University of Reading

The impact of liquidity on senior credit index spreads during the subprime crisis

Article

Accepted Version

Marra, M. (2015) The impact of liquidity on senior credit index spreads during the subprime crisis. International Review of Financial Analysis, 37. pp. 148-167. ISSN 1057-5219 doi: https://doi.org/10.1016/j.irfa.2014.11.016 Available at http://centaur.reading.ac.uk/39177/

The impact of liquidity on senior credit index spreads during the subprime crisis

Miriam Marra *

ICMA Centre - Henley Business School - The University of Reading

Abstract

This paper examines the effects of liquidity during the 2007–09 crisis, focussing on the Senior Tranche of the CDX.NA.IG Index and on Moody's AAA Corporate Bond Index. It aims to understand whether the sharp increase in the credit spreads of these AAA-rated credit indices can be explained by worse credit fundamentals alone or whether it also reflects a lack of depth in the relevant markets, the scarcity of risk-capital, and the liquidity preference exhibited by investors. Using cointegration analysis and error correction models, the paper shows that during the crisis lower market and funding liquidity are important drivers of the increase in the credit spread of the AAA-rated structured product, while they are less significant in explaining credit spread changes for a portfolio of unstructured credit instruments. Looking at the experience of the subprime crisis, the study shows that when the conditions under which securitisation can work properly (liquidity, transparency and tradability) suddenly disappear, investors are left highly exposed to systemic risk.

Keywords: Senior Tranche CDX Index; Subprime crisis; Credit risk; Liquidity risk; Systemic risk.
JEL classification: G01, G10, G12, G13.

---

*ICMA Centre, Henley Business School, University of Reading, Whiteknights, Reading, RG6 6BA, UK; email: m.marra@icmacentre.ac.uk; phone: +44 (0)118 378 8239. I thank an anonymous referee, Ron Anderson, Chris Brooks, Gordon Gemmill, Ian Marsh, and Anthony Neuberger, for insightful and constructive suggestions; Alper Odabasioglu and Xiaoxia Ye for their valuable comments as conferences' discussants, and all participants at: the *Conference on Systemic Risk: Liquidity Risk, Governance and Financial Stability*, organized by the Federal Reserve of New York, the Bank of England, the Reserve Bank of Australia and the Institute of Global Finance at the UNSW, in Sydney, Australia, July 2013; and the *Bicentenary Conference of AIDEA 2013* - in Lecce, Italy, September 2013. I thank the Risk Management Institute at National University of Singapore (Credit Research Initiative) for allowing access to individual firms' data on forecasts of probability of default. All remaining errors are my own.

1 Introduction

Before the subprime crisis started, the trading volume of credit derivatives had grown at a very fast pace from less than US$1 trillion in 1997 to around US$26 trillion in 2007.[1] Structured products with complex payoffs, such as collateralized debt obligations (CDOs), were created using the securitisation technology (pooling and tranching claims with different risk exposures) and were sold in the market. In 2003, CDOs represented 20% of the total credit derivatives market. However, in 2008 this figure decreased drastically to less than 5%. In the second half of 2007, disruptions started in the U.S. subprime mortgage market and then spread to other apparently unrelated markets, causing a sudden "drying up" of liquidity and an increase in the premia of all structured finance products (CDOs), including the top-rated (AAA) ones.[2] A widespread view is that the dysfunctionality of these top-rated structured products during the financial crisis of 2007–09 was caused by *market* and *funding* liquidity frictions. In this paper we explore this view by focussing on the Senior Tranche of the Credit Default Swap Index for North American investment-grade corporate bonds (ST CDX.NA.IG) in the period that runs from September 2006 to May 2009.[3] Moreover, we also examine the credit spread of Moody's AAA Corporate Bond Index in order to detect whether market and funding liquidity frictions have had the same or different effects on *senior structured* versus *senior unstructured* credit indices. Although both ST CDX and AAA Bond Index are senior products with AAA ratings, there is a major difference between them. The 125 firms which compose the CDX.NA.IG Index are mostly A or BBB rated. However, due to the tranching process, the Senior Tranche of the CDX.NA.IG Index bears the losses from the underlying pool of credit default swaps (CDSs) only after the principal of all the subordinated tranches has been exhausted. This prioritization rule allows the ST CDX to have very low default probability and a AAA rating, at least in normal times. The AAA Bond Index is formed instead by bonds issued by actual AAA-rated firms. It is

[1] British Bankers Association data. For further detailed statistics, see Choudhry (2010) at pages 58–69.

[2] The rise and fall of the CDO market has boosted the development of theoretical models for pricing of these instruments (see for discussion Collin-Dufresne, 2009).

[3] For a detailed explanation of the time sample selection, see subsection 2.2.1.

interesting therefore to examine empirically the determinants of the credit spreads of the two indices and explore how they were affected by the financial crisis (characterised by a loss of liquidity, transparency and tradability in the relative markets).

The post-crisis literature about the pricing of CDOs and CDX tranches is mainly concentrated in the papers of Coval, Jurek, and Stafford (2009) and Collin-Dufresne, Goldstein, and Yang (2012). Coval et al. (2009) claim that before the subprime crisis the observed spread on Senior Tranches of the CDX Index was too low, so its dramatic increase during the crisis can be explained as a correction of a pre-existent mispricing. In other words, before the crisis investors relied too much on credit ratings and ST CDX writers insured "economic catastrophe bonds" without appreciating their large exposure to systemic risk and without demanding an adequate compensation for bearing this risk. Collin-Dufresne et al. (2012) note that these conclusions cannot be reconciled with the sophistication of traders in CDX (and CDO) markets, who would not be willing to bear so much risk without a proper evaluation and a fair compensation. Calibrating a more complex structural model to match the entire term structure of CDX index spreads (rather than only the five-year spreads), they show that the CDX tranches were on average fairly priced both before and during the financial crisis. Thus, they reject the hypothesis of a large pre-crisis mispricing of CDX Senior Tranches. Although the predictions of Collin-Dufresne et al. (2012) display some improvement over the predictions of Coval et al. (2009), the structural model they use can price the Senior Tranche 15–30% CDX spread fairly well over the crisis period only by setting a crash-risk parameter to the worst possible scenario. One aspect that has been omitted in the analysis by both Coval et al. (2009) and Collin-Dufresne et al. (2012) is the study of the time variation in the non-default components of the Senior Tranche CDX spread, particularly in its liquidity premium component.

The liquidity factor is a potentially important determinant of both structured and unstructured credit spreads. A study of its time-varying impact on credit spreads can help to shed some light on the pricing of the ST CDX and AAA Bond Index. The existing literature explains how market liquidity can affect a portfolio of credit spreads. In particular, Longstaff

(1995) and Ericsson and Renault (2006) develop models of liquidity premia in corporate bond markets based on imperfect marketability: more illiquid bonds carry larger yields as compensation for investors who hold them. Bongaerts, de Jong, and Driessen (2011) develop a pricing model for credit derivatives and explain that the liquidity premia in CDS and CDX arise as a result of the heterogeneity between buyers and sellers of CDS protection. Some previous empirical research has detected significant liquidity components in corporate bond spreads (Chen, Lesmond, & Wei, 2007; Dick-Nielsen, Feldhütter, & Lando, 2012; Huang & Huang, 2012; and Longstaff, Mithal, & Neis, 2005) and in single-name CDSs (Chen, Cheng, & Wu, 2013; Chen, Fabozzi, & Sverdlove, 2010; Leland, 2008; and Tang & Yan, 2007).

In addition, the lack of funding liquidity can affect aggregate credit spreads via two channels. First, it can cause higher costs for firms to obtain short-term funds. This issue can prevent firms from operating regularly; it can increase their likelihood of default and widen their credit spreads. A clustering of firms' defaults can cause the spread of the Senior Tranche of the CDX Index to widen. Second, an increase in short-term funding costs has a negative impact on traders in credit markets. The models by Brunnermeier and Pedersen (2009) and He and Krishnamurthy (2012), among others, show that when funding liquidity is extremely scarce, traders may not be able to take or maintain their positions in bonds and tranches of CDS indexes. The tightening of funding liquidity may induce fire-sales of securities and exacerbate the loss of market liquidity; in turn, the evaporation of market liquidity may worsen the funding shortage.[4]

The empirical literature on CDX tranche pricing has not yet explored the effect of market and funding liquidity frictions during the financial crisis of 2007–09. Fabozzi, Wang, Yeh, and Chen (2009) examine CDX.NA.IG tranches spreads over the limited pre-crisis sample of 2003–05 and find that liquidity (proxied by the firms' total market capitalisation) have no power to explain changes in the Senior Tranche spread. Alexander and Kaeck (2008)

[4]Sometimes, it is market liquidity that evaporates first. For instance, in the summer of 2007, the inability to value and trade complex structured credit products caused a run on off-balance sheet vehicles (conduits and Special Investment Vehicles – SIVs) where the products were located, as investors refused to renew the asset-backed commercial paper that financed them (Borio, 2010).

examine iTraxx Europe spread changes over the pre-crisis period using Markov-switching regressions. They notice that the implied volatility of equity index options becomes a major determinant of changes in CDS index spreads during more turbulent times, while equity index returns have a predominant role in more stable periods. Scheicher (2008) examines the determinants of the daily price movements in CDX index tranches (North America CDX and European iTraxx). Using simple regression analysis on variables in first differences, he finds that during the financial crisis the credit-tranche premia are influenced by a large unobservable component (different from the credit fundamentals suggested by a structural model). Our paper attempts to fill this gap in the literature: it focuses on the Senior Tranche (15–30%) of the CDX.NA.IG Index and aims to detect the contribution of market and funding liquidity to the increase in the tranche spread.[5]

In order to study the effects of liquidity on the senior credit indices we need to disentangle them from the effects of changes in credit risk fundamentals and investor sentiment.[6] We base the empirical analysis of credit risk fundamentals on the inputs of the structural model first introduced by Merton (1974). The model establishes that the main *observable* determinants of the firm's default probability (and credit spread) are the firm's equity value and volatility, the firm's leverage, and the term structure of risk-free interest rates. In addition, since we study a portfolio (or index) of credit spreads, we need to take into account the probability of clustered defaults among all firms constituents. Practitioners and academics often refer to the slope of the implied volatility curve for equity index options (plotted against options' moneyness) as an indicator of investors' appraisal of the likelihood of market-wide crashes and clustered defaults. Therefore, in our analysis we include also this key variable. To conduct the analysis of the dynamics of credit indices spreads, we use cointegration and error correction models (ECMs). The cointegration analysis detects an arbitrage equilibrium

[5]In our work, funding liquidity is proxied by the one-month commercial paper spread (over the one-month Treasury-Bill yield), while market liquidity is proxied by the Senior Tranche CDX bid–ask spread. A higher bid–ask spread on ST CDX means higher transaction costs associated with this market. A higher commercial paper spread means higher costs for firms to obtain short-term funds.

[6]In this work "sentiment" is defined as a measure of the relative pessimism/optimism of investors with respect to future movements in the equity market and it is proxied by the equity put–call volume ratio provided by the Chicago Board Options Exchange (CBOE) and by the difference between the VXO implied volatility index and the historical S&P 100 volatility. For discussion on non-default variables, see subsection 2.2.3.

between credit spreads and those *state fundamental* variables (equity index returns and volatility, the equity index option implied volatility skew, and the level and slope of the term structure of interest rates) that the theory of structural models suggests to be closely related to credit spreads. Daily movements in the credit spreads are then examined through ECMs where, in addition to these state variables, changes in liquidity are also used as explanatory variables for changes in ST CDX and AAA Bond Index credit spreads. Cointegration and ECM analysis are performed using daily data.

We find that the signs predicted by the theory for the relationship between credit spreads and state fundamental variables are all confirmed for both senior credit indices. However, while liquidity is found to be a main driver of the increase in the spread of the Senior Tranche CDX Index during the crisis period, it appears insignificant during the more stable pre-crisis period. Furthermore, although liquidity has much higher explanatory power during the crisis than before for the AAA Bond Index spread also, the liquidity variables are not statistically significant when used in the ECM regressions. These findings have interesting implications. As mentioned earlier, the firms underlying the CDX.NA.IG Index are mostly BBB or A-rated; however, before the crisis, securitisation, tranching and high liquidity and standardisation of the CDX index contracts had also contributed to keep the ST CDX spread relatively small and significantly lower than the spread on the AAA Bond Index, which is composed of actual AAA-rated companies' bonds (see Figure 1). Due to their infrequent trading, AAA bonds tend to be more illiquid securities.[7] However, when systemic illiquidity problems appear during the subprime crisis, the ST CDX Index appears more affected than the AAA Bond Index by the liquidity shortage. One possible explanation for this finding is that the severe dysfunctionality of more complex multilayered AAA CDO Tranches have undermined investors' confidence in trading securitised products and their reliance on credit ratings, thereby also drying up the liquidity in more standardised markets, such as the ST CDX.NA.IG.

[7] The comparison between the two indices is subject to some caveats. The CDX.NA.IG Index includes CDSs written on bonds of financial and industrial firms, while Moody's AAA Bond Index includes only bonds for industrial firms. Moreover, the CDS constituents of the CDX index have five years' maturity, while in the AAA Bond Index only bonds with remaining maturities as close as possible to 30 years are included.

There are two main elements of novelty and contribution in our work. The first element is the investigation of liquidity effects on the credit spread of a structured product (the Senior Tranche of the CDX Index) which – to the best of our knowledge – has not been examined in the empirical literature until this moment, in particular with reference to the subprime crisis. The second element is the use of cointegration analysis and ECMs to shed some light on the determinants of the credit spreads of structured credit derivatives. The arbitrage relationship between credit spreads and state (credit risk) variables is seen as an "equilibrium" occasionally disturbed by investors' concerns about illiquidity. Most previous studies have examined the determinants of credit spreads using a first-differences regression approach (e.g., for corporate bonds, Collin-Dufresne, Goldstein, & Martin, 2001; for CDX tranches, Scheicher, 2008). However, such analysis is solely concerned with short-run movements in the variables and disregards potentially useful "long-run" information. On the contrary, we identify an equilibrium arbitrage relationship between the state credit risk variables and credit index spreads (in levels) and then detect occasional disturbances/deviations related to investors' higher concerns regarding illiquidity and to a more pessimistic market sentiment.

The remainder of the paper is organised as follows. Section 2 describes the empirical methodology and the variables employed in the analysis. Sections 3 and 4 develop the main analysis and illustrate the results. Section 5 presents several robustness checks on the methodology and the results. Section 6 gives the conclusions.

2 Methodology

2.1 Overview

The main aim of this paper is to investigate whether, during the 2007–09 crisis, senior structured credit products were hit by illiquidity and market disruptions, rather than solely by adverse movements in their underlying credit risk fundamentals (which we define as "state" variables). In addition, we want to analyse whether the effects of illiquidity and market disruptions are similar for a AAA-rated *structured* credit index and for an AAA-rated *unstructured* credit index. To do so, we examine the determinants of credit spreads of the Senior Tranche of CDX.NA.IG Index and of Moody's AAA Corporate Bond Index. We first specify an equilibrium relationship between credit spreads and state variables. Structural models of credit risk suggest that credit spreads should be closely related to equity value and volatility, and to the risk-free interest rate process. Since we look at large portfolios of credit instruments we will consider equity market value and volatility, but also equity market implied volatility skewness as this accounts for the risk of clustering in defaults (correlation risk). To analyse the equilibrium/arbitrage relationship we use the cointegration approach proposed by Engle and Granger (1987). The analysis is performed at the daily frequency. In practice, we estimate an equilibrium equation for daily credit spreads and state variables (in levels) by means of a least squares regression (cointegrating equation); then we analyse the stationarity of the regression residuals in order to detect cointegration. If cointegration is detected, we estimate a valid ECM. To test the effects of "frictional" or "non-default" factors which are not considered by the classic structural model, we also augment the ECMs by adding liquidity and market sentiment proxies as explanatory variables. This methodology aims at detecting: i) whether the cointegrating equation can represent, albeit in a simplified manner, an arbitrage relationship towards which credit spreads tend to align over time; ii) whether, in the context of augmented ECMs, the short-term dynamics of credit spreads over the whole sample, the pre-crisis period, and the crisis period can also be explained by liquidity factors and investor sentiment (besides changes in the fundamental financial variables).[8]

2.2 Data description

2.2.1 Credit spreads

The CDX Senior Tranche spread is represented by the quoted premium for the 15-30% tranche of the on-the-run CDX index. The on-the-run CDX index series is composed of

[8]Several robustness checks on this methodology, including non-linearities and structural breaks in the cointegration equation, will be presented in section 5. They show a substantial invariability of the ECMs results.

the series 7, 8, 9, 10, 11 and 12 of the North American Investment Grade CDX index (CDX.NA.IG.), covering a period that goes from 20 September 2006 to 20 May 2009. Data on the CDX.NA.IG. Index Senior Tranche are taken from Bloomberg. The data provider offers a continuous time series for the tranche premium starting from the third quarter of 2006. After May 2009 the quoting convention across market makers changed and Bloomberg started providing CDX Index tranche information in terms of "points upfront" rather then premia.[9] The equivalent premia on the CDX Index can be estimated by making specific assumptions on the recovery rates. However, to avoid using "estimated" ST CDX premia and to employ instead only quoted premia, we limit our analysis to the period that goes from September 2006 to May 2009, which is also the most interesting one for the analysis of the subprime crisis. The cointegration analysis will be performed on the ST CDX Index composed by rolled-over on-the-run contracts that are switched every six months, as soon as a new series start trading. The main reason for switching contracts is trading volume considerations. As explained by Brooks, Rew, and Ritson (2001) in similar cointegration analysis on future stock indices, the on-the-run contracts are the most liquid ones and this is essential as time series tests require the most frequent price observations. Additionally, we favour the selection of the most liquid CDX Index contracts in order not to bias the results towards finding "negative liquidity effects" on the credit index spread and to provide more conservative evidence in this respect. Finally, the quoted price of each CDX series is obtained as the average quoted price of the underlying CDS contracts written on 125 investment-grade firms. The "retention ratio" for the firms across all series (from 7 to 12) is 80%: namely, 100 firms remain stable constituents of the CDX.NA.IG Index over the whole period September 2006 to May 2009.

The AAA Bond Index spread is represented by the difference between Moody's AAA Bond Index quoted yield and the nominal yield for 20-year Treasury bonds at constant maturity. Moody's AAA Bond Index yield is the average yield across a large portfolio of AAA industrial

---

[9] If a CDS or CDX index trades with an upfront fee, the counterparty buying protection on a single-name or a basket of companies' credit must make an initial upfront payment (a percentage of the notional contract value) to the protection seller as well as paying a running spread of 500 bps.

bonds. Moody's includes in this portfolio bonds with remaining maturities as close as possible to 30 years and drops bonds when their remaining life falls below 20 years, when they are susceptible to redemption, or when they are downgraded. Data on Moody's AAA Bond Index yield and the 20-year Treasury bond yield are obtained from the New York Federal Reserve Bank website.

2.2.2 Descriptive statistics for credit spreads

From relatively low levels in 2006 and in the first semester of 2007, the ST CDX spread increases in the second semester of 2007 and comes back to its previous levels towards the end of the same year (Figure 1). The spread increases again during the first semester of 2008 in response to the Bear Stearns failure, and then it registers a higher spike around Lehman Brothers bankruptcy in September 2008. Later on, during the first quarter of 2009, the spread decreases, but it maintains a much higher level than the initial one. The pattern followed by the AAA Bond Index spread is similar.

The distribution of the daily ST CDX spread has a high positive skew (Table 1 reports the summary statistics). The range of variability in the spread is also large: the series goes from a minimum value of 0.018% (or 1.8 bps) to a maximum value of 2.10% (or 210 bps). The first difference in the log ST CDX spread is very volatile over the selected sample, with huge peaks concentrated in the year 2007 (Figure 2). Its distribution is leptokurtic and positively skewed, so it is clearly non-normal (Table 2 reports the summary statistics). The range of variability in log changes is also wide. The series goes from a minimum value of -60% to a maximum of 93%. The distribution of the AAA Bond Index spread has a positive skew of the same magnitude as the ST CDX spread (see Table 1) and varies widely from a minimum value of 0.45% (or 45 bps) to a maximum of 2.02% (or 202 bps). However, the mean and median of the AAA Bond Index spread are almost double the mean and median of the ST CDX spread. Also the first difference in the log AAA Bond Index spread is quite volatile, but mostly in the second and third quarters of 2007 and at the end of 2008, with values going from a minimum of -15.7% to a maximum of 16.8%. Its distribution is strongly leptokurtic (see Table 2).[10]

Over almost all of the sample the ST CDX spread level remains below the AAA Bond Index spread (see Figure 1 and Table 1). The relation is opposite in terms of innovations (see Table 2). The higher spread for the AAA Bond Index and its narrower change over time is also due to the infrequent trading of AAA bonds, which causes stale prices. To confirm this intuition, Table 3 shows that the AAA Bond Index spread presents larger autocorrelation than the ST CDX spread.

2.2.3 Fundamental credit risk variables

The state variables used in our analysis of the fundamental drivers of credit risk are those typically used by the empirical literature on structural models (see, among others, Campbell & Taskler, 2003; Collin-Dufresne et al. 2001; Eom, Helwege, & Huang, 2004; Longstaff & Schwartz, 1995; and Tang & Yan, 2007): equity value, equity volatility, the short-term (spot) risk-free interest rate, and the slope of the term structure of risk-free interest rates.

We employ the S&P 100 Index as a proxy for the equity value of a large portfolio of U.S. firms. The structural model predicts that the relation between the credit index spread and the equity index value should be negative: higher firm values mean higher growth in the firm's earnings, so lower probabilities of default and tighter credit spreads. We measure the equity index value using 180-day rolling cumulative log returns on the S&P 100 Index ($S\&P100\ Cum.Ret.$). This is a "normalised" measure of the level of the equity index (i.e. an indication of a "high" or "low" market compared to six months before).[11]

[10] In unreported analysis we compare the first difference in the *spreads* (absolute changes) with the first difference in the *log spreads* (relative percentage changes), for the ST CDX and for the AAA Bond Index. The variability of the first difference in the spreads over the pre-crisis period (from September 2006 to July 2007) is much lower than over the crisis period and is almost negligible. Thus, a time series comparison between the two sub-samples would not be particularly effective. We therefore favour a comparison between first differences in the log ST CDX spread and log AAA Bond Index spread; however, we also will repeat the analysis using the other measure as a robustness check (see subsection 5.4 for discussion).

[11] In preliminary explorative analysis we detect a positive relationship between credit spreads and the *daily* equity index price. This result is counter-intuitive in the structural model perspective. The reason for this result is that the equity index price at the daily frequency can be a very noisy proxy for the aggregate value of the equity market, which is better captured by our "normalised" measure.

The proxy used for equity index volatility is the S&P 100 Index option implied volatility (VXO). As alternative proxy for equity index volatility we also use the S&P 100 historical volatility computed using a rolling window of 30 days. According to the structural model theory, when volatility is larger, default probability is higher and the protection seller (or the bond investor) requires larger spreads. Therefore, the relation between credit index spreads and equity index volatility should be positive. All data on the S&P 100 Index are taken from Bloomberg.

In addition, the level of the interest rate may have a significant impact on credit index spreads. A higher interest rate increases the risk-neutral expected growth rate of the firm values, which results in lower probabilities of default and lower credit spreads. Furthermore, a higher interest rate reduces the present value of CDS cash flows, the value of the default protections, and the required premia. We use the five-year Treasury nominal yield at constant maturity (taken from the New York FED database) as a proxy for the riskless interest rate ($5y\ Treasury\ Yield$). According to the structural model predictions, we should find a negative relationship between interest rates and credit index spreads.

As the interest rate is a critical variable, the process that establishes the spot rate should be equally important. This process depends, amongst other things, on the slope of the term structure of risk-free interest rates (*TS Slope*) which we proxy with the difference between 30-year and 2-year nominal Treasury yields (see also Ericsson, Jacobs, & Oviedo). The effect of this variable on credit spreads can be mixed. On the one hand, an increase in the slope of the term structure may signal expectations of an expansionary monetary policy, rising future short-term interest rates, a recovering economy, an increase in firms' values and lower default probabilities (Bedendo, Cathcart, & El Jahel, 2007). In this case, we should find a negative relationship between the slope of the Treasury curve and credit index spreads (as in Collin-Dufresne et al., 2001; and Greatrex, 2009). On the other hand, larger liquidity spreads on long-term bonds, flight-to-quality and flight-to-liquidity may induce an increase in both the term structure slope and credit index spreads.[12]

[12] If market participants expect higher volatility in the future, even if interest rates are anticipated to decline,

We also consider a specification for the cointegrating equation that includes a proxy for market-wide jump risk.[13] Controlling for market-wide jump risk (also called crash risk) is particularly important in our analysis: an increase in correlation between the defaults of several firms may cause systemic contagion, sudden jumps to default (in particular for safer top-rated firms) and an increase in the ST CDX spread and in the AAA Bond Index spread. We proxy the market-wide jump risk component using the slope of the S&P 100 Index implied volatility ($S\&P100\ Option\ Impl.Vol.Slope$), i.e. the difference between the implied volatilities of 90% in-the-money and at-the-money S&P 100 call options obtained from Bloomberg (see also Collin-Dufresne et al., 2001; and Tang & Yan, 2007).[14] A more negative "smirk" in the implied volatility of equity index options suggests greater investor fears of extreme market crashes, which typically hit several firms simultaneously. Thus, a more negative smirk should lead to higher spreads on senior credit indices. While we consider a proxy for jump risk, we do not include any direct control for default correlation risk in the CDX tranches structure. In fact, as mentioned earlier, jump and correlation risk-components of credit spreads are strictly interrelated and easily distinguished and measured by different variables, especially in the univariate framework of our analysis.[15]

long-term government bond yields will increase, generating a steeper positive slope of the term structure. Moreover, if there is a large demand for short-term government bonds because of investors' flight-to-liquidity and flight-to-quality, then the yields of short-term bonds are expected to decrease and the slope of the term structure to increase (other things being equal), irrespective of investors' views about future events.

[13]The jump-to-default risk is the risk that a credit defaults suddenly before the market has incorporated its increased default risk into current spreads. The pioneering work of Leland (2004, 2006) suggests that the jump component in the asset process is critical to match observed default probabilities with theoretical ones. This finding is further confirmed by the empirical work of Cremers, Driessen, and Maenhout (2008), Gemmill and Keswani (2011), and Zhang, Zhou, and Zhu (2009).

[14]The Black–Scholes model for pricing options assumes a constant level of volatility. However, the volatility curve implied by the market prices of equity index options at different moneyness levels displays a "smirk" that has been attributed to market participants' fear of large negative jumps in the equity market (Cont & Tankov, 2004).

[15]The market standard model for implied correlation is a variant of the one-factor Gaussian copula model. Gaussian copula-implied correlations for CDX tranches were quoted by dealers until 2008. Subsequently, the Gaussian model was widely dismissed because it had heavily underestimated the realised losses in highly-rated tranches of CDOs during the crisis.

2.2.4 Non-default variables

In our work, funding liquidity is proxied by the one-month commercial paper spread (over the one-month Treasury-Bill yield), while market liquidity is proxied by the Senior Tranche CDX bid–ask spread.[16] The liquidity proxies need to be as little correlated as possible with the state variables (in particular with equity returns and volatility, and the level and slope of the term structure of interest rates). For instance, market liquidity can also be partially captured by the S&P 100 Index returns and by the liquidity spread in the interest rates term-structure. Consequently, the effect of the liquidity proxies on credit spreads in our work is likely to be an underestimation of the overall real impact of liquidity.

We also control for the effect of changes in market sentiment, which is proxied by the equity put–call volume ratio provided by the Chicago Board Options Exchange (CBOE), i.e. the ratio between put and call volumes for all equity options traded on the CBOE. Dennis and Mayhew (2002) point out that a high put–call volume ratio is a good proxy for trading pressure and negative market sentiment. Bandopadhyaya and Jones (2008) demonstrate that this variable can be a better measure of market sentiment than the VIX index. Since investors buy put options when they expect the market to fall, and call options when they expect the market to rise, the ratio of puts to calls gives analysts a way to measure the relative pessimism of the marketplace. It follows that the relationship between the put–call ratio and credit index spreads should be positive. We also employ the difference between the VXO implied volatility index and the 30-days (GARCH estimated) S&P 100 historical volatility as an alternative proxy for market sentiment. If option markets are relatively efficient, the implied volatility should be a valid forecast of future realised volatility, as it subsumes the information contained in all other market variables to predict future volatility.[17] As a result, a wide positive difference between implied and historical equity index volatility may contain information about investors' expectations of a large increase in the future level of market

[16] A higher bid–ask spread on ST CDX means higher transaction costs associated with this market. A higher commercial paper spread means higher costs for firms to obtain short-term funds.

[17] The results of two well-known studies (Christensen & Prabhala, 1998; and Fleming, 1998) suggest that implied volatility is, indeed, an efficient forecast of future realized volatility: it outperforms historical volatility and contains incremental information for forecasting.

volatility. The expectation of higher market volatility should lead CDS-suppliers to write fewer contracts (thereby reducing market liquidity provisions and widening the ST CDX bid–ask spread and the ST CDX premium) and CDS-buyers to request more protection against market-wide default risk (thereby increasing the demand for the ST CDX Index and its premium).

2.3 Empirical analysis

2.3.1 Cointegration using the OLS

Given the vector of variables $\boldsymbol{x}_t$ and the vector of cointegrating parameters $\boldsymbol{\alpha}$:

$$\boldsymbol{x}_t = \begin{pmatrix} ST\ CDX\ Spread_t \\ 1 \\ S\&P100\ Cum.Ret._t \\ 5y\ Treasury\ Yield_t \\ TS\ Slope_t \\ VXO_t \end{pmatrix} \qquad \boldsymbol{\alpha} = \begin{pmatrix} -1 \\ \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \end{pmatrix}$$

we define the cointegration equilibrium as: $\boldsymbol{\alpha}'\boldsymbol{x}_t = 0$.
Since this equilibrium does not hold at all times, we define a temporary equilibrium error u_t: $\boldsymbol{\alpha}'\boldsymbol{x}_t = u_t$. The variables are said to be cointegrated if their linear combination u_t is stationary over time (i.e. u_t rarely drifts far away from zero and, if it does, it often crosses the zero line).

After testing that all variables are I(1), we estimate the following OLS cointegrating regression:

$$\begin{aligned} ST\ CDX\ Spread_t = \alpha_1 + \alpha_2\ S\&P100\ Cum.Ret._t + \alpha_3\ Treasury\ Yield_t + \\ \alpha_4\ TS\ Slope_t + \alpha_5\ VXO_t + u_t \end{aligned} \tag{1}$$

We obtain the OLS residuals $\widehat{u}_t$ and use them to test the existence of a cointegrating relationship between the dependent variable and the state variables by means of an Augmented Dickey-Fuller test, with MacKinnon (2010) critical values. If the null hypothesis of unit root is rejected, then we can classify the state variables and the credit spreads as cointegrated.

2.3.2 Estimation of error correction model (ECM)

If the variables are found cointegrated, we estimate the following ECM by OLS:

$$\Delta\ Log\ ST\ CDX_t = \vartheta\ ECT_{t-1} + \sum_{i=1}^{p} \rho_i \Delta\ Log\ ST\ CDX_{t-i} + \sum_{i=0}^{p} \beta_i \Delta\ S\&P100\ Cum.Ret._{t-i} + \sum_{i=0}^{p} \gamma_i \Delta\ Treasury\ Yield_{t-i} + \sum_{i=0}^{p} \delta_i \Delta\ TS\ Slope_{t-i} + \sum_{i=0}^{p} \theta_i \Delta\ VXO_{t-i} + \nu_t \quad (2)$$

where p is the number of lags included and $ECT_{t-1} = \widehat{u}_{t-1}$ is the so-called error correction term represented by the first lag of the residuals from the cointegrating regression (1). By estimating this ECM we test whether and to what extent daily changes in the ST CDX spread are driven by: (i) changes in state variables; and (ii) correction of the ST CDX spread deviation from the equilibrium relationship. The error correction term coefficient ϑ represents the speed of adjustment towards the equilibrium (proportion of yesterday's disequilibrium that is corrected today).

The procedure we employ to estimate a parsimonious ECM is the following. We initially introduce a number of lags p for changes in the variables that are enough to make the residuals of the ECM serially uncorrelated (we use Q-statistics for this purpose). Next, we eliminate the insignificant lagged variables and re-estimate the model again, ensuring that the residuals are still not serially correlated.

2.3.3 Inclusion of liquidity proxies in ECM

Finally, we examine whether changes in market and funding liquidity are significant to explain daily movements in the ST CDX spread. We add to the right-hand side of the ECM equation (2) the current and lagged terms of the proxies for changes in funding liquidity (commercial paper spread) and market liquidity (ST CDX bid–ask spread). We also control for market sentiment (proxied either by the difference between VXO index and S&P 100 GARCH volatility, or by the equity option put–call ratio).[18]

After estimating this augmented ECM model over the whole sample, we want to distinguish whether, according to our initial hypothesis, liquidity effects on the structured credit index spread are stronger during the crisis period. We therefore re-estimate the augmented ECM model over different sub-samples: *pre-crisis* sub-sample (20 September 2006 to 20 July 2007), *middle crisis* sub-sample (21 July 2007 to 20 May 2008), and *all-crisis* sub-sample (20 July 2007 to 20 May 2009).

We repeat all the analysis for the AAA Bond Index spread. The state variables used for the AAA Bond Index spread are the same as for the ST CDX spread. As liquidity proxies we employ the commercial paper spread and the five-year swap spread.[19]

2.3.4 Discussion on the validity of the cointegration analysis

For the cointegration analysis we prefer the Engle and Granger (1987) procedure to the Johansen (1991) vector error correction model (VECM) procedure. The Engle and Granger (1987) test assesses the existence and the nature (i.e. the parameters) of the cointegrating relationship independently from the exogenous frictional variables and the number of lags introduced in the ECM. The disadvantages of the Johansen (1991) VECM estimation procedure are the following: i) instability of the cointegrating parameters: the estimation returns different estimates of the coefficients of the cointegrating equation depending on the

[18]These variables are all stationary in levels. They are not included in the cointegrating term, as the cointegrating equation represents the arbitrage relationship between credit spreads and state variables that holds in equilibrium. Frictions are tested instead as short-run disturbances to this equilibrium.

[19]Collin-Dufresne et al. (2001) also use the five-year swap spread as an indicator of bond market illiquidity, as it is derived from a parallel market of corporate transactions. Sun, Sundaresan, and Wang (1993), Brown, Harlow and Smith (1994) and Grinblatt (2001) find that liquidity risk is a more plausible explanation for swap spreads than credit risk. Huang, Neftci, and Jersey (2003) and Duffie and Singleton (1999) confirm the prevailing view among swap traders that over short- and medium-term horizons swap spreads are mainly an indicator of "market liquidity", while their dynamics are influenced significantly by "credit risk" over long horizons.

number of lags and the exogenous variables included in the VECM, while the cointegration test disregards the exogenous variables; and ii) test of lagged effects: using a VECM we cannot test whether changes in the dependent variable (credit spreads) can be explained by *contemporaneous* changes in the state credit risk variables. Nevertheless, Johansen (1991) VECMs (including frictional variables as exogenous regressors) are also estimated in order to control for potential endogeneity of the state variables (see subsection 5.3).

One criticism that can arise against the use of cointegration analysis is that the sample of 20 months of daily data (about 660 observations) is too short to detect an equilibrium relationship. Blanco, Brennan, and Marsh (2005) use cointegration analysis over a sample of 18 months to examine the arbitrage relationship between CDSs and their underlying bonds (rather then between the CDS index and underlying credit risk variables from the structural model, as we do). The researchers justify the use of cointegration analysis in the following way. They argue that when one examines an arbitrage pricing relationship, one can expect relatively rapid reversion to equilibrium, so that a relatively short sample of data may be meaningful. To validate this intuition, they report the results of Hakkio and Rush (1991). Their answer to the question of how long the "long run" must be in order to use cointegration analysis meaningfully is that it all depends on the nature of the data being used. Hakkio and Rush (1991) find that in cointegration analysis the ratio of the length of the dataset to the half-life of deviations from a no-arbitrage equilibrium is more relevant than the length of the dataset alone. If the half-life of deviations from the long-run equilibrium is relatively short, then a relatively short sample of observations might be enough to determine if the variables are cointegrated. Therefore, we conduct a heuristic analysis of the length of the deviations from the long-run equilibrium by looking at the frequency of switches of sign in the cointegrating residuals. We anticipate here the results of this analysis. The residuals do not drift away from zero; instead they often cross the zero line taking both positive and negative values. Heuristically, we proxy the average half-life deviations with half the average number of days that pass before the residuals switch sign. We find that the average half-life of deviations across our sample is around eight days. Another way to look at the half-life of deviations is to examine the correlogram of the residuals series and identify the lag (or number of days) at which the autocorrelation coefficient becomes 0.50. Table 4 shows that the half-life of residuals is relatively short (about eight days) for both the ST CDX spread and the AAA Bond Index spread. This finding confirms the previous result and supports the idea that the cointegration technique can be validly used for our study. The ratio between the total length of the sample and the half-life of deviations from the cointegration equilibrium for the ST CDX spread is about 82.5 (=660 days/8 days). To draw a parallel with the literature on exchange rates and purchasing power parity (PPP), where cointegration analysis is widely employed, Rogoff (1996) describes the "remarkable consensus" about half-lives of PPP deviations as of 3 to 5 years (using long-horizon data). More recent papers using post-1973 data report shorter half-lives of 2 to 2.5 years. Even taking the lowest estimation (2 years), a researcher would need around 165 years of data on exchange rates to obtain a ratio of 82.5 between the length of the sample and the half-life deviation. Most papers in the area rely instead on samples not longer than 30–50 years.[20]

Moreover, Hakkio and Rush (1991) show that in the case of a relatively short sample, employing higher-frequency observations, such as daily data without temporal aggregation, could be useful since the expansion of the number of observations can increase the precision of the estimation. Haug (2002) also studies the effects of time-aggregation and the role of the span of data for the power of cointegration tests. His results show that the high-frequency of observations for any given span of data improves the performance and the power of cointegration tests, in particular with short spans of data. Moreover, he shows that when the data are likely to display excess kurtosis, outliers and nonlinearities (as in most practical cases), the Engle and Granger (1987) test for cointegration is preferable and more powerful than the Johansen (1991) test. This result reinforces our methodological choice, in addition to the other reasons already explained in the earlier part of this section.

Another criticism that can arise against the use of cointegration and ECMs is that the period under analysis (including the financial crisis of 2007–09) is a period of dramatic

[20] See also Blanco et al. (2005) on this topic.

re-pricing of risks in the financial markets, so the search for an "equilibrium" relationship between credit spreads and state variables can be affected by structural changes (regime breakpoints). We tackle this possible criticism in two steps. As a first step, we restate that our main hypothesis to be tested is that the financial crisis of 2007–09 has *not* invalidated the *existence* of an arbitrage relationship between the dependent variable and the state variables (which is based on the structural model theory of Merton (1974)); instead, the disruptions in this arbitrage relationship and the wider increase in credit spreads are to be ascribed to liquidity and sentiment frictions in the financial markets. This hypothesis does *not* exclude – however – that the *nature* of the relationship may have changed over the crisis period. In other words, we can investigate the existence of breakpoints in the arbitrage relationship (i.e. shifts in the intercept and slope coefficients of the cointegrating equation). As a second step, in order to validate our hypothesis, we need to demonstrate that even when we take into account endogenous structural breaks, our key variables continue to be cointegrated and the results of the estimation of the ECMs (also including the frictions) do not change substantially. This analysis is performed as a robustness check and the results are illustrated in subsection 5.1. We anticipate here that: i) the results of the cointegration tests with endogenous structural breaks align with the results of the Engle and Granger (1987) test (i.e. a strong rejection of the null of no cointegration); and ii) the augmented ECM analysis, with or without structural breaks in the cointegration equation, leads to very similar results. This robustness check should mitigate any concerns that our main results may be driven by mis-specification of the cointegration equation and biases in unit root tests. We pass now to describe the results of our main analysis.

3 Results

3.1 Results from Engle–Granger (1987) cointegration test and ECM estimation

In the analysis of non-stationarity, both the ADF test and the Phillips–Perron test cannot reject the hypothesis that the CDX Senior Tranche spread, the AAA Bond Index spread and all state variables are I(1) processes (see Table 5: Panel A).[21] The liquidity and market sentiment proxies are, however, found to be stationary. We proceed therefore with the steps required for the Engle and Granger (1987) cointegration test and ECM analysis.

The parameters of the cointegrating equation for credit index spreads are estimated using OLS. We provide four different specifications (Models I, II, III, and IV). The difference between Models I/III and Models II/IV is that the latter also include the S&P 100 Index option implied volatility slope, which captures the jump risk component in credit spreads. Moreover, while in Models I and II we use the VXO index as proxy for equity volatility, in Models III and IV we use the S&P 100 30-day rolling historical volatility. Thus, the results of the estimations can also help to detect whether there is a substantial difference between the effects of forward- and backward-looking measures of volatility.

The results of the OLS cointegrating regressions for the AAA Bond Index spread and ST CDX spread are shown in Table 6. The coefficients for the equity cumulative returns, the interest rate, and the slope of the term structure are higher for the ST CDX spread than for the AAA Bond Index spread. All signs predicted by the structural model are found in the results. The term structure slope and the equity volatility have a positive sign for both credit index spreads. The Treasury yield and the S&P 100 cumulative returns have a negative effect on both credit index spreads. There are no major differences in the results delivered by the various models. When the implied volatility slope is included, the coefficients of the other variables become only slightly lower. When the historical volatility is used instead of the VXO index, the coefficients are also slightly lower.

The sensitivity of credit index spreads to interest-rate factors is quite large, in particular for the CDX Senior Tranche spread. In Model I a positive daily change in interest rates of 25 basis points would lead to around a 4.5 basis point decrease in the spread on the Senior Tranche ($-0.18 \times 0.25 = -0.045$). A large change in the spread between 30-year and 2-year

[21] In particular, the nonstationarity is consistent with the five-year maturity structure of the CDSs constituents of the CDX.NA.IG index. The ST CDX spread patterns change over time progressively towards the maturity of its CDS components.

Treasury yields of 100 basis points would lead to a 9 basis point increase in the spread of the CDX Senior Tranche. The positive estimated coefficient for the slope of the term structure can be also explained by the positive effects that liquidity premia have on both the term structure slope and the spread of CDX tranches. Thus, the slope of the term structure already captures some of the liquidity effects that may explain the surge in the ST CDX spread.

In Table 6 we observe that the relationship between credit spreads and the five-year Treasury yield is stronger than the relationship between credit spreads and the S&P 100 Index level, in terms of the magnitude of the estimated coefficients. Structural models consider a corporate bond to be equivalent to a risk-free bond less a put option on the firm's value. A possible explanation for the limited magnitude of the equity index coefficient is that for senior credit instruments the put option is so far out-of-the-money that it represents a small position in the underlying asset. Thus, the equity level is a less important variable for their prices.

Although we cannot make any inference on the estimated coefficients of the OLS cointegrating regressions, we analyse whether their residuals are stationary (see Table 7: Panel A for the results). For all model specifications and for both the ST CDX and the AAA Bond Index spreads we can reject the null hypothesis of no cointegration between credit spreads and fundamental credit risk variables.[22]

In the ECMs estimated for the log ST CDX and AAA Bond Index spread innovations, the changes in the state variables display the expected signs that the theory suggests and that the cointegrating regressions have already confirmed for the relationship between the variables in levels (see Table 8). Moreover, the negative and significant error correction terms in all the estimated ECMs suggest a reversion of credit spreads to their equilibrium or no-arbitrage level predicted by the cointegrating equation. The estimated speed of adjustment towards this cointegration equilibrium is around 6.5% per day for the ST CDX spread and 4% for the AAA Bond Index spread.

[22] The only exception is Model III for the AAA Bond Index spread where the ADF statistics suggests no evidence of cointegration. For this reason in the following part of the analysis we disregard this model specification.

3.2 Results from the analysis of liquidity effects

Next, we add the proxies for changes in funding and market liquidity and investor sentiment as regressors in the ECMs[23] (see results in Table 9), after filtering out potential outliers.[24] We notice that the adjusted R^2s increase for the log ST CDX spread innovations with respect to the adjusted R^2s reported in Table 8, while they remain invariant for the log AAA Bond Index spread innovations. Accordingly, the non-default variables are found to be highly significant in the ECMs for the ST CDX spread, but always insignificant in the ECMs for the AAA Bond Index spread.[25]

Table 10 shows the results of the ECM estimation in terms of the standard deviation impact (economic significance) of the explanatory variables. Economic significance is measured as the product between the estimated coefficient from the ECM and the ratio of the standard deviation of the explanatory variable to the standard deviation of the dependent variable. The ST CDX spread changes appear to be driven mainly by innovations in the level and slope of the equity index implied volatility and by the disequilibrium adjustment. Interestingly, the other main drivers of changes in the ST CDX spread are market liquidity (the ST CDX bid–ask spread), funding liquidity, and market sentiment, which display relatively high economic significance.

In Model II, an increase of one standard deviation (SD) in VXO between two consecutive days can generate an average increase of 0.145 SD in the log ST CDX spread, if all the other

[23] In Models I and II, the proxy used for investor sentiment is the put–call ratio. The difference between VXO and S&P 100 GARCH-estimated volatility is used as a proxy for risk-aversion only in Model IV.

[24] All explanatory variables used in the ECMs, the CDX.NA.IG Index Senior Tranche spread and the AAA Bond Index spread are initially filtered from potential outliers. In particular, we winsorise the variables at the 0.1% lowest and highest values. We also delete observations for the CDX.NA.IG Index Senior Tranche spread which exhibit at least one of the following conditions: null bid price, null ask price, and/or negative bid–ask spread (Ask price – Bid price <0).

[25] To capture market liquidity effects on the ST CDX spread we use the ST CDX bid–ask spread. For the AAA Bond Index spread we employ the five-year swap spread. This variable is generally considered in the literature as a good indicator of both market and funding liquidity. However, when we exclude the swap spread change from the ECM regression, we notice that the coefficient for the innovations in commercial paper spread remains invariant (this suggests no collinearity problem). Consistently, the correlation between innovations in the five-year swap spread and innovations in commercial paper spread is quite low (only 6%). These results support the idea of using the swap spread to capture changes in corporate bond market liquidity, rather than in funding liquidity.

variables remain constant; while a daily one SD negative movement in the volatility slope can cause an increase of 0.11 SD in the log ST CDX spread on average. Equity (historical) volatility has a much lower effect on the AAA Bond Index spread (around a 0.02 SD increase in log spread for a one SD change in volatility).

A daily increase of one standard deviation (SD) in the log ST CDX bid–ask generates on average an increase of 0.14 SD in the log ST CDX spread.[26] Similarly, the positive effects of a one SD increase in the commercial paper spread and put–call ratio on the log ST CDX spread change are respectively 0.08 and 0.13 SD (the lagged put–call ratio has an additional 0.09 SD impact). The economic impact of changes in the put–call ratio and commercial paper spread on the log ST CDX spread is about 20 times larger than their impact on the log AAA Bond Index spread. Moreover, innovations in market liquidity (five-year swap spread), funding liquidity and put–call ratio are found to be statistically insignificant to explain daily changes in the log AAA Bond Index spread.

In order to understand whether the crisis has exacerbated the effect of liquidity on credit spreads, we re-estimate the augmented ECMs for Models I, II and IV and for both the ST CDX and AAA Bond Index spreads on three different sub-samples: the *pre-crisis period* (20 September 2006 to 20 July 2007), the *middle crisis period* (20 July 2007 to 20 May 2008), and the *all crisis* period (20 July 2007 to 20 May 2009).[27] Unreported results show that there are no significant differences in the effects of fundamental credit risk variables on the log AAA Bond Index and ST CDX spread changes across the three sub-periods considered. Table 11 reports only the estimated coefficients for the non-default variables in the ECMs for the ST CDX spread. For Models I and II liquidity and market sentiment are insignificant

[26] We address potential concern of a double-causality between changes in the log ST CDX quoted premium and changes in the log ST CDS bid–ask spread. First, we notice that their correlation over the whole sample is only about 14%. Second, Granger-causality tests (including different numbers of lags) strictly reject the hypothesis that changes in the log ST CDX premium can cause changes in the log ST CDX bid–ask spread, while they cannot reject that causality runs in the opposite direction, i.e. that changes in liquidity costs cause changes in log ST CDS premium.

[27] The estimated equations represent non-standard ECMs, because we use the lagged value of the residuals obtained from the estimation of the cointegration equations over the whole sample (September 2006 to May 2009) as error correction terms, in order to study movements in the dependent variable over the shorter pre-crisis and crisis sub-samples.

over the pre-crisis period, but become highly significant over the crisis period. Additionally, their estimated coefficients increase from one period to the other. Over the middle crisis period we find that the first difference of the log ST CDX bid–ask spread (proxy for changes in market liquidity) is the only significant non-default variable. Its beta coefficient also records the highest value in this sub-sample. The coefficient for changes in the commercial paper spread switches from insignificant and negative in the pre-crisis period, to positive and statistically significant in the crisis periods. For Model IV, current and lagged changes in the market sentiment proxy are found to be significant in both pre-crisis and crisis periods, the funding liquidity variable becomes significant only in the all-crisis sub-period, while the ST CDX bid–ask spread is also significant in the middle crisis period. For all the estimated models the adjusted R^2s are much higher over the crisis than over the pre-crisis period. Panel A of Table 12 reports the economic significance of the three non-default explanatory variables in Model II. In all the sub-samples, the changes in the log ST CDX bid–ask spread record the highest SD impact on the changes in the log ST CDX spread, followed by the changes in the put–call ratio and commercial paper spread. The market liquidity impact reaches the highest level during the middle crisis period, when an increase of one standard deviation (SD) alone can generate a 0.23 SD increase in log ST CDX, everything else being equal.

We also examine whether the effect of market liquidity (the first difference of the log ST CDX bid–ask spread) on the ST CDX credit spread comes mainly from an unexpected change (shock) or from an expected change in liquidity (or from both).[28] To distinguish between the two components, we first run an AR (12) on the log ST CDX bid–ask spread change. Autoregressive terms up to lag 5 are all found significant at least at the 10% significance level; higher-order lags are insignificant, so they are dropped from the AR model. We then construct the residuals from the AR model with five lags and define them as the unexpected changes or "shocks" in liquidity. The fitted values from the AR model instead represent the expected changes in liquidity. We include both variables in the augmented ECMs (for this

[28] We thank an anonymous referee for providing this suggestion.

purpose we use Model II). Using all sample data, both liquidity variables appear significant at the 1% level; the former has an estimated coefficient of 0.05, the latter a coefficient of 0.10. However, the economic significance (in terms of standard-deviation impact) of the two variables is very close (0.10 and 0.11 SD, respectively). The results are reported in Table 12: Panel B. In the pre-crisis sample both liquidity variables are insignificant. If we restrict the analysis to the crisis sample, we find that the economic impacts of the liquidity shocks and of expected liquidity changes in the period July 2007 to May 2008 are respectively 0.18 and 0.16 SD; while in the period July 2007 to May 2009 they become 0.24 and 0.05 SD. Market liquidity shocks therefore represent the most significant "friction" – both statistically and economically – that contributes to an increase in the ST CDX spread during the financial crisis.[29]

To compare the economic significance of liquidity with respect to the state variables and market sentiment proxy and to analyse how they change over time, we group the variables that were found to be statistically significant in the ECMs into five factor-blocks: an adjustment factor (including lagged values of credit spread changes and an error correction term); an equity factor (including current and lagged equity index returns, and changes in the level and slope of the VXO index); an interest rate process factor (including current and lagged changes in interest rates and term structure slope); a market sentiment factor (including current and lagged values of changes in put–call ratio); and a liquidity Factor (including changes in the commercial paper spread and in the log ST CDX bid–ask spread or in swap spread).[30] For each block we sum the economic significance (SD impact) of all variable-components over the pre-crisis and crisis sub-samples. The results are reported in Table 13. The net positive impact of the equity factor (obtained by adding up the negative impact of an increase in equity index returns and in volatility slope and the positive impact

[29] Note that for the reminder of the analysis we will continue to define the market liquidity proxy as the overall change in log ST CDX bid–ask spread, without distinction between shocks and expected changes, in order to obtain more conservative results of the overall economic significance of liquidity versus other credit spread components.

[30] Since in Model II for the AAA Bond Index spread, the equity factor includes only current and lagged values of the equity index level, we repeat the analysis using Model IV that instead includes in the equity factor also the historical volatility of the equity index. However, we find that the results for Model II and Model IV do not differ substantially.

of an increase in equity volatility) decreases from the pre-crisis to the crisis period. Contrarily, the net impact of the interest rate factor (obtained by summing the negative impact of an increase in interest rate and the positive impact of an increase in the term structure slope) switches from positive in the pre-crisis period to negative in the crisis periods. These results also shed some light on the power relationships between the variables within each factor-block, which determine the prevalent sign of the impact. Noticeably, the positive impact of the liquidity factor increases from very low levels in the pre-crisis period (0.04) to much higher levels in the crisis periods (0.25), if compared to the other factors. A similar result is also found for the market sentiment factor.

Further, we analyse which factor categories have the highest explanatory power in terms of adjusted R^2s by estimating five regressions for the first difference of the log ST CDX and AAA Bond Index spreads on each of these five factor-blocks over the pre-crisis and crisis sub-samples. The results are reported in Table 14. For the ST CDX spread the adjusted R^2s of all five factor-block regressions increase from the pre-crisis to the crisis period. For the AAA Bond Index spread the adjusted R^2s of the equity factor and the market sentiment factor remain almost invariant, whereas the adjusted R^2 of the adjustment factor decreases over the crisis period. On the contrary, the adjusted R^2 of the liquidity factor largely increases over the mid-crisis sub-sample (from 0.31% to 6.48%) with respect to the other blocks (the increase in the adjusted R^2 of the interest rate block regression is also quite substantial). Therefore, while the liquidity proxies do not display significant coefficients in the ECM regressions for the log AAA Bond Index spread innovations, they do carry more explanatory power during the mid-crisis periods in comparison to other factors.

Finally, we examine how the individual explanatory power of the liquidity proxies has changed over time. For this purpose we estimate rolling bivariate correlations (based on a moving window of 60 days) between the first difference in the log ST CDX spread changes and innovations in: i) the log bid–ask spread; and ii) the commercial paper spread. Figure 2 shows a clear increase in the correlation between changes in the log ST CDX bid–ask and changes in the log ST CDX spread in July 2007 (the beginning of the crisis), and then around the peaks of the crisis (March 2008: Bear Stearns' bankruptcy; September 2008: Lehman Brothers' bankruptcy). The correlation between the first differences in the log ST CDX spread and commercial paper spread records the highest peaks towards the end of 2007 and in September 2008 (Figure 3).

In conclusion, all these findings confirm that market and funding liquidity had a large impact on the dramatic increase in the spread of the Senior Tranche of CDX.NA.IG Index during the crisis period of 2007–09, even after controlling for fundamental state variables related to firms' higher credit risk and for the effect of higher investor pessimism in the market. Although for the AAA Bond Index the liquidity variables are never statistically and economically significant when used in the ECM regressions, we also find some evidence that the explanatory power of the liquidity factor alone is much higher during the crisis than before (also with respect to the credit risk variables). Therefore, the ECM findings do not rule out the possibility that the Corporate Bond Index spread contains a liquidity premium (which increased during the crisis period); they only show that, given the methodology and the proxies employed, changes in market and funding liquidity do not appear to be as statistically and economically significant to explain changes in the spreads of simple unstructured credit instruments as they are for more complex structured credit derivatives.

4 Tests of ST CDX mispricing corrections during the crisis

So far we have investigated liquidity effects on senior credit index spreads assuming a cointegrating equilibrium between credit index spreads and credit risk variables and then examining their short-term movements in ECMs, in order to see what happens that cannot be explained by these fundamental variables. However, besides higher illiquidity and worse market sentiment, another possible reason for the large increase in the ST CDX spreads during the crisis is the "repricing" of investment-grade structured credit securities. Coval et al. (2009) claim that this repricing is due to the correction of an ex-ante failure of investors to appropriately charge for systemic risk. According to this hypothesis, prior to the crisis, the Senior Tranche of the CDX.NA.IG Index was underpriced. The crisis may have therefore caused a new permanent equilibrium between credit spreads and credit-risk fundamentals, rather than a temporary deviation from an existing (pre-crisis) equilibrium.

Although in our paper we do not calibrate an explicit structural model, as Coval et al. (2009) do, the cointegration analysis takes into account the same fundamental drivers of credit spreads considered by their structural model. If the mispricing hypothesis of Coval et al. (2009) is correct, then we should observe that the widening of the Senior Tranche CDX spread during the crisis represents a permanent — rather then a temporary — departure from the predictions of the pre-crisis equilibrium model (i.e. a correction of the mispricing). Thus, we test the mispricing hypothesis against our alternative hypothesis that the pre-crisis equilibrium model can predict approximately only the default risk component of the tranche spread, but cannot capture the extra-premia due to market and funding illiquidity which widened during the crisis.

To test the mispricing hypothesis we estimate the cointegration equation over a pre-crisis period (20 September 2006 to 20 February 2007) and then predict the ST CDX spreads over the crisis sample, using the cointegrating parameters estimated over the pre-crisis period and updated values of the fundamental variables over the crisis period. In this way we obtain the deviations of the predicted ST CDX spreads from the actual ST CDX spreads (so-called "forecast errors") and, by regressing the changes in the log ST CDX spread over the crisis period on fundamental variables, liquidity proxies, a market sentiment proxy and on the lagged forecast error, we capture the adjustment towards/away from the pre-crisis equilibrium. This OLS regression represents an "atypical" ECM: the correction term is in fact represented by the lagged forecast errors, rather than by the lagged residuals from the cointegrating regression.[31] If the ST CDX spread movements during the crisis period represent adjustments towards the pre-crisis equilibrium relationship, then we should find that the lagged forecast error carries a significant negative coefficient. If, instead, during the crisis the ST CDX spread drifts away from the pre-crisis equilibrium relationship, then

[31] We use the same ECM parsimonious specifications that have been used in the previous analysis (section 3).

the lagged forecast error should carry a significant positive coefficient. Additionally, this analysis allow us to examine whether changes in funding and market liquidity continue to explain short-term (daily) changes in the ST CDX spread, even after controlling for the pre-crisis model forecast error.

As Models I, II and IV deliver similar results, we focus the discussion of the results on Model II. Table 15 shows that, depending on the sub-sample considered, the predicted changes are between 22% and 43% correlated with the observed changes in the log ST CDX spread. By performing principal component analysis (unreported results) we also find that the first principal component explains more than 50% of the predicted changes and around 20% of the actual changes, but captures almost 80% of common movements between the two series. Therefore, the predicted changes in ST CDX track fairly well the observed daily changes in the ST CDX spreads over the crisis period, although the latter remain much wider on average.

Table 16 shows the results of the "atypical" ECM. We find that the lagged forecast error is never significant in explaining changes in the actual log ST CDX spread over the crisis period, also when changes in liquidity and the put–call ratio are not included as regressors. However, in all cases the sign of the estimated coefficient for the forecast error is negative. Although the lack of significance prevents us from drawing clear conclusions, we do not observe a positive significant coefficient for the lagged forecast error. Thus, we reject the hypothesis that the ST CDX spread during the crisis has drifted away from the pre-crisis model predictions.

As a further analysis, we perform an OLS regression to instead detect whether during the crisis period liquidity frictions are important drivers of the deviations of observed spreads from the spreads predicted by the pre-crisis model. In Table 17 we observe that wider illiquidity causes a significant increase in the forecast errors.

5 Robustness checks

In this last part of the work we perform several robustness checks.[32]

5.1 Structural breaks in the cointegration relationship

In section 4 we have performed a predictive analysis of the ST CDX spread using as in-sample period the months before the beginning of the crisis. We have chosen February 2007 as the starting point of the crisis because this is the period when the earlier events begun to unfold. We have noticed that using a pre-crisis arbitrage relationship to forecast changes in the ST CDX spreads during the crisis is largely insufficient, while market frictions needs to be considered. Although we do not clearly observe any significant evidence of pre-crisis mispricing, since credit spreads do not "travel far away" from the pre-crisis equilibrium, we have not examined whether they may revert towards a "new" no-arbitrage equilibrium. Therefore, a more formal analysis is now conducted as a robustness check to take into account the effects of possible endogenous structural breaks in the cointegrating variables during the crisis period for both the ST CDX and the AAA Bond Index spreads. This analysis is similar in spirit to the analysis in section 4 with the noticeable differences that: i) we now let data "speak for themselves"; ii) we employ a battery of econometric tests for unit roots and cointegration that consider endogenous regime breakpoints; and iii) we do not test for pre-crisis mispricing, but for a possible shift in the cointegration/arbitrage relationship between our variables. The final aim of this analysis is to understand whether this can change the key results of the Augmented ECMs on the significance of frictions for the increase in the credit spreads.

Perron (1989) argues that in presence of structural breaks the ADF and Phillips–Perron tests can lead to an under-rejection of the unit root hypothesis. He proposes a modified Dickey–Fuller test with a known exogenous structural break. An alternative (and more robust) approach is the one that considers structural breaks as unknown and endogenous

[32] Some of the results of these robustness checks are unreported for brevity, but they are available upon request.

to the data (Maddala & Kim, 2003). Zivot and Andrews' (1992) unit root test belongs to this alternative family of tests. It performs sequential ADF tests and endogenises the structural break by choosing the breakpoint that gives the least favourable view of the unit root hypothesis (therefore it reduces the bias of under-rejection of the unit root). We perform the Zivot and Andrews (1992) test on all variables (in levels) for which the classic ADF and Phillips–Perron tests cannot reject the unit root hypothesis in Panel A of Table 5. The results are displayed in Panel B of Table 5 and show that for all variables (except for the TS slope) we still cannot reject the unit root hypothesis, even when we consider structural breaks.

The problem of unit root testing in the presence of structural breaks can also affect the ADF test on the cointegrating residuals, which we have performed in the Engle–Granger (1987) cointegration analysis of section 3. An alternative test for cointegration in the presence of unknown structural breaks is provided by Gregory and Hansen (1996). This is a multivariate application of the univariate test with structural breaks of Zivot and Andrews (1992) performed earlier on individual variables. Gregory and Hansen (1996) propose an extension of the classic ADF test (and Phillips Z-tests) for a unit root in the residuals from the cointegration equation, allowing for a shift in either the intercept alone or in the entire coefficient (slope) vector of the cointegration equation. The test does not require a prior identification of the structural break that causes the shifts, so it prevents informal data analysis (such as a visual examination of time series plots) from contaminating the choice of the breakpoint. The test also returns an estimate of the breakpoint. This residuals-based test for cointegration allows us to examine whether the ST CDX spread (and the AAA Bond Index spread) are cointegrated with the credit risk variables (from a structural model), also taking into account that the cointegrating vector may have shifted at some unknown point in the sample. We perform the test on the residuals from the cointegration Models I and III, as the critical values reported by Gregory and Hansen (1996) are only for cointegration equations with up to four regressors. Results are reported in Table 7: Panel B. The Gregory and Hansen (1996) ADF tests for Model I (including either a shift in the intercept or shifts in all coefficients) reject the null of no cointegration respectively at the 2.5% and 5% significance level for the ST CDX spread and at the 1% significance level for the AAA Bond Index spread, against the alternative of cointegration with shifts due to structural breaks.[33] For Model III, the ADF cointegration test with structural breaks rejects the null of no cointegration again at the 2.5% and 5% significance level for the ST CDX spread, but it cannot reject the null for the AAA Bond Index spread (consistently with the results of the classic ADF test reported in Table 7: Panel A). Notably, for the ST CDX spread, the Gregory and Hansen (1996) test estimates that the breakpoint may occur just a few weeks after the Lehman Brothers default on 15 September 2008, which is considered the worst event of the financial crisis. The Gregory and Hansen (1996) ADF test for the AAA Bond Index spread instead indicates various possible breakpoints in the third quarter of 2007 or in 2008. To test for the presence of breakpoints in the cointegration equations and get clear-cut estimates of when they may have occurred, we also perform a Quandt–Andrews test on the cointegration equations of Model I and Model II for the ST CDX spread and the AAA Bond Index spread.[34] As expected, the test rejects the null hypothesis of no breakpoints. The estimated breakpoints are identified at the end of September 2008 for the ST CDX spread and 16 September 2008 (the day after the Lehman default) for the AAA Bond Index. For brevity, these results are not reported here, but are available upon request.

To summarise, we show in Table 7 that both the classic ADF test of cointegration from the Engle and Granger (1987) methodology and the modified ADF tests based on the Gregory and Hansen (1996) methodology reject the null hypothesis of no cointegration. This implies that there is some equilibrium relationship between the ST CDX spread (AAA Bond Index spread) and the credit risk variables, and it confirms the basic intuition behind the structural

[33] The critical values for the test are obtained by Gregory and Hansen (1996) via Monte-Carlo simulations on different sample sizes. Their largest sample includes 300 observations. Our sample includes more than double this number (667 daily observations). Once again, this suggests that the sample size used in our research should not cause any loss of power in the cointegration test.

[34] The idea behind the Quandt–Andrews test is that a single Chow Breakpoint Test is performed at every observation between two dates. The individual test statistics (i.e. the Likelihood Ratio F-statistics and the Wald F-statistics) from those Chow tests are then summarised into one test statistic (equal to their average value or their maximum value) for a test against the null hypothesis of no breakpoints between the two dates. See also Andrews (1993) and Andrews and Ploberger (1994).

models of credit risk. This result does not necessarily indicate the presence of structural breaks. However, if we take into account the result of the Quandt–Andrews tests, a structural break is very likely to appear in the cointegration equations after the dramatic events of the financial crisis in 2007–09, and particularly after the Lehman Brothers default event on 15 September 2008. We therefore re-estimate the cointegration equations using the "regime" breakpoints obtained from the Quandt–Andrews tests as dummy variables (also interacted with the other regressors). Next, we use the residuals from these equations to re-estimate the ECMs with and without frictional variables. In Table 18 we illustrate the results for the ECMs relative to the ST CDX spread and the AAA Bond Index spread. For this purpose, we show only the results for Model II (as we view it as the most complete specification). We can compare these results to the previous ECM results for Model II (reported in Table 9: Column 2). We observe that none of the key coefficients change. The error correction term for ST CDX has a much higher estimated coefficient in the "new" ECM regression than in the previous one in Table 9. This suggests that taking into account structural breaks in the cointegration equation helps to reveal a faster movement of the ST CDX credit spreads back to a no-arbitrage equilibrium (now also robust to structural shifts in the parameters). The significance of the frictional variables remains very high and the estimated coefficients of comparable magnitude with those reported in Table 9. For the AAA Bond Index, all the results remain invariant and the frictional variables stay insignificant.

5.2 Non-linearities in the cointegration relationship

Furthermore, we control for non-linear effects of fundamental and frictional variables (squares and cubes) in both the cointegrating regression and the ECMs, in order to mitigate our concerns regarding a possible specification error caused by the linear estimation of a non-linear relationship between credit index spreads, equity and interest rate variables. We do not observe any major impact of higher-order terms on the regression results. Only the first difference in the squared equity implied volatility (VXO) is found significant in the ECM estimation. This is consistent with the non-linear relationship between credit spreads and equity volatility predicted by the structural model theory (Merton, 1974). Most importantly, the signs and levels of significance of the liquidity proxies remain invariant.

5.3 Use of Johansen VECM in lieu of Engle–Granger ECM

We also control for potential endogeneity of the state variables by means of: i) re-estimation of the Engle–Granger ECMs, excluding contemporaneous changes in fundamental state variables; and ii) estimation of the Johansen VECM, including as endogenous variables the credit spreads and state variables, and as exogenous variables the changes in market and funding liquidity and the put–call ratio. The Engle–Granger ECM re-estimations deliver very similar results to the original ECMs (discussed in section 3). Likewise, in the VECM analysis no substantial differences are observed in the level of statistical and economic significance of the liquidity variables. However, changes in the equity index value and implied volatility slope now appear insignificant in explaining changes in the ST CDX spread, despite the fact that the equity implied volatility slope displays a much larger coefficient in the cointegrating equation. Finally, in the VECMs for the AAA Bond Index, we detect some significant (albeit weak) effects of changes in the swap spread (a proxy for market liquidity), which have not been found in the previous ECM analysis.

5.4 Selection of dependent variables

We check the effects of the staleness of AAA bond prices in our analysis. There is a limited number of AAA bonds in the corporate bond market and they trade only rarely. Since AA corporate bonds are more numerous and more frequently traded, we repeat the whole analysis of Section 3 for Moody's AA Bond Index spread. We observe stronger evidence in favour of cointegration between the AA Bond Index spread and the fundamental credit risk variables. However, as for the AAA Bond Index, in the error correction models the proxies for liquidity lack significance, even when the analysis concerns solely the crisis sub-period.

In addition, we re-estimate the ECMs using as dependent variables the first differences in credit spreads (absolute changes), rather than first differences in the *log* credit spreads (relative percentage changes), to ascertain that there is no substantial difference in the results. In the ECMs for first differences in the ST CDX spread, the level of economic and statistical significance of the liquidity proxies is very similar to the one found for first differences in the log ST CDX spread, although for all model specifications the adjusted R^2s of the ECMs are much higher, on average by 10%.

5.5 Selection of credit risk variables

Finally, in our fifth and last check we test the robustness of our selection of state variables and, in particular, of the S&P 100 Index returns as a measure of firm value. In the structural model of Merton (1974), the relative value of the firm's debt to the total (unobservable) value of its assets (i.e. the leverage) is a key variable that determines changes in the firm's probability of default and credit spread. Thus, we repeat the Engle–Granger analysis and the Johansen VECM analysis replacing the S&P 100 Index cumulative returns with:

- The average book leverage for 100 firms underlying the CDX.NA.IG Index Series 7–12. For each firm, the book leverage ratio is constructed (using COMPUSTAT data) as the ratio of the firm's book value of liabilities (i.e. total current liabilities plus one half of long-term liabilities) over the firm's total book value of assets.

- The average market leverage for 100 firms underlying the CDX.NA.IG Index Series 7–12. For each firm, the market leverage ratio is constructed (using COMPUSTAT data) as the ratio of the firm's book value of liabilities over the firm's total market value of equity (i.e. number of common shares outstanding times current market value of shares) plus its book value of liabilities.

Additionally, we repeat the analysis using as the credit-risk state variable an explicit measure of the aggregate probability of default estimated from the structural model (Merton, 1974; Duan & Wang, 2012). Data on the probabilities of default (estimated over a 5-year forecast horizon) for U.S. firms are downloaded from the website of the Credit Risk Initiative of the

Risk Management Institute (RMI) at the National University of Singapore. Since we are considering senior credit indices, we use two alternative measures of the aggregate probability of default (PD):

- The lowest 25th percentile value of the probability of default across a large universe of 5,797 (industrial and financial) firms in the U.S.;
- The average probability of default across 25 firm components of the CDX.NA.IG Index (Series 7–12) which are also found included in the RMI database.

When we repeat all the empirical analysis for the ST CDX Index spread replacing the S&P 100 Index value first with the book and market leverage ratios and then with a measure of probability of default for top-rated firms, all main results (for the cointegration, the ECM, and the significance of the liquidity variables) do not show any substantial change. However, all adjusted R^2s for the ECMs are lower than in the benchmark analysis in sections 3.2 and 3.3. When we repeat the empirical analysis for the AAA Bond, we observe instead that in the Augmented ECMs the liquidity proxies now appear statistically significant. Nevertheless, their economic significance for the AAA Index spread remain much lower than for the ST CDX spread. This result confirms our previous finding that, when systemic funding and market liquidity problems appeared during the crisis, they had a larger effect on the ST CDX Index than on the AAA Bond Index. This puzzling finding may also be driven by the severe problems in more complex multilayered AAA CDO Tranches, which have further undermined investors' confidence in the trading of securitised products and their reliance on high credit ratings, thereby also temporarily drying up the liquidity of standardised CDO products, such as the Senior Tranche of CDX.NA.IG.

6 Conclusions

In this work we examine the effect of liquidity on senior credit index spreads through a cross-asset comparison of structured and unstructured AAA-rated portfolios of credit instruments, i.e. the Senior Tranche of the CDX.NA.IG Index (ST CDX) and Moody's AAA Bond Index, and through a time series comparison of the determinants of their credit spreads before and during the subprime crisis 2007–09.

To distinguish liquidity effects from credit-risk effects, we examine various components of the credit spreads using cointegration analysis and ECMs. We consider a set of state variables related to credit-risk fundamentals (from the structural model theory) and a set of frictional variables that represent changes in market and funding liquidity and in investor "sentiment".

The signs predicted by the structural model theory for the relationship between credit spreads and state variables (equity index returns, equity index volatility, and interest rates) are all verified by the cointegration analysis, for both the ST CDX and the AAA Bond Index. The ST CDX and the AAA Bond Index spreads are linked to credit risk fundamentals via an arbitrage relationship towards which they tend to align over time (on average over a fortnight). However, in the shorter term, lower market and funding liquidity has a significant positive impact on movements in the ST CDX spread over the crisis period (July 2007 – May 2009). The strongest effect comes from the unexpected change (shock) in the liquidity costs. By contrast, liquidity lacks significance in explaining changes in the ST CDX spread over the pre-crisis period (September 2006 – July 2007) and it appears less relevant in explaining changes in the AAA Bond Index spread over both the pre-crisis and crisis periods. Thus, this paper suggests that AAA-rated structured credit products (such as the ST CDX) can be affected by frictional factors that may instead be less prominent in simpler unstructured credit markets.

Further analysis suggests that the increase in the ST CDX spread is more likely due to wider investors' concern of a "drying-up" of market and funding liquidity than to the correction of a pre-existing underpricing of this Senior Tranche. Consistently, we observe that the deviations between the observed ST CDX spread and the spread predicted by a pre-crisis equilibrium credit risk model can be significantly explained by lower market and funding liquidity and higher investor pessimism.

While new literature on the correct pricing model for structured credit derivatives flourishes and contrasting explanations are offered as to why top-rated structured credit premia dramatically increased during the financial crisis of 2007–09, our empirical analysis sheds some light on the critical role of market and funding liquidity. This work supports the hypothesis that market and funding liquidity contributed to the surge in the spread of the Senior Tranche CDX.NA.IG Index during the subprime crisis. Regulators, rating agencies and risk-managers should take liquidity into account in the evaluation of Senior Tranches of structured credit derivatives and should develop more sophisticated tools to appreciate the time-varying liquidity premia. A sudden drying-up of liquidity can drastically reduce the benefits of securitisation, while leaving investors highly exposed to systemic risk.

References

Alexander, C., and A. Kaeck (2008): "Regime Dependent Determinants of Credit Default Swap Spreads," *Journal of Banking and Finance*, 32(6), 1008–1021.

Andrews, D. W. K. (1993): "Tests for Parameter Instability and Structural Change With Unknown Change Point," *Econometrica*, 61(4), 821–856.

Andrews, D. W. K., and W. Ploberger (1994): "Optimal Tests When a Nuisance Parameter is Present Only Under the Alternative," *Econometrica*, 62(6), 1383–1414.

Bandopadhyaya, A., and A. L. Jones (2008): "Measures of Investor Sentiment: A Comparative Analysis Put–Call Ratio vs. Volatility Index," *Journal of Business and Economics Research*, 6(8), 27–34.

Bedendo, M., L. Cathcart, and L. El Jahel (2007): "The Slope of the Term Structure of Credit Spreads: An Empirical Investigation," *Journal of Financial Research*, 30(2), 237–257.

Blanco, R., S. Brennan, and I. W. Marsh (2005): "An Empirical Analysis of the Dynamic Relation between Investment-Grade Bonds and Credit Default Swap," *Journal of Finance*, 60(5), 2255–2281.

Bongaerts, D., F. de Jong, and J. Driessen (2011): "Derivative Pricing with Liquidity Risk: Theory and Evidence from the Credit Default Swap Market," *Journal of Finance*, 66(1), 203–240.

Borio, C. (2010): "Ten Propositions about Liquidity Crises," *CESifo Economic Studies*, 56(1), 70–95.

Brooks, C., A. G. Rew, and S. Ritson (2001): "A trading strategy based on the lead–lag relationship between the spot index and futures contract for the FTSE 100," *International Journal of Forecasting*, 17, 31–44.

Brown, K. C., W. V. Harlow, and D. J. Smith (1994): "An Empirical Analysis of Interest Rate Swap Spreads," *Journal of Fixed Income*, 3, 61–78.

Brunnermeier, M., and L. Pedersen (2009): "Market Liquidity and Funding Liquidity," *Review of Financial Studies*, 22(6), 2201–2238.

Campbell, J. Y., and G. B. Taksler (2003): "Equity Volatility and Corporate Bond Yields," *Journal of Finance*, 58(6), 2321–2350.

Chen, L., D. A. Lesmond, and J. Wei (2007): "Corporate Yields Spreads and Bond Liquidity," *Journal of Finance*, 62(1), 119–149.

Chen, R., X. Cheng, and L. Wu (2013): "Dynamic Interactions Between Interest-Rate and Credit Risk: Theory and Evidence on the Credit Default Swap Term Structure," *Review of Finance*, 17(1), 403–441.

Chen, R., F. Fabozzi, and R. Sverdlove (2010): "Corporate Credit Default Swap Liquidity and Its Implications for Corporate Bond Spreads," *Journal of Fixed Income*, 20(2), 31–57.

Choudhry, M. (2010): *Structured Credit Products: Credit Derivatives and Synthetic Securitization (2nd Ed.)*. John Wiley & Sons.

Christensen, B. J., and N. R. Prabhala (1998): "The Relation between Implied and Realized Volatility," *Journal of Financial Economics*, 50, 125–150.

Collin-Dufresne, P. (2009): "A Short Introduction to Correlation Markets," *Journal of Financial Econometrics*, 7, 12–29.

Collin-Dufresne, P., R. S. Goldstein, and J. S. Martin (2001): "The Determinants of Credit Spread Changes," *Journal of Finance*, 56(6), 2177–2207.

Collin-Dufresne, P., R. S. Goldstein, and F. Yang (2012): "On the Relative Pricing of Long Maturity Index Options and CDX Tranches," *Journal of Finance*, 67(6), 1983–2014.

Cont, R., and P. Tankov (2004): *Financial Modelling with Jump Processes*. Chapman and Hall.

Coval, J. D., J. Jurek, and E. Stafford (2009): "Economic Catastrophe Bonds," *American Economic Review*, 99(3), 628–66.

Cremers, K. J. M., J. Driessen, and P. Maenhout (2008): "Explaining the Level of Credit Spreads: Option-Implied Jump Risk Premia in a Firm Value Model," *Review of Financial Studies*, 21(5), 2209–2242.

Dennis, P., and S. Mayhew (2002): "Risk-Neutral Skewness: Evidence from Stock Options," *Journal of Financial and Quantative Analysis*, 37(3), 471–493.

Dick-Nielsen, J., P. Feldhütter, and D. Lando (2012): "Corporate Bond Liquidity before and after the Onset of the Subprime Crisis," *Journal of Financial Economics*, 103(3), 471–492.

Duan, J. C., and T. Wang (2012): "Measuring Distance-to-Default for Financial and Non-Financial Firms," *Global Credit Review*, 2, 95–108.

Duffie, D., and K. J. Singleton (1999): "Modeling Term Structures of Defaultable Bonds," *Review of Financial Studies*, 12(4), 687–720.

Engle, R. F., and C. W. J. Granger (1987): "Co-Integration and Error Correction: Representation, Estimation, and Testing," *Econometrica*, 55(2), 251–276.

Eom, Y. H., J. Helwege, and J. Huang (2004): "Structural Models of Corporate Pricing: An Empirical Analysis," *Review of Financial Studies*, 17(2), 499–544.

Ericsson, J., K. Jacobs, and R. Oviedo (2009): "The Determinants of Credit Default Premia," *Journal of Financial and Quantitative Analysis*, 44, 109–132.

Ericsson, J., and O. Renault (2006): "Liquidity and Credit Risk," *Journal of Finance*, 61(5), 2219–2250.

Fabozzi, J. F., Y. C. Wang, S. K. Yeh, and R. R. Chen (2009): "An Empirical Analysis of the CDX Index and its Tranches," *Applied Economics Letters*, 16, 1425–1431.

Fleming, J. (1998): "The Quality of Market Volatility Forecasts implied by S&P 100 Index Option Prices," *Journal of Empirical Finance*, 5, 317–345.

Gemmill, G., and A. Keswani (2011): "Downside Risk and the Size of Credit Spreads," *Journal of Banking and Finance*, 35(8), 2021–2036.

Greatrex, C. A. (2009): "Credit Default Market Determinants," *Journal of Fixed Income*, 18(3), 18–32.

Gregory, A. W., and B. E. Hansen (1996): "Residual-based Tests for Cointegration in Models with Regime Shifts," *Journal of Econometrics*, 70(1), 99–126.

Grinblatt, M. (2001): "An Analytic Solution for Interest Rate Swap Spreads," *International Review of Finance*, 2(3), 113–149.

Hakkio, C. S., and M. Rush (1991): "Cointegration: How Short is the Long Run?," *Journal of International Money and Finance*, 10, 571–581.

Haug, A. A. (2002): "Temporal Aggregation and the Power of Cointegration Tests: A Monte Carlo Study," *Oxford Bulletin of Economics and Statistics*, 64, 399–412.

He, Z., and A. Krishnamurthy (2012): "Intermediary Asset Pricing," *American Economic Review*, 103(2), 732–770.

Huang, J., and M. Huang (2012): "How Much of Corporate-Treasury Yield Spread Is Due to Credit Risk?: A New Calibration Approach," *Review of Asset Pricing Studies*, 2(2), 153–202.

Huang, Y., S. Neftci, and I. Jersey (2003): "What Drives Swap Spreads, Credit or Liquidity?," ICMA Centre Discussion Paper in Finance 2003–2005.

Johansen, S. (1991): "Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models," *Econometrica*, 59(6), 1551–1580.

Leland, H. (2004): "Predictions of Default Probabilities in Structural Model of Debt," *Journal of Investment Management*, 2, 5–20.

Leland, H. (2006): "Structural Models in Corporate Finance - Lecture 2: A New Structural Model," Princeton Lectures in Finance, September 20–22.

Leland, H. (2008): "Structural Models and the Credit Crisis," C.R.E.D.I.T. Liquidity and Credit Risk, Venice, September 22.

Longstaff, F. A. (1995): "How Much Can Marketability Affect Security Values?," *Journal of Finance*, 50(5), 1767–1774.

Longstaff, F. A., S. Mithal, and E. Neis (2005): "Corporate Yields Spreads: Default Risk or Liquidity? New Evidence from the Credit Default Market," *Journal of Finance*, 60(5), 2213–2253.

Longstaff, F. A., and E. S. Schwartz (1995): "A Simple Approach to Valuing Risky Fixed and Floating Rate Debt," *Journal of Finance*, 50(3), 789–819.

MacKinnon, J. H. (2010): "Critical Values for Cointegration Tests," Mimeo, Department of Economics, Queen's University Working Paper.

Maddala, G. S., and I. Kim (2003): *Unit Roots, Cointegration, and Structural Change*. Cambridge University Press.

Merton, R. (1974): "On the Pricing of Corporate Debt: The Risk Structure of Interest Rates," *Journal of Finance*, 29, 449–470.

Perron, P. (1989): "The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis," *Econometrica*, 57, 1361–1401.

Rogoff, K. (1996): "The Purchasing Power Parity Puzzle," *Journal of Economic Literature*, 34, 647–668.

Scheicher, M. (2008): "How has CDO Market Pricing changed during the Turmoil? Evidence from CDS Index Tranches," European Central Bank Paper Series, No. 910.

Sun, T., S. Sundaresan, and C. Wang (1993): "Interest Rate Swaps: An Empirical Investigation," *Journal of Financial Economics*, 34, 77–99.

Tang, D. Y., and H. Yan (2007): "Liquidity and Credit Default Spread," AFA 2007 Chicago Meetings Paper.

Zhang, B. Y., H. Zhou, and H. Zhu (2009): "Explaining Credit Default Swap Spreads with the Equity Volatility and Jump Risks of Individual Firms," *Review of Financial Studies*, 22(12), 5099–5131.

Zivot, E., and D. W. K. Andrews (1992): "Further Evidence on the Great Crash, the Oil-Price Shock, and the Unit-Root Hypothesis," *Journal of Business and Economic Statistics*, 10(3), 251–270.

Figures and Tables

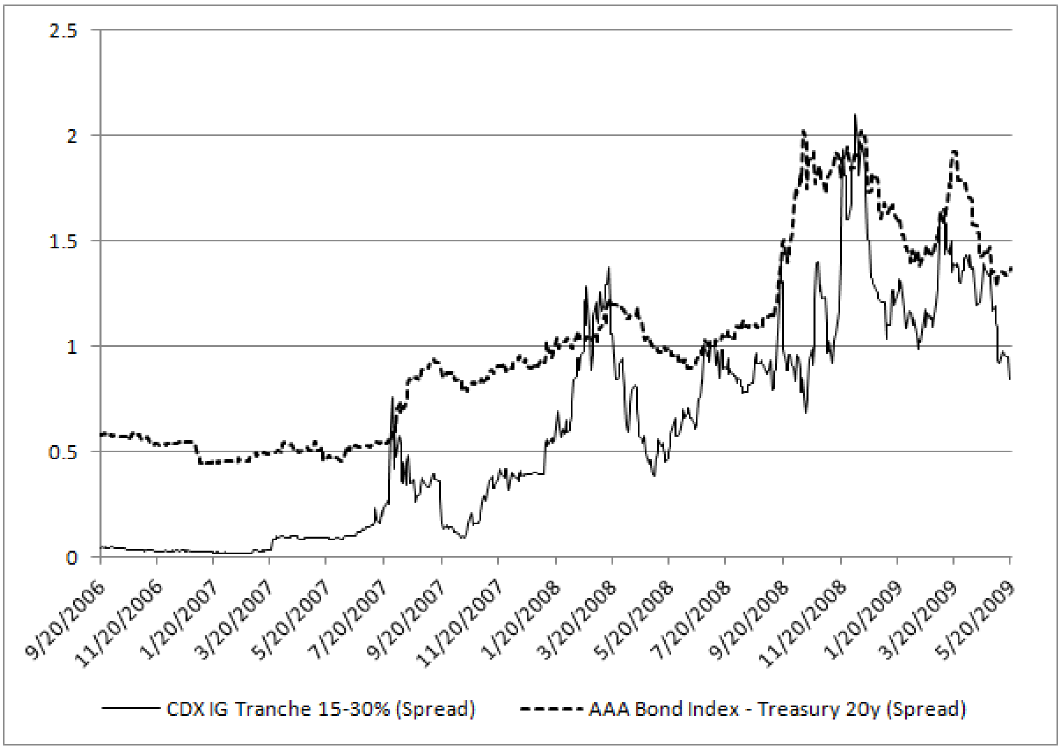

Figure 1: Time-series of Moody's AAA Bond Index spread and CDX.NA.IG Index Senior Tranche spread
(Percentage units; daily frequency; period: 20 Sept 2006 to 20 May 2009.)

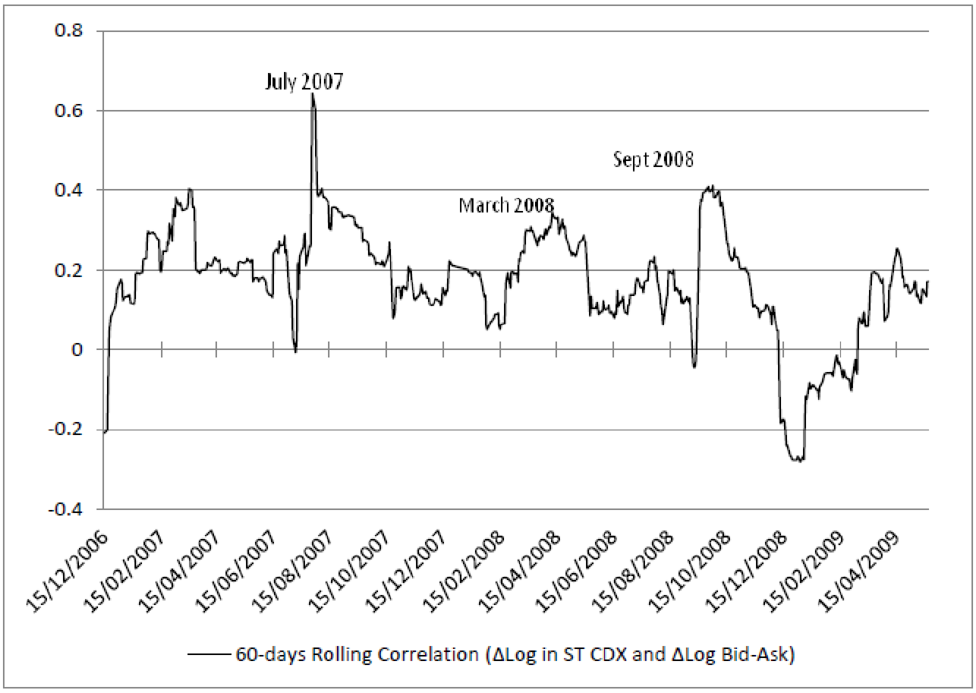

Figure 2: Rolling correlation between changes in log CDX.NA.IG Index Senior Tranche spread and changes in market liquidity
(Market liquidity measured by ST CDX bid–ask spread. Rolling window of 60 consecutive days.)

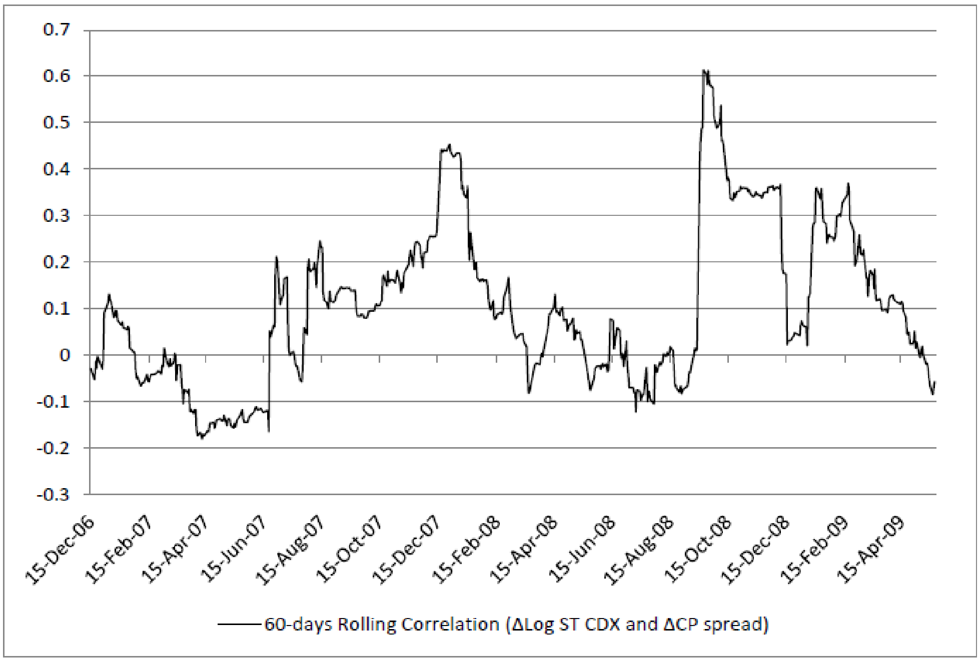

Figure 3: Rolling correlation between changes in log CDX.NA.IG Index Senior Tranche spread and changes in funding liquidity
(Funding liquidity measured by commercial paper spread. Rolling window of 60 consecutive days.)

Table 1
Summary statistics for Moody's AAA Bond Index spread (over 20y TCM) and CDX.NA.IG Index Senior Tranche spread
(Variables measured in percentage units; daily frequency; period: 20 Sept 2006 to 20 May 2009.)

	AAA Bond Index Spread	*ST CDX Spread*
Mean	0.999	0.597
Median	0.940	0.502
Maximum	2.020	2.100
Minimum	0.450	0.018
Std. dev.	0.447	0.507
Skewness	0.588	0.537
Kurtosis	2.283	2.268
Jarque–Bera	52.382	46.587
Probability	<0.0001	<0.0001
Observations	662	662

Table 2
Summary statistics for changes in the log Moody's AAA Bond Index spread (over 20y TCM) and in the log CDX.NA.IG Index Senior Tranche spread
(Variables measured in percentage units; daily frequency; period: 20 Sept 2006 to 20 May 2009.)

	Δ *Log AAA Bond Index Spread*	Δ *Log ST CDX Spread*
Mean	0.130	0.441
Median	0.000	0.019
Maximum	16.834	93.069
Minimum	–15.719	–59.996
Std. dev.	2.551	10.192
Skewness	0.143	0.920
Kurtosis	10.780	18.300
Jarque–Bera	1671.858	6540.788
Probability	<0.0001	<0.0001
Observations	662	662

Table 3

Analysis of autocorrelation for Moody's AAA Bond Index spread and CDX.NA.IG Index Senior Tranche spread

(5 lags considered; in OLS coefficient column, significant lags of AR(5) OLS regressions are indicated in bold.)

	Lag	Auto corr.	Partial AC	Q-Stat	Prob.(Q)	OLS coefficient	Std. errors	t-stat	P-value
$ST\ CDX_t$	1	0.991	0.991	653.0	**0.000**	**0.010**	0.0004	26.065	**0.000**
	2	0.981	–0.028	1294.6	**0.000**	0.000	0.0006	0.740	0.460
	3	0.971	–0.061	1923.4	**0.000**	**–0.001**	0.0006	–1.801	**0.072**
	4	0.961	0.030	2540.4	**0.000**	–0.001	0.0006	–1.167	0.244
	5	0.953	0.086	3147.8	**0.000**	**0.001**	0.0004	2.542	**0.011**
$\Delta\ Log\ ST\ CDX_t$	1	–0.021	–0.021	0.3	0.586	–0.013	0.0390	–0.337	0.736
	2	–0.008	–0.009	0.3	0.844	–0.011	0.0390	–0.287	0.775
	3	0.022	0.022	0.7	0.880	0.024	0.0390	0.609	0.543
	4	–0.009	-0.008	0.7	0.948	–0.011	0.0390	–0.257	0.797
	5	–0.029	–0.029	1.3	0.936	–0.029	0.0390	–0.743	0.458
AAA_t	1	0.997	0.997	660.4	**0.000**	**0.010**	0.0004	26.065	**0.000**
	2	0.993	–0.003	1317.1	**0.000**	0.000	0.0006	0.740	0.460
	3	0.990	0.073	1970.9	**0.000**	**–0.001**	0.0006	–1.801	**0.072**
	4	0.987	–0.079	2621.0	**0.000**	–0.001	0.0006	–1.167	0.244
	5	0.983	–0.042	3267.1	**0.000**	**0.001**	0.0004	2.542	**0.011**
$\Delta\ Log\ AAA_t$	1	–0.038	–0.038	0.9	0.322	–0.039	0.0392	–0.989	0.323
	2	–0.089	–0.090	6.2	**0.044**	**–0.075**	0.0389	–1.916	**0.056**
	3	0.096	0.089	12.4	**0.006**	**0.090**	0.0389	2.319	**0.021**
	4	0.101	0.102	19.2	**0.001**	**0.101**	0.0390	2.580	**0.010**
	5	–0.058	–0.035	21.4	**0.001**	–0.035	0.0392	–0.886	0.376

Table 4
Autocorrelation coefficients (up to lag 10) of residuals from OLS cointegrating regressions

Lag	Dependent var.	Model I	Model II	Model III	Model IV
1	*ST CDX Spread*	0.932	0.925	0.928	0.919
	AAA Bond Index Spread	0.874	0.872	0.925	0.897
2	*ST CDX Spread*	0.876	0.866	0.863	0.853
	AAA Bond Index Spread	0.784	0.778	0.857	0.813
3	*ST CDX Spread*	0.812	0.799	0.79	0.781
	AAA Bond Index Spread	0.733	0.723	0.818	0.768
4	*ST CDX Spread*	0.746	0.732	0.72	0.71
	AAA Bond Index Spread	0.669	0.657	0.771	0.711
5	*ST CDX Spread*	0.693	0.677	0.663	0.652
	AAA Bond Index Spread	0.634	0.617	0.728	0.66
6	*ST CDX Spread*	0.639	0.623	0.605	0.594
	AAA Bond Index Spread	0.601	0.583	0.695	0.626
7	*ST CDX Spread*	0.587	0.569	0.549	0.537
	AAA Bond Index Spread	0.56	0.544	0.663	0.593
8	*ST CDX Spread*	**0.523**	**0.503**	**0.485**	**0.471**
	AAA Bond Index Spread	**0.525**	**0.508**	0.617	**0.519**
9	*ST CDX Spread*	0.464	0.444	0.429	0.414
	AAA Bond Index Spread	0.49	0.477	0.585	0.549
10	*ST CDX Spread*	0.405	0.384	0.368	0.352
	AAA Bond Index Spread	0.467	0.455	**0.551**	0.488

Table 5

Unit root tests on Moody's AAA Bond Index spread, CDX.NA.IG Index Senior Tranche spread, and all explanatory variables

(In Panel A the classic Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests are performed. For all ADF and PP test-equations a constant is included, but no trend. *** and ** indicate respectively 1% and 5% significance level in rejecting the unit root hypothesis. MacKinnon (2010) critical values are used. The appropriate lag lengths are chosen according to Schwartz criterion.

In Panel B the Zivot–Andrews (1992) unit root tests in presence of endogenous structural breaks in the ADF equation are performed as robustness check for all variables for which ADF and PP tests cannot reject the unit root hypothesis (in levels). ** indicate 5% significance level in rejecting the unit root hypothesis. Zivot–Andrews (1992) critical values are used. The appropriate lag lengths are chosen according to Schwartz criterion.)

Panel A: Augmented Dickey–Fuller Tests and Philips–Perron tests of unit roots

Variables	ADF Test		PP Test	
	Levels	1st differences	Levels	1st differences
S&P100 Cum.Ret.	0.09	-14.87^{***}	–0.06	-31.74^{***}
Treasury Yield	–0.88	-27.29^{***}	–0.73	-27.22^{***}
TS Slope	–0.26	-24.28^{***}	–0.28	-24.25^{***}
VXO	–1.66	-15.96^{***}	–2.1	-33.0^{***}
S&P100 Impl.Vol.Slope	–2.56	-26.47^{***}	-3.02^{**}	-58.57^{***}
ST CDX Spread	–1.77	-25.03^{***}	–1.77	-25.03^{***}
AAA Bond Index Spread	–0.95	-13.92^{***}	–0.99	-25.2^{***}
Comm. Paper Spread	-3.64^{***}		-4.10^{***}	
ST CDX Bid–Ask Spread	-3.59^{***}		-5.58^{***}	
Five-year Swap Spread	–1.68	-18.81^{***}	-3.40^{**}	-61.95^{***}
Put–Call Ratio	-7.65^{***}		-16.27^{***}	
Diff Impl.-GARCH Vol.	-9.60^{***}		-10.07^{***}	

Panel B: Zivot–Andrews robustness tests of unit roots (with unknown structural breaks)

	Levels
S&P100 Cum.Ret.	–2.79
Treasury Yield	–4.38
TS Slope	-5.02^{**}
VXO	–0.98
S&P100 Impl.Vol.Slope	–0.88
ST CDX Spread	–1.54
AAA Bond Index Spread	–2.18

Table 6

OLS cointegrating regression estimates

(All variables are measured in percentage units; daily frequency; period: 20 Sept 2006 to 20 May 2009; obs. 661)

Model specifications:

Model I:

$Credit\ Spread_t = \alpha_1 + \alpha_2\ S\&P100\ Cum.Ret._t + \alpha_3\ Treasury\ Yield_t + \alpha_4\ TS\ Slope_t + \alpha_5\ VXO_t + u_t$

Model II:

$Credit\ Spread_t = \alpha_1 + \alpha_2\ S\&P100\ Cum.Ret._t + \alpha_3\ Treasury\ Yield_t + \alpha_4\ TS\ Slope_t + \alpha_5\ VXO_t + \alpha_6\ S\&P100\ Impl.Vol.\ Slope_t + u_t$

Model III:

$Credit\ Spread_t = \alpha_1 + \alpha_2\ S\&P100\ Cum.Ret._t + \alpha_3\ Treasury\ Yield_t + \alpha_4\ TS\ Slope_t + \alpha_5\ S\&P100\ Hist.\ Vol_t + u_t$

Model IV:

$Credit\ Spread_t = \alpha_1 + \alpha_2\ S\&P100\ Cum.Ret._t + \alpha_3\ Treasury\ Yield_t + \alpha_4\ TS\ Slope_t + \alpha_5\ S\&P100\ Hist.\ Vol._t + \alpha_6\ S\&P100\ Impl.Vol.\ Slope_t + u_t$

Explanatory variables	*Constant*	*S&P100 Cum.Ret.*	*Treasury Yield*	*TS Slope*	*VXO*	*S&P100 Hist.Vol.*	*S&P100 Impl.Vol. Slope*
Dependent variables							
			Model I				
ST CDX Spread	0.863	–0.003	–0.178	0.095	0.007		
AAA Bond Index Spread	0.973	–0.002	–0.124	0.052	0.014		
			Model II				
ST CDX Spread	1.052	–0.004	–0.162	0.087	0.005		–0.011
AAA Bond Index Spread	1.105	–0.002	–0.113	0.046	0.012		–0.007
			Model III				
ST CDX Spread	0.886	–0.004	–0.171	0.108		0.004	
AAA Bond Index Spread	0.950	–0.002	–0.104	0.075		0.010	
			Model IV				
ST CDX Spread	1.104	–0.004	–0.152	0.093		0.003	–0.013
AAA Bond Index Spread	1.122	–0.002	–0.089	0.062		0.009	–0.010

Table 7

Cointegration tests: unit root tests on residuals from cointegrating regressions

Model specifications:

Model I:

$Credit\ Spread_t = \alpha_1 + \alpha_2\ S\&P100\ Cum.Ret._t + \alpha_3\ Treasury\ Yield_t + \alpha_4\ TS\ Slope_t + \alpha_5\ VXO_t + u_t$

Model II:

$Credit\ Spread_t = \alpha_1 + \alpha_2\ S\&P100\ Cum.Ret._t + \alpha_3\ Treasury\ Yield_t + \alpha_4\ TS\ Slope_t + \alpha_5\ VXO_t + \alpha_6\ S\&P100\ Impl.Vol.\ Slope_t + u_t$

Model III:

$Credit\ Spread_t = \alpha_1 + \alpha_2\ S\&P100\ Cum.Ret._t + \alpha_3\ Treasury\ Yield_t + \alpha_4\ TS\ Slope_t + \alpha_5\ S\&P100\ Hist.\ Vol_t + u_t$

Model IV:

$Credit\ Spread_t = \alpha_1 + \alpha_2\ S\&P100\ Cum.Ret._t + \alpha_3\ Treasury\ Yield_t + \alpha_4\ TS\ Slope_t + \alpha_5\ S\&P100\ Hist.\ Vol._t + \alpha_6\ S\&P100\ Impl.Vol.\ Slope_t + u_t$

MacKinnon (2010) critical values used for Engle–Granger ADF tests on residuals from cointegrating regression (T=661; no-trend, only constant):

With 5 var. in cointegration: –4.99 (at 1% sign. level ***); –4.44 (at 5% sign. level **); –4.15 (at 10% sign. level *);

With 6 var. in cointegration: –5.28 (at 1% sign. level ***); –4.73 (at 5% sign. level **); –4.44 (at 10% sign. level *).

Gregory and Hansen (1996) critical values for modified ADF tests on residuals from cointegrating regression with structural breaks (T=661; no-trend, only constant):

With 5 var. in cointegration and level shift (i.e. endogenous unknown structural break only in the intercept of the equation): –6.05 (at 1% Sign.Level ***); –5.80 (at 2.5% sign. level †); –5.56 (at 5% sign. level **); –5.31 (at 10% sign. level *)

With 5 var. in cointegration and regime shift (i.e. endogenous unknown structural breaks in all coefficients of the equation): –6.92 (at 1% sign. level ***); –6.64 (at 2.5% sign. level †); –6.41 (at 5% sign. level **); –6.17 (at 10% sign. level *).

Panel A: Engle and Granger (1989) ADF tests on residuals		
Model specification	Dependent variables	t-stat ADF for residuals
I	*ST CDX Spread*	–4.46**
I	*AAA Bond Index Spread*	–4.99**
II	*ST CDX Spread*	–4.72**
II	*AAA Bond Index Spread*	–5.13**
III	*ST CDX Spread*	–4.51**
III	*AAA Bond Index Spread*	–4.10
IV	*ST CDX Spread*	–4.90**
IV	*AAA Bond Index Spread*	–4.58**
Panel B: Gregory and Hansen (1996) modified ADF Tests on residuals		
Model specification	Dependent variables	t-stat ADF for residuals
I	*ST CDX Spread*:	
I	Level shift	–5.97†
I	Regime shift	–6.70**
I	*AAA Bond Index Spread*:	
I	Level shift	–7.43***
I	Regime shift	–7.94***
III	*ST CDX Spread*:	
III	Level shift	–5.86†
III	Regime shift	–6.56**
III	*AAA Bond Index Spread*:	
III	Level shift	–4.89
III	Regime shift	–5.25

Table 8

Estimation of error correction models for Moody's AAA Bond Index spread and CDX.NA.IG Index Senior Tranche spread

Sample: 9/22/2006 – 5/20/2009; Obs. 656; White heteroskedasticity-consistent standard errors in parenthesis; ***, **, and * indicate respectively 1%, 5%, and 10% confidence level; All variables are measured in percentage units. Procedure for estimation of the parsimonious ECM: 1) Introduction of a number a lags p for changes in variables which are enough to make the residuals serially uncorrelated; 2) Exclusion insignificant variables; 3) Re-estimation.

Dependent variable	Δ *Log ST CDX Spread*			Δ *Log AAA Bond Index Spread*		
Explanatory variables	Model I	Model II	Model IV	Model I	Model II	Model IV
Δ *Log ST CDX Spread (Lag 1)*	–0.06	–0.06	–0.06			
	(0.06)	(0.06)	(0.06)			
Δ *Log AAA Bond Index Spread (Lag 1)*				–0.05	–0.08*	–0.08*
				(0.04)	(0.04)	(0.04)
Δ *Log AAA Bond Index Spread (Lag 2)*				–0.08*	–0.08*	–0.11**
				(0.05)	(0.05)	(0.05)
Δ *Log AAA Bond Index Spread (Lag 3)*					0.06	
					(0.04)	
Δ *Log AAA Bond Index Spread (Lag 4)*					0.11**	
					(0.05)	
Δ *S&P100 Cum. Ret.*	–0.36		–0.73***	–0.18**	–0.14**	–0.13*
	(0.23)		(0.19)	(0.07)	(0.07)	(0.06)
Δ *S&P100 Cum. Ret. (Lag 1)*			–0.29	–0.10*	–0.12**	–0.14**
			(0.21)	(0.06)	(0.06)	(0.06)
Δ *S&P100 Cum. Ret. (Lag 2)*		–0.39**	–0.29	–0.10*	0.13**	–0.13**
		(0.17)	(0.18)	(0.06)	(0.06)	(0.06)
Δ *S&P100 Cum. Ret. (Lag 3)*					–0.13**	–0.15***
					(0.06)	(0.05)
Δ *Treasury Yield*	–21.65***	–21.63***	–23.18***	–6.51***	–6.65***	–6.52***
	(4.95)	(4.81)	(4.95)	(1.3)	(1.23)	(1.26)
Δ *Treasury Yield (Lag 1)*	–17.40***	–16.75***	–15.39***			
	(5.3)	(5.25)	(5.56)			
Δ *TS Slope*	8.66	8.38	11.79**	5.71***	5.18***	5.06***
	(5.61)	(5.55)	(5.51)	(1.91)	(1.89)	(1.9)
Δ *TS Slope (Lag 1)*					2.46	2.76*
					(1.59)	(1.56)
Δ *VXO*	0.47***	0.58***				
	(0.18)	(0.14)				
Δ *VXO (Lag 1)*	0.49***	0.53***				
	(0.14)	(0.14)				
Δ *S&P100 Hist. Vol.*						0.15**
						(0.07)
Δ *S&P100 Hist. Vol. (Lag 1)*			0.39*			0.04
			(0.22)			(0.12)
Δ *S&P100 Hist. Vol. (Lag 2)*						0.14**
						(0.08)
Δ *S&P100 Impl. Vol. Slope (Lag 1)*		–0.87***	–0.90***			
		(0.27)	(0.27)			
Error Correction Term	–6.81**	–6.52**	–6.32**	–3.58***	–3.75***	–4.31***
	(2.87)	(2.78)	(2.83)	(1.21)	(1.32)	(1.58)
$Adj-R^2$	13.1%	14.7%	12.8%	12.2%	15.5%	14.9%

Table 9

Estimation of augmented ECMs for Moody's AAA Bond Index spread and CDX.NA.IG Index Senior Tranche spread with liquidity variables

Sample: 9/22/2006 – 5/20/2009; obs. 656; White heteroskedasticity-consistent standard errors in parenthesis; ***, **, and * indicate resp. 1%, 5%, and 10% confidence level; all variables are measured in percentage units.
Procedure for estimation of the parsimonious ECM: 1) Introduction of a number a lags p for changes in variables which are enough to make the residuals serially uncorrelated; 2) Exclusion insignificant variables; 3) Re-estimation.

Dependent variable	Δ *Log ST CDX Spread*			Δ *Log AAA Bond Index Spread*		
Changes in state variables - estimated coefficients and std. errors						
Explanatory variables	Model I	Model II	Model IV	Model I	Model II	Model IV
Δ *Log ST CDX Spread (Lag 1)*	–0.06	–0.06	–0.06			
	(0.06)	(0.06)	(0.06)			
Δ *Log AAA Bond Index Spread (Lag 1)*				–0.05	–0.07*	–0.08**
				(0.04)	(0.04)	(0.04)
Δ *Log AAA Bond Index Spread (Lag 2)*				–0.08*	–0.08	–0.11**
				(0.05)	(0.05)	(0.05)
Δ *Log AAA Bond Index Spread (Lag 3)*					0.06	
					(0.04)	
Δ *Log AAA Bond Index Spread (Lag 4)*					0.11**	
					(0.05)	
Δ *S&P100 Cum. Ret.*	–0.24		–0.28	–0.18**	–0.15**	–0.15*
	–0.25		(0.22)	(0.07)	(0.07)	(0.09)
Δ *S&P100 Cum. Ret. (Lag 1)*			–0.04	–0.10*	–0.12**	–0.13**
			(0.23)	(0.06)	(0.06)	(0.05)
Δ *S&P100 Cum. Ret. (Lag 2)*		–0.42**	–0.34**	–0.09	–0.13**	–0.13**
		(0.18)	(0.17)	(0.06)	(0.07)	(0.06)
Δ *S&P100 Cum. Ret. (Lag 3)*					–0.14**	–0.15***
					(0.06)	(0.05)
Δ *Treasury Yield*	–16.01***	–16.24***	–18.58***	–6.12***	–6.14***	–6.30***
	(4.79)	(4.73)	(5.11)	(1.39)	(1.32)	(1.36)
Δ *Treasury Yield (Lag 1)*	–18.26***	–17.31***	–16.42***			
	(5.06)	(5.02)	(5.42)			
Δ *TS Slope*	4.6	4.57	9.16*	5.42***	4.84**	4.97***
	(5.6)	(5.56)	(5.39)	(1.91)	(1.88)	(1.81)
Δ *TS Slope (Lag 1)*					2.55	2.67*
					(1.61)	(1.56)
Δ *VXO*	0.45**	0.51***				
	(0.18)	(0.14)				
Δ *VXO (Lag 1)*	0.49***	0.54***				
	(0.14)	(0.15)				
Δ *S&P100 Hist. Vol.*						0.15**
						(0.07)
Δ *S&P100 Hist. Vol. (Lag 1)*			0.70***			0.04
			(0.25)			(0.13)
Δ *S&P100 Hist. Vol. (Lag 2)*						0.14*
						(0.08)
Δ *S&P100 Impl. Vol. Slope (Lag 1)*		–0.77***	–0.79***			
		(0.26)	(0.26)			
Error Correction Term	–6.64**	–6.22**	–6.22**	–3.56***	–3.76***	–4.27***
	(2.85)	(2.76)	(2.8)	(1.21)	(1.32)	(1.57)
Changes in liquidity and investor sentiment - estimated coefficients and std. errors						
Δ *Comm. Paper Spread*	5.94**	5.06**	5.05*	0.48	0.24	0.29
	(2.64)	(2.72)	(2.73)	(0.67)	(0.63)	(0.61)
Δ *Log ST CDX Bid–Ask Spread*	0.06***	0.06***	0.06***			
	(0.02)	(0.02)	(0.02)			
Δ *five-year Swap Spread*				0.31	0.59	0.63
				(1.7)	(1.67)	(1.71)
Δ *Put–Call Ratio*	0.10***	0.11***		0.004	0.006	
	(0.03)	(0.03)		(0.008)	(0.007)	
Δ *Put–Call Ratio (Lag 1)*	0.07**	0.08**				
	(0.03)	(0.03)				
Δ $Diff\ Impl. - GARCH\ Vol.$			0.40***			0.02
			(0.15)			(0.05)
Δ $Diff\ Impl. - GARCH\ Vol.$ *(Lag 1)*			0.43***			
			(0.15)			
$Adj - R^2$	17%	18%	17%	12%	15%	15%

Table 10

Economic significance (standard deviation impact) of explanatory variables in the ECMs for Moody's AAA Bond Index spread and CDX.NA.IG Index Senior Tranche spread

(The economic significance is measured as the impact of one standard deviation change in the explanatory variable on the dependent variable. The impact is expressed as a fraction of the standard deviation in the dependent variable.)

Dependent variable	Δ *Log ST CDX Spread*			Δ *Log AAA Bond Ind. Spread*		
Explanatory variables	Model I	Model II	Model IV	Model I	Model II	Model IV
Δ *Log ST CDX Spread* (*Lag* 1)	–0.060	–0.060	–0.060			
Δ *Log AAA Bond Ind. Spread* (*Lag* 1)				–0.013	–0.018	–0.020
Δ *Log AAA Bond Ind. Spread* (*Lag* 2)				–0.020	–0.020	–0.028
Δ *Log AAA Bond Ind. Spread* (*Lag* 3)					0.015	
Δ *Log AAA Bond Ind. Spread* (*Lag* 4)					0.028	
Δ *S&P*100 *Cum. Ret.*	–0.049		–0.057	–0.037	–0.031	–0.031
Δ *S&P*100 *Cum. Ret.* (*Lag* 1)			0.0001	–0.0002	–0.0002	–0.0003
Δ *S&P*100 *Cum. Ret.* (*Lag* 2)		–0.001	–0.0008	–0.0001	–0.0003	–0.0003
Δ *S&P*100 *Cum. Ret.* (*Lag* 3)					–0.0003	–0.0003
Δ *Treasury Yield*	–0.001	–0.001	–0.001	–0.001	–0.001	–0.001
Δ *Treasury Yield* (*Lag* 1)	–0.002	–0.001	–0.001			
Δ *TS Slope*	0.028	0.028	0.056	0.033	0.029	0.03
Δ *TS Slope* (*Lag* 1)					0.015	0.016
Δ *VXO*	0.128	0.145				
Δ *VXO* (*Lag* 1)	0.139	0.153				
Δ *S&P*100 *Hist. Vol.*						0.021
Δ *S&P*100 *Hist. Vol.* (*Lag* 1)			0.129			0.006
Δ *S&P*100 *Hist. Vol.* (*Lag* 2)						0.020
Δ *S&P*100 *Impl. Vol. Slope* (*Lag* 1)		–0.113	–0.099			
Error Correction Term	–0.108	–0.100	–0.116	–0.035	–0.036	–0.033
Δ *Comm. Paper Spread*	0.096	0.081	0.081	0.008	0.004	0.005
Δ *Log ST CDX Bid–Ask Spread*	0.138	0.138	0.138			
Δ *five-year Swap Spread*				0.002	0.005	0.005
Δ *Put–Call Ratio*	0.116	0.127		0.005	0.007	
Δ *Put–Call Ratio (Lag 1)*	0.081	0.093				
Δ *Diff Impl.* – *GARCH Vol.*			0.127			0.006
Δ *Diff Impl.* – *GARCH Vol.* (*Lag* 1)			0.137			

Table 11

Estimation of error correction models for CDX.NA.IG Index Senior Tranche spread over the pre-crisis and crisis sub-periods: results for liquidity and market sentiment proxies only

(Sample: Pre-crisis 22/09/2006 – 20/07/2007, Middle crisis 21/07/2007 – 20/05/2008, All crisis 21/07/2007 – 20/05/2009; White heteroskedasticity-consistent standard errors in parenthesis; ***, **, and * indicate respectively 1%, 5%, and 10% confidence level; all variables measured in percentage units.)

Dependent variable: Δ *Log ST CDX Spread*									
	Model I			Model II			Model IV		
Explanatory variables	Pre-crisis	Middle crisis	All crisis	Pre-crisis	Middle crisis	All crisis	Pre-crisis	Middle crisis	All crisis
Δ *Comm. Paper Spread*	–2.87	4.04	6.56**	–4.67	3.02	5.60**	–7.02	0.70	5.63**
	(7.63)	(4.06)	(2.79)	(7.59)	(4.12)	(2.9)	(7.07)	(4.61)	(2.94)
Δ *Log ST CDX Bid–Ask Spread*	0.03	0.11***	0.06**	0.03	0.12***	0.07**	0.03	0.12***	0.07***
	(0.02)	(0.04)	(0.03)	(0.02)	(0.04)	(0.03)	(0.02)	(0.05)	(0.03)
Δ *Put–Call Ratio*	0.07	0.13	0.10**	0.08	0.14	0.10**			
	(0.05)	(0.08)	(0.04)	(0.05)	(0.08)	(0.04)			
Δ *Put–Call Ratio(Lag 1)*	–0.005	0.03	0.08**	–0.01	0.04	0.07**			
	(0.06)	(0.07)	(0.04)	(0.07)	(0.07)	(0.04)			
Δ $Diff\ Impl. - GARCH\ Vol.$							1.07**	0.57	0.37**
							(0.47)	(0.48)	(0.17)
Δ $Diff\ Impl. - GARCH\ Vol.\ (Lag\ 1)$							1.29**	1.24*	0.31*
							(0.63)	(0.6)	(0.16)
$Adj - R^2$	9%	25%	21%	8%	26%	23%	6%	26%	22%

Table 12

Impact of one standard deviation change in liquidity and market sentiment proxies on changes in the log CDX.NA.IG Index Senior Tranche spread (ECM Model II) over the pre-crisis and crisis sub-samples

(The impact is expressed as a fraction of the standard deviation in the dependent variable; ***, **, and * indicate respectively 1%, 5%, and 10% significance level;
Pre-crisis: 20 Sept 2006 – 20 July 2007, Middle crisis: 21 July 2007 – 20 May 2008, All crisis: 21 July 2007 – 20 May 2009.)

Panel A				
	All sample	Pre-crisis	Middle crisis	All crisis
Δ *Put–Call Ratio*	0.127 ***	0.076	0.142 *	0.120 ***
Δ *Put–Call Ratio(Lag 1)*	0.090 **	-0.013	0.044	0.091 ***
Δ *Comm. Paper Spread*	0.081 **	–0.032	0.051	0.104 ***
Δ *Log ST CDX Bid–Ask Spread*	0.131 ***	0.071	0.228 ***	0.150 ***
Panel B (with expected and unexpected changes in market liquidity)				
	All sample	Pre-crisis	Middle crisis	All crisis
Δ *Put–Call Ratio*	0.129 ***	0.079	0.137 *	0.119 **
Δ *Put–Call Ratio(Lag 1)*	0.088 **	–0.038	0.044	0.090 *
Δ *Comm. Paper Spread*	0.085 **	–0.034	0.045	0.105 **
Δ *Log ST CDX Bid–Ask Spread (expected comp.)*	0.098 ***	0.048	0.161 **	0.053 **
Δ *Log ST CDX Bid–Ask Spread (shock)*	0.110 ***	0.097	0.182 ***	0.236 ***

Table 13

Net impact of one standard deviation change in explanatory variables (grouped in 5 blocks) on changes in the log CDX.NA.IG Index Senior Tranche spread (ECM Model II) over the pre-crisis and crisis sub-samples

(The impact is expressed as a fraction of the standard deviation of the dependent variable. The five blocks are: Adjustment factor - including the error correction term and lagged changes in the log ST CDX spread; Equity factor - including current and lagged changes in the equity index value, current and lagged changes in the VXO index and in the slope of S&P 100 implied volatility; Interest rate process factor - including current and lagged changes in the level and slope of the term structure of Treasury yields; Market sentiment factor - including current and lagged changes in the put–call ratio; and Liquidity factor - including changes in the commercial paper spread and in the log ST CDX bid–ask spread;
Pre-crisis: 20 Sept 2006 – 20 July 2007, Middle crisis: 21 July 2007 – 20 May 2008, All crisis: 21 July 2007 – 20th May 2009.).

	All sample	Pre-crisis	Middle crisis	All crisis
Adjustment factor	–0.1599	0.1910	–0.2219	–0.1551
Equity factor	0.0997	0.2553	0.1267	0.0560
Interest rate factor	–0.2523	0.1262	–0.3259	–0.2991
Liquidity factor	0.2122	0.0400	0.2794	0.2539
Market Sentiment Factor	0.2176	0.0627	0.1856	0.2110

Table 14

Adjusted R^2s of five block-wise regressions for changes in the log CDX.NA.IG Index Senior Tranche spread (ECM Model II) and for changes in the log Moody's AAA Bond Index spread (ECM Model IV) over the pre-crisis and crisis sub-samples

(The five blocks are: Adjustment factor - including the error correction term and lagged changes in the log ST CDX spread (or AAA Bond Index spread); Equity factor - including current and lagged changes in the equity index value, current and lagged changes in the VXO index and in slope of the S&P 100 implied volatility; Interest rate process factor - including current and lagged changes in the level and slope of the term structure of Treasury yields; Market sentiment factor - including current and lagged changes in the put–call ratio; and Liquidity factor - including changes in the commercial paper spread and in the log ST CDX bid–ask spread (or five-year swap spread).
Pre-crisis: 20 Sept 2006 – 20 July 2007, Middle crisis: 21 July 2007 – 20 May 2008, All crisis: 21 July 2007 – 20 May 2009.)

	Δ *Log ST CDX Spread*			Δ *Log AAA Bond Ind. Spread*		
	Pre-crisis	Middle crisis	All crisis	Pre-crisis	Middle crisis	All crisis
Adjustment factor	0.46%	2.62%	2.34%	5.45%	6.31%	1.18%
Equity factor	2.39%	9.17%	9.60%	2.86%	3.22%	2.74%
Interest rate factor	1.05%	12.57%	9.98%	3.08%	7.21%	7.76%
Liquidity factor	0.14%	5.15%	4.74%	0.31%	6.48%	2.43%
Market sentiment factor	0.88%	6.09%	5.96%	0.92%	0.44%	0.13%

Table 15

Correlation between observed changes in the log CDX.NA.IG Index Senior Tranche spread and changes predicted by the pre-crisis Models I, II, and IV

(Sample: February 2007 – December 2009; 4 different sub-samples are also considered. Correlations are computed on the changes at daily frequency.)

	Corr (Δ *Log ST CDX Spread*, Δ *Log ST CDX Spread from pre-crisis Model I*)
Feb 2007 – May 2009	27.70%
Feb 2007 – July 2007	21.40%
July 2007 – Dec 2007	36.71%
Dec 2007 – May 2008	42.48%
May 2008 – Dec 2009	30.39%

	Corr (Δ *Log ST CDX Spread*, Δ *Log ST CDX Spread from pre-crisis Model II*)
Feb 2007 – May 2009	26.81%
Feb 2007 – July 2007	20.37%
July 2007 – Dec 2007	35.54%
Dec 2007 – May 2008	42.48%
May 2008 – Dec 2009	31.86%

	Corr (Δ *Log ST CDX Spread*, Δ *Log ST CDX Spread from pre-crisis Model IV*)
Feb 2007 – May 2009	28.15%
Feb 2007 – Jul 2007	21.75%
July 2007 – Dec 2007	36.69%
Dec 2007 – May 2008	42.51%
May 2008 – Dec 2009	33.61%

Table 16

Estimation of atypical error correction Model II for CDX.NA.IG Index Senior Tranche spread over the crisis Period, using lagged values of pre-crisis model forecast errors as correction term

(Sample: 20/02/2007 - 20/05/2009; White heteroskedasticity-consistent standard errors in parenthesis; ***, **, and * indicate respectively 1%, 5%, and 10% confidence level; all variables are measured in percentage units.)

	ECM without frictional variables	ECM with frictional variables
Dependent variables	Δ *Log ST CDX Spread*	Δ *Log ST CDX Spread*
Explanatory variables		
Δ *Log ST CDX Spread (Lag 1)*	–0.06 (0.06)	–0.06 (0.06)
Δ *S&P100 Cum. Ret. (Lag 2)*	–0.41** (0.16)	–0.43** (0.18)
Δ *TS Slope*	–21.30*** (5.03)	–15.30*** (4.92)
Δ *TS Slope (Lag 1)*	–16.94*** (6.04)	–17.36*** (5.25)
Δ *TS Slope (Lag 2)*	10.19* (5.81)	5.82 (6.02)
Δ *VXO*	0.59*** (0.12)	0.52*** (0.14)
Δ *VXO (Lag 1)*	0.55*** (0.16)	0.55*** (0.15)
Δ *S&P100 Impl.Vol. Slope (Lag 1)*	–1.09*** (0.39)	–0.95*** (0.36)
Forecast error (Lag 1)	–0.68 (0.53)	–0.54 (0.54)
Δ *Comm. Paper Spread*		5.03** (2.76)
Δ *Log ST CDX Bid–Ask Spread*		0.07** (0.02)
Δ *Put–Call Ratio*		0.12*** (0.04)
Δ *Put–Call Ratio(Lag 1)*		0.08*** (0.04)
$Adj - R^2$	14%	18%

Table 17

Determinants of changes in pre-crisis model forecast error

(Sample: 20/02/2007 – 20/05/2009; White heteroskedasticity-consistent standard errors in parenthesis;
***, **, and * indicate respectively 1%, 5%, and 10% confidence level; all variables are measured in percentage units.
Explanatory variables included in OLS specification (A): change in commercial paper spread, change in the log ST CDX bid–ask spread; current and lagged changes in the put–call ratio.
Explanatory variables included in OLS specification (B): change in commercial paper spread, change in the log ST CDX bid–ask spread; current and lagged changes in the difference between implied volatility (VXO index) and GARCH-estimated volatility of S&P100 Index.)

	OLS specification (A)	OLS specification (B)
Dependent variables	Δ *Log Forecast Error ST CDX Spread*	Δ *Log Forecast Error ST CDX Spread*
Explanatory variables		
Constant	0.29 (0.68)	0.31 (0.68)
Δ *Log Forecast Error ST CDX Spread* (*Lag* 1)	–0.06 (0.07)	–0.08 (0.07)
Δ *Comm. Paper Spread*	9.30** (4.54)	9.51** (4.55)
Δ *Log ST CDX Bid–Ask Spread*	0.08** (0.04)	0.08** (0.04)
Δ *Put–Call Ratio*	0.18*** (0.06)	
Δ *Put–Call Ratio(Lag 1)*	0.24*** (0.06)	
Δ $Diff\ Impl. - GARCH\ Vol.$		0.70*** (0.23)
Δ $Diff\ Impl. - GARCH\ Vol.$ (*Lag* 1)		0.70*** (0.25)
$Adj - R^2$	6%	6%

Table 18

Estimation of augmented ECMs for Moody's AAA Bond Index spread and CDX.NA.IG Index Senior Tranche spread with liquidity variables.
ECTs obtained as lagged residuals from cointegration equation (Model II) estimated with endogenous structural breaks in all coefficients

Sample: 22/09/2006 – 20/05/2009; Obs. 656; White heteroskedasticity-consistent standard errors in parenthesis; ***, **, and * indicate respectively 1%, 5%, and 10% confidence level; All variables are measured in percentage units. Procedure for estimation of the parsimonious ECM: 1) Introduction of a number a lags p for changes in variables which are enough to make the residuals serially uncorrelated; 2) Exclusion insignificant variables; 3) Re-estimation.

Dependent variable	Δ *Log ST CDX Spread*	Δ *Log AAA Bond Index Spread*
Changes in state variables - estimated coefficients and std. errors		
Explanatory variables	Model II	Model II
Δ *Log ST CDX Spread* (*Lag* 3)	–0.07* (0.004)	
Δ *Log AAA Bond Index Spread* (*Lag* 2)		–0.06 (0.04)
Δ *Log AAA Bond Index Spread* (*Lag* 3)		0.05 (0.04)
Δ *Log AAA Bond Index Spread* (*Lag* 4)		0.13*** (0.04)
Δ *S&P100 Cum. Ret.* (*Lag* 1)		–0.14** (0.06)
Δ *S&P100 Cum. Ret.* (*Lag* 2)		–0.18*** (0.05)
Δ *S&P100 Cum. Ret.* (*Lag* 3)		–0.21*** (0.05)
Δ *Treasury Yield*	–14.53*** (5.19)	–6.79*** (1.54)
Δ *Treasury Yield* (*Lag* 1)	–16.66 (4.92)	
Δ *T.S. Slope*	2.72 (6.74)	5.03*** (1.83)
Δ *VXO*	0.33** (0.15)	
Δ *VXO* (*Lag* 1)	0.37*** (0.14)	
Δ *S&P100 Impl. Vol. Slope* (*Lag* 1)	–0.73*** (0.27)	
Δ *S&P100 Impl. Vol. Slope* (*Lag* 5)		–0.17** (0.07)
Error Correction Term (ECT)	–26.69*** (4.24)	–6.31*** (1.76)
Changes in liquidity and investor sentiment - estimated coefficients and std. errors		
Δ *Comm. Paper Spread*	5.30** (2.39)	–0.004 (0.61)
Δ *Log ST CDX Bid–Ask Spread*	0.07*** (0.02)	
Δ $five - year$ *Swap Spread*		–0.24 (1.51)
Δ *Put-Call Ratio*	0.10*** (0.04)	0.007 (0.01)
Δ *Put–Call Ratio(Lag 1)*	0.06 (0.04)	
$Adj - R^2$	21%	16%