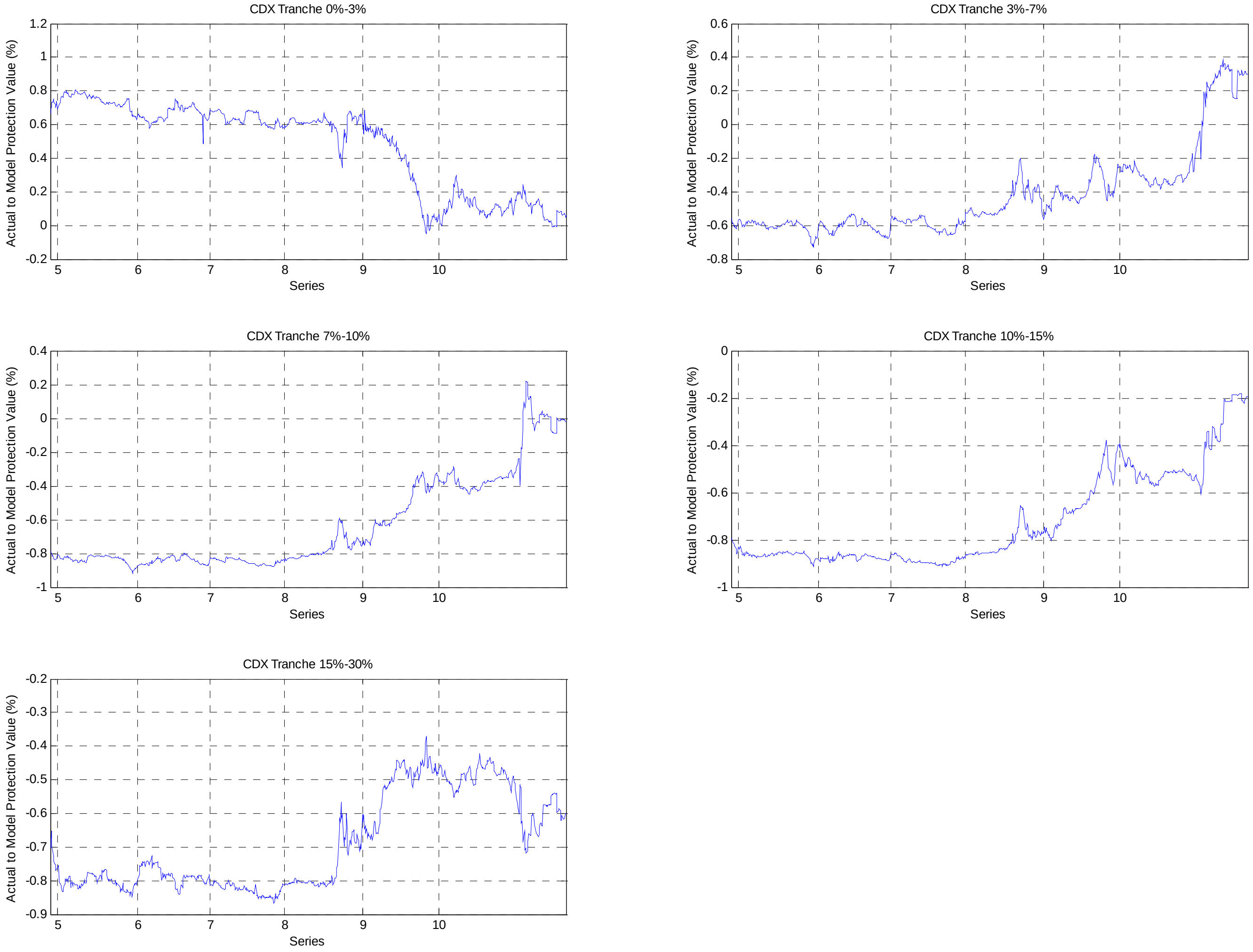

Figure 8 plots the ratio of actual to model price of protection on each of the CDX tranches through time.

Figure 9
Yield Spreads Plotted Against Expected Loss Rates

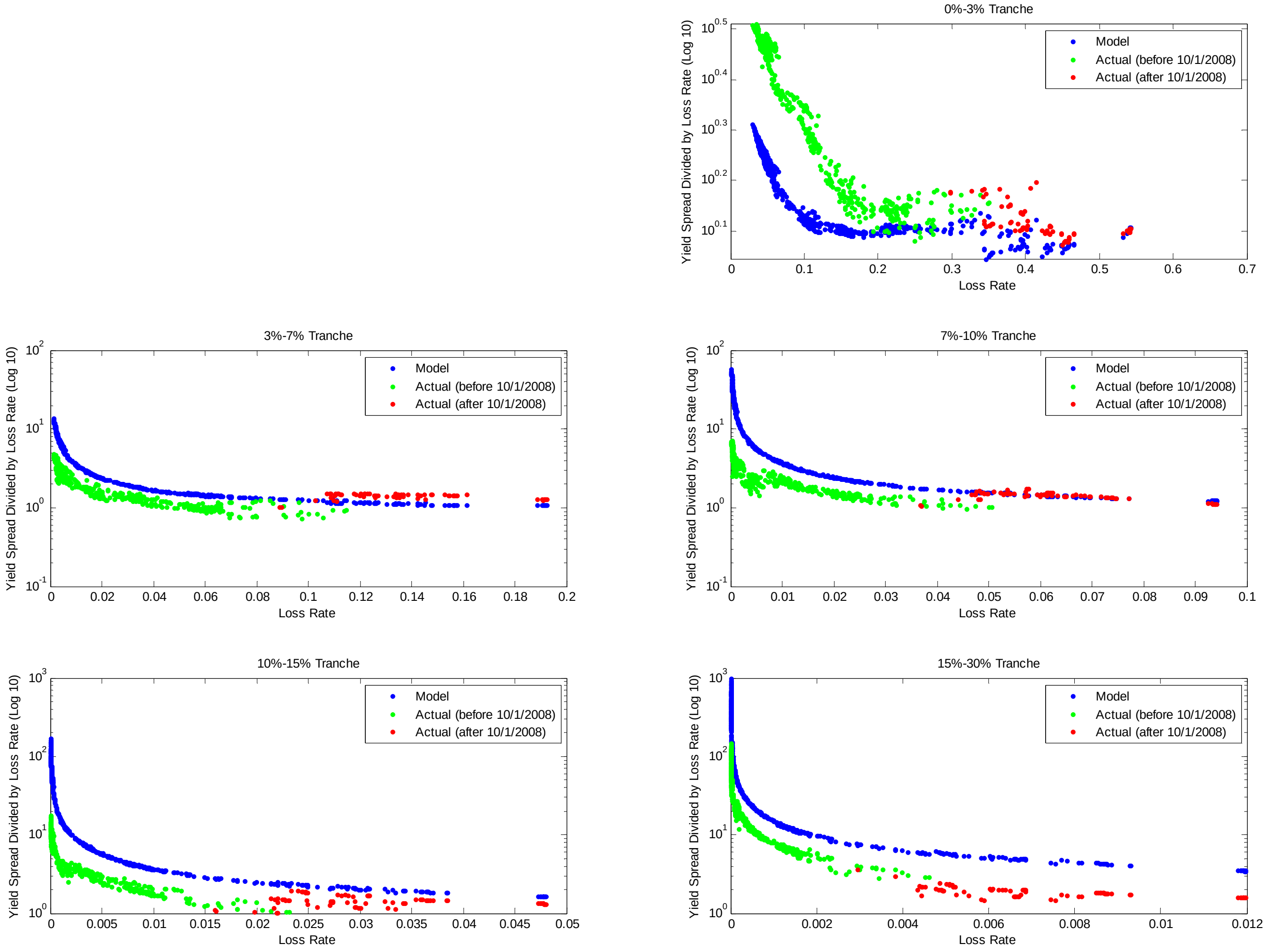

Figure 9 plots the ratio of the yield spread to the loss rate – the credit risk ratio – against the loss rate. Both the model and the actual ratios are plotted. Each point represents a specific date from our sample.

Table 1
Summary of Various Capital Market Measures throughout the Crisis

Panel A: Various Capital Market Measures on Key Event Dates

Date	VIX	ATM 5-yr Vol	S&P 500	5-yr Swap	CDX.IG Spread	IG Bond Spread	[7, 10] Tranche Spread	Event
1/3/2007	12.0%	18.7%	1,417	5.06%	0.33%	0.33%	0.14%	Year begins
1/2/2008	23.2%	25.2%	1,447	4.07%	0.81%	1.22%	1.29%	Year begins
2/29/2008	26.5%	26.0%	1,331	3.42%	1.65%	1.88%	3.45%	
3/17/2008	32.2%	27.0%	1,277	3.17%	1.85%	1.97%	4.64%	Bear Stearns failure
3/31/2008	25.6%	26.0%	1,323	3.30%	1.43%	1.97%	3.22%	
8/29/2008	20.7%	25.4%	1,283	4.03%	1.43%	2.04%	3.43%	
9/8/2008	22.6%	25.2%	1,268	3.91%	1.38%	2.00%	3.41%	Fannie, Freddie and Merrill Lynch
9/15/2008	31.7%	25.3%	1,193	3.69%	1.94%	2.48%	5.04%	Lehman failure
9/16/2008	30.3%	26.3%	1,214	3.45%	2.00%	2.59%	5.07%	AIG failure and Reserve Fund "breaks the buck"
9/30/2008	39.4%	27.8%	1,166	3.98%	1.68%	2.61%	4.81%	
12/31/2008	40.0%	35.3%	903	2.10%	2.14%	4.40%	8.13%	Year end

Panel B: Percentage Change in Variables over the Period

Period	VIX	ATM 5-yr Vol	S&P 500	5-yr Swap	CDX.IG Spread	IG Bond Spread	[7, 10] Tranche Spread	Event
1/3/07 - 1/2/08	92.4%	34.5%	2.2%	-19.6%	145.4%	270.5%	821.4%	First year of crisis
1/2/08 - 12/31/08	72.6%	40.0%	-37.6%	-48.4%	164.5%	259.8%	530.2%	Second year of crisis
1/1/08 - 2/28/08	14.5%	3.3%	-8.1%	-16.0%	104.2%	54.1%	167.4%	
2/28/08 - 3/31/08	-3.5%	-0.1%	-0.6%	-3.5%	-13.3%	4.5%	-6.7%	Bear Stearns failure
3/31/08 - 8/31/08	-19.4%	-2.2%	-3.0%	22.1%	0.1%	3.8%	6.5%	
8/31/08 - 9/30/08	90.8%	9.2%	-9.1%	-1.2%	17.4%	27.8%	40.2%	Lehman, AIG, Fannie & Freddie, Merrill Lynch
9/30/08 - 12/31/08	1.5%	26.9%	-22.6%	-47.2%	27.2%	68.4%	69.0%	

Table 1 reports levels and percent changes in different financial variables during the financial crisis. Column 2 reports the VIX index. Column 3 reports the 5-year at-the-money volatility quotes. Column 4 lists the closing level of the S&P 500 index. Column 5 lists the 5-year swap rate. In Column 6 is the CDX investment grade index. Column 7 reports the 5-year IG bond spread. Column 8 reports the spread on the 7-10 tranche of the CDX.IG index.

Table 2
Mispricing by Quarter

Quarter	[0,3]	[3,7]	[7,10]	[10,15]	[15,30]
2005:3	0.725	0.589	0.822	0.833	0.758
2005:4	0.776	0.597	0.830	0.864	0.801
2006:1	0.710	0.618	0.845	0.866	0.810
2006:2	0.647	0.596	0.842	0.874	0.767
2006:3	0.684	0.616	0.839	0.874	0.800
2006:4	0.648	0.575	0.840	0.889	0.819
2007:1	0.610	0.611	0.859	0.890	0.838
2007:2	0.620	0.520	0.812	0.850	0.807
2007:3	0.588	0.404	0.721	0.762	0.699
2007:4	0.514	0.435	0.627	0.708	0.560
2008:1	0.192	0.324	0.409	0.517	0.468
2008:2	0.158	0.306	0.391	0.525	0.498
2008:3	0.109	0.295	0.351	0.523	0.487
2008:4	0.111	0.272	0.100	0.319	0.613

Table 2 reports the root mean squared percentage pricing errors of our model by quarter. Included in the final quarter are pricing errors through January 20, 2009.

Table 3
Trading Strategy Returns

	[0,3]	[3,7]	[7,10]	[10,15]	[15,30]	Portfolio
2005:09 - 2009:01 (n=854)						
Average	19.5%	30.9%	58.9%	58.0%	28.4%	39.1%
Std	24.3%	52.0%	62.6%	62.4%	68.3%	38.2%
Sharpe	0.80	0.59	0.94	0.93	0.42	1.02
t-stat	1.48	1.09	1.73	1.71	0.76	1.88
skew	(0.40)	1.58	1.54	1.05	0.32	1.37
2007:07 - 2009:01 (n=395)						
Average	36.1%	52.0%	115.4%	120.9%	83.6%	81.6%
Std	31.8%	57.2%	68.4%	63.8%	74.8%	41.2%
Sharpe	1.14	0.91	1.69	1.89	1.12	1.98
t-stat	1.43	1.14	2.12	2.37	1.40	2.48
skew	(0.33)	0.58	1.94	1.45	0.78	1.79

Table 3 reports the returns to our trading strategy across the entire sample (Panel A) and the second half of the sample (Panel B). The panels include average annualized returns and standard deviations, the Sharpe ratio, a t-statistic on null hypothesis of zero average returns, and the skewness of daily realized returns. The [0,3] column reports returns from selling the equity tranche and purchasing the replicating portfolio of S&P index options. The next four columns report returns from purchasing the tranche and selling the replicating portfolio of index options. The final column reports the properties of returns that are the equally-weighted daily average of the five tranches.