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**Working Paper**

## Implied correlations of iTraxx tranches during the financial crisis

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**Frankfurt School – Working Paper Series**

**No. 145**

**Implied Correlations of iTraxx Tranches  
during the Financial Crisis**

by Thomas Heidorn and Dennis Kahlert

June 2010



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## Abstract

Implied Base Correlations of Single-tranche CDOs on standardized Credit Indices such as the iTraxx Europe have been used in the credit derivatives market for price communication. During the financial crisis, implied correlations have been quite volatile indicating the growing fraction of systematic credit risk of STCDOs. This paper analyses the determinants of tranche implied base correlations for the period September 2006 until April 2009. It will be shown that realized asset correlations between iTraxx Europe corporates are not able to explain the extreme movements of tranche implied correlations during the financial crisis. Additionally, it will be seen that the worsening creditworthiness of market participants in the interbank market as well as growing pressure on their refinancing conditions correlated significantly with the development of implied base correlations of iTraxx tranches.

Key words: Implied Correlation, Asset Correlation, Systematic Credit Risk, Market Liquidity, Funding Liquidity

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## 1 Introduction

Before summer 2007, international credit markets were characterized by tight credit spreads, which had been the result of low refinancing costs of financial institutions preceding the crisis (BIS, 2008). In order to receive yield-pick-ups over the swap curve, investments in structured credit grew rapidly since 2004 and became the most profitable business field for arrangers, rating agencies and investors.

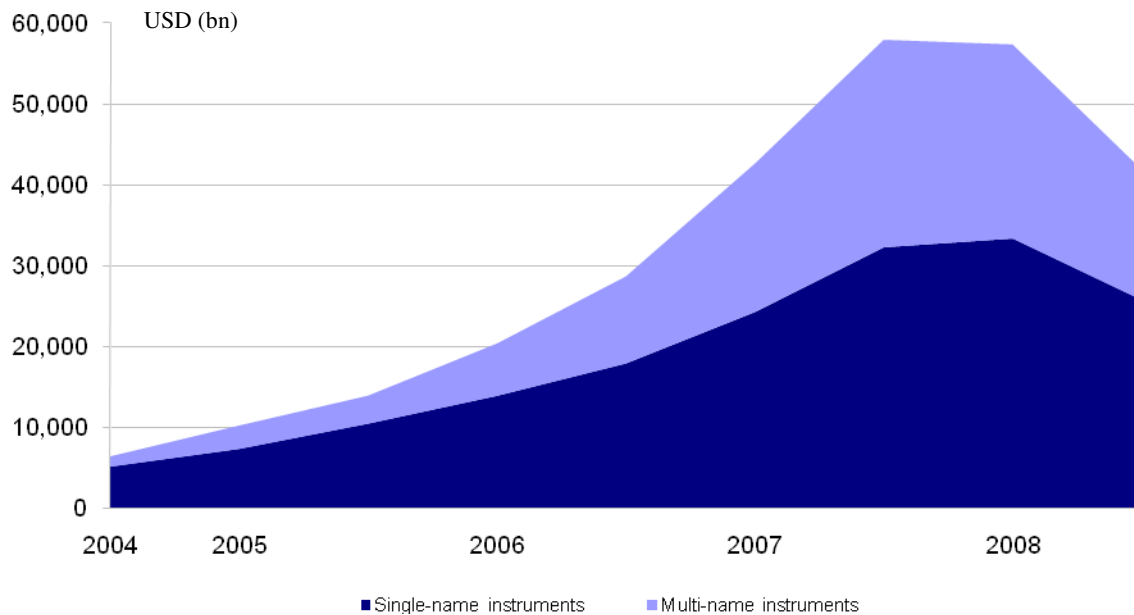


Figure 1: Outstanding Notional of Credit Default Swaps (BIS, 2009)

Since the introduction of standardized index tranches on the iTraxx Europe, the existing liquidity switched from individual structured credit exposure to active trading in the new tranche- and index-market. For selling protection in the 6-9% mezzanine-tranche in summer 2004, the market paid investors 60bp, whereas two years later the spread for identical risk exposure decreased to 20bp (Scheicher, 2008). After the outbreak of the subprime crisis in summer 2007, market participants became extremely skeptical towards any form of credit risk exposure, even if there was no direct relationship to subprime. The obvious wrong credit risk estimations of the rating agencies lead to a sudden drying-out of primary and secondary credit markets. Implied correlations of iTraxx tranches as well as their spreads reached levels which have not been observable before. The premium for credit exposure in the above mentioned mezzanine-tranche was ten times higher at the end of 2008 compared to summer 2006. At the beginning of 2009, the market for standardized credit exposure on iTraxx Europe disrupted completely. Prices for on-the-run tranches had not been quoted any more. For off-the-run tranches, prices had still been available because some market participants were forced to keep them on their books.

## 2 Data and Analysis

### 2.1 Development of Implied Correlations during the Financial Crisis

We have obtained daily quoted implied base correlations of iTraxx Europe tranches with five years to maturity from Bloomberg for the period September 2006 to April 2009. Series 6 of the iTraxx Europe, which started on September 20<sup>th</sup> 2006, is the first reference portfolio. It follows Series 7 (March 2007 - September 2007), Series 8 (September 2007 - March 2008) and Series 9 (March 2008 - September 2008). For Series 10 (September 2008 - March 2009) and 11 (March 2009 - September 2009) implied base correlations had not been quoted any more. Hence, we use implied base correlations of Series 9 for the respective period. For October 2006 only three quotes are available (10/11/2006, 10/17/2006 and 10/20/2006). For the periods 11/18/2006 - 11/28/2006, 03/21/2006 - 03/25/2006 as well as 05/05/2007 - 05/20/2007 implied base correlations had not been quoted and will therefore not be part of the database.

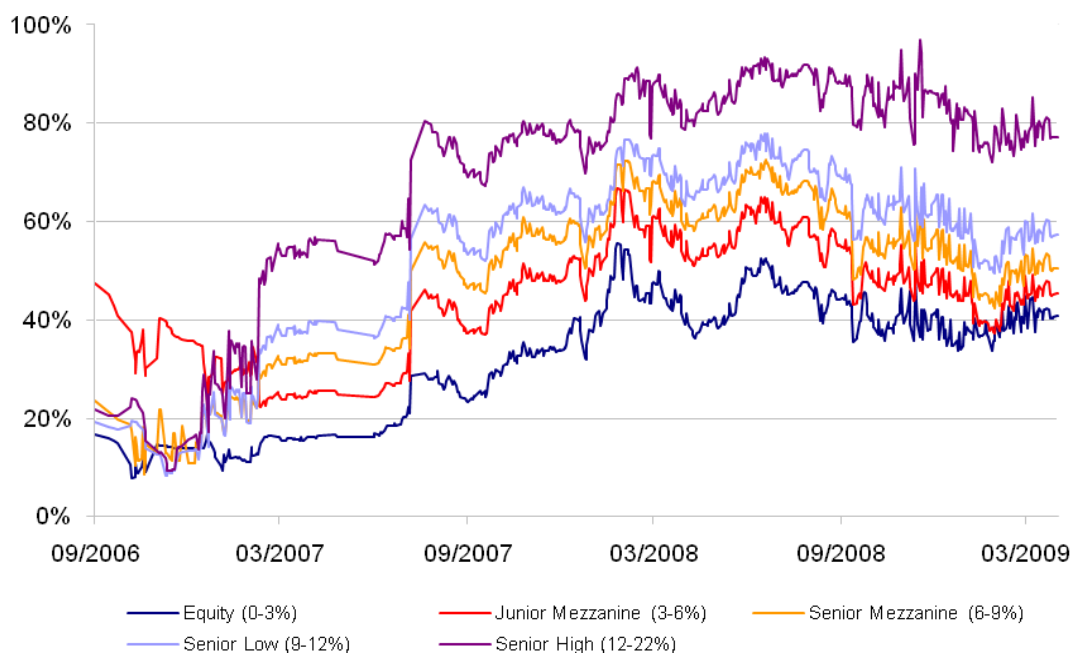


Figure 2: Implied Base Correlations during the Financial Crisis

Due to the very similar development of implied base correlations of the various tranches, the implied base correlation of the equity tranche will be in the center of our analysis. The first significant increase in implied base correlations could be observed in February 2007, when realized defaults in subprime credits became public.<sup>1</sup> Especially, implied correlations

<sup>1</sup> In February 2007, a heavy loss of the ABX.HE-Index for weak credit qualities occurred. The index is a synthetic price index (CDS-format) on 20 subprime-RMBS (Markit, 2009).

of tranches with high subordination reacted quite sensitively to the first indicators of growing systematic credit risk in the market for structured credit.

	<b>Equity</b>	<b>Junior Mezz</b>	<b>Senior Mezz</b>	<b>Senior Low</b>	<b>Senior High</b>
<b>Equity</b>	100.00%	91.22%	93.11%	91.36%	89.25%
<b>Junior Mezz</b>		100.00%	88.10%	83.48%	74.83%
<b>Senior Mezz</b>			100.00%	99.17%	95.54%
<b>Senior Low</b>				100.00%	97.83%
<b>Senior High</b>					100.00%

Table 1: Correlations of Implied Base Correlations (September 2006 - April 2009)

This level of implied base correlation was fairly stable until the outbreak of the subprime crisis in summer 2007, when implied correlations of all tranches suddenly jumped for 50% and more. Two Hedge-Funds of Bear Stearns, which were heavily invested in subprime RMBS, could not meet their margin calls in June 2007 and the bank injected 3.2bn USD. During the same month, S&P downgraded subprime-backed securities of 7.3 bn USD notional amount and when other rating agencies followed, the downward spiral began. In July 2007, the market for ABCP refinancing of SPVs became illiquid, and IKB became the first European victim of the subprime crisis when it could not provide the short-term liquidity of its conduit “Rhineland Funding”. A bailout of 3.5bn USD paid by state guaranteed and private banks had to be organized (Brunnermeier, 2009).



Figure 3: Outstanding Asset-Backed Commercial Paper (Federal Reserve Board, 2009)

From August to September 2007, implied correlations of iTraxx tranches decreased slightly. During this period massive mark-to-market losses of hedge funds, which relied on

quantitative trading strategies, took place. Fire sales driven by margin calls put pressure on international credit- and money markets and the ECB was forced to provide additional 95bn EUR (overnight-) liquidity for European interbank money markets.

The FED followed with injections of 24bn USD, reduced the discount rate by 1% to 4.75% and accepted additional securities for secured funding. On a short term basis these interventions had been effective which can be seen in the development of implied base correlations. Nevertheless, implied correlations reached a new high in October/November 2007 when Northern Rock was nationalized.

At the beginning of 2008, the markets became nervous about the worsening conditions of US-monoliners, which not only secured Agency-Bonds, but also RMBS and other structured credit products of 2.400bn USD notional amount in order to provide an AAA-rating for those securities (Brunnermeier, 2009). When Fitch downgraded the monoliner AM-BAC, international stock markets collapsed (Asia: -15%, Europe, USA and Japan: -6%) and the spreads between Agency-Bonds and US-Treasuries increased drastically. Consequently, Bear Stearns could not meet its short term refinancing in March 2008 and JP Morgan took over the bank for 236m USD (2 USD per share), which resulted in the highest level of implied correlation until then. During the following months, implied correlations normalized somewhat until summer 2008, when the implicit state guarantees for the bond insurers Fannie Mae and Freddie Mac had been converted to an explicit one. Nevertheless, their share prices dropped further and implied base correlations again increased in a market of growing systematic credit risk. Simultaneously, the equity of Lehman Brothers lost almost its complete market value and efforts to win international investors in order to strengthen Lehman's capital base failed. Money market refinancing became impossible for the bank, which had to declare bankruptcy on September 15<sup>th</sup> 2008.

Only one day later Bank of America took over Merrill Lynch and in the same week, the equity value of AIG, which was heavily invested in the CDS market, dropped by 90%. Accordingly, the Federal Reserve injected 160bn USD into the insurer's capital base. Implied correlations had been quite volatile during this period, but remained on the level which they had reached during the events in early September 2008.

At the end of the year, the pressure on international money markets further increased until global interbank markets completely collapsed. The spread between cash and derivatives markets reached an all-time high which resulted in a concerted step of western central banks (ECB, Fed, BoE, SNB and BoJ) decreasing their key interest rates by 50bp in November 2008. The first quarter of 2009 was characterized by state initiatives in order to strengthen banks' balance sheets as well as their refinancing conditions through explicit guarantees for issued debt and retail clients' deposits. Key interest rates of developed economies reached historical lows of 1% and less until the end of the relevant period (except the Euro Area: 1.25%).



	<b>Equity</b>	<b>Junior Mezz</b>	<b>Senior Mezz</b>	<b>Senior Low</b>	<b>Senior High</b>
<b>mean</b>	33.25%	45.23%	49.62%	55.01%	70.93%
<b>median</b>	37.20%	46.74%	54.35%	61.29%	78.30%
<b>maximum</b>	55.68%	66.77%	72.48%	77.91%	96.90%
<b>minimum</b>	7.88%	22.22%	8.67%	8.37%	9.26%
<b>standard deviation</b>	12.32%	11.32%	16.04%	17.64%	21.60%
<b>N</b>	591	591	591	591	591

Table 2: Descriptive Statistics of Implied Base Correlations (September 2006 - April 2009)

## 2.2 Asset Correlation and Implied Correlation

Analyzing the impact of realized asset correlations between the firms in the reference portfolio on the market implied base correlation (equity) results from the theoretical background of the HLPGC-Model, which had been widely used to quote implied correlations. Within this approach, the joint probability of hitting the default barrier is driven by the correlation of the firms asset-returns. Consequently, the question is whether or not and how realized asset correlations influenced the implied base correlation of the equity-tranche during the financial crisis.

Generally, two different approaches to calculate asset correlations can be applied. At first, the indirect method determines the asset values of all firms in the reference portfolio and then measures the correlation of their asset-returns. The direct method approximates asset correlations with stock price return correlations (Credit Metrics, 2002). This second method is justifiable, because asset- and equity correlation are identical when the time frame approaches zero (Düllmann, 2008). Moreover, equity price changes of investment-grade corporates almost exactly reflect their asset value changes. The value of debt is only influenced by the equity return if the creditworthiness of the firm is weak (Mashal et al., 2003).

Consequently, we approximate realized asset correlations between iTraxx Europe corporates with the correlations of their equity returns. Therefore, we represent every single firm's equity return with Vasicek's One-Factor-Model (Vasicek, 1987), which decomposes the return in a systematic and an idiosyncratic factor:

$$Y_i = \sqrt{\rho_i} M + \sqrt{1 - \rho_i} \varepsilon_i$$

The factor loading  $\sqrt{\rho_i}$  of the systematic risk factor can either be interpreted as the sensitivity of the equity return on the systematic-/market risk (beta) or as the square root of the asset correlation of the respective firm. The correlation with the systematic risk factor equals the square root of the firm's asset correlation, which are supposed to be pairwise identical among the names in the portfolio (Düllmann et al., 2003).

Within the market model, the EUROSTOXX Index will be defined as the relevant systematic risk factor for all debtors in the portfolio. The realized asset correlation can then be

calculated as the average of the squared correlations between every firm's equity-log-return with the market's log-return (Düllmann, 2007).<sup>2</sup>

The resulting charts in figure 4 show that realized asset correlations increase in an environment of falling equity markets. Especially, strong downturns of the EUROSTOXX at the end of 2008 were accompanied by higher asset correlations. In contrast, realized asset correlations tended to decrease in an upward moving market (March 2007 - July 2007).<sup>3</sup>



Figure 4: EUROSTOXX and Realized Asset Correlation during the Financial Crisis ( $\rho = -78.36\%$ )

Compared to market implied base correlations, realized asset correlations reacted less sensitively to the increase of systematic risk during the financial crisis. Only the dramatic events of September 2008 influenced the development of realized asset correlations between iTraxx Europe firms significantly.

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<sup>2</sup> The relevant data for the stock price returns of iTraxx Europe companies as well as for the EUROSTOXX have been obtained from Thomson Reuters.

<sup>3</sup> Negative relationships between the return of a market index and the realized asset- or equity correlation between the firms in the index can also be confirmed for longer time periods (e.g. Ang et al., 2002).

## Implied Correlations of iTraxx Tranches during the Financial Crisis

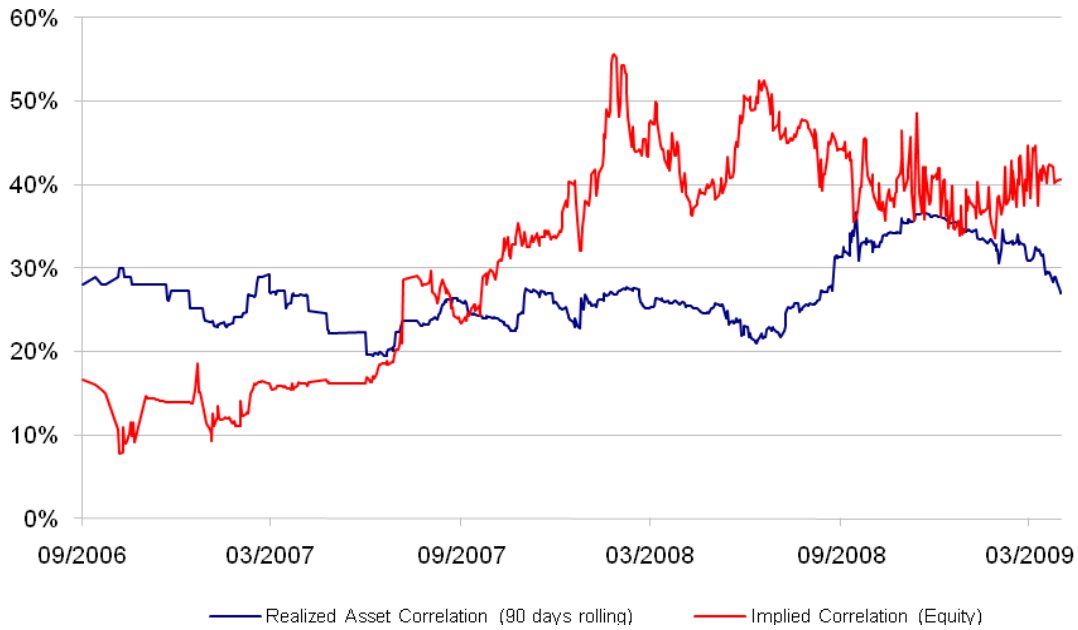


Figure 5: Realized and Implied Correlation

Since November 2007 implied correlations are considerably higher than realized correlations. We have concluded that the market demands a correlation risk premium since the start of the subprime crisis. The difference between implied- and realized correlation therefore represents the market opinion about the risk that the realized asset correlation will change in the near future. When realized correlation increases, the premium tends to decrease (e.g. end of 2008), which means that the market expects less “upward correlation risk” (Tarashev, 2008). Contrary to this, the relationship seems to be inverted in times of decreasing realized asset correlations although a clear dependency cannot be observed. In particular, the development of realized asset correlations could not explain the quoted implied base correlations during the financial crisis.

Implied Correlations of iTraxx Tranches  
during the Financial Crisis

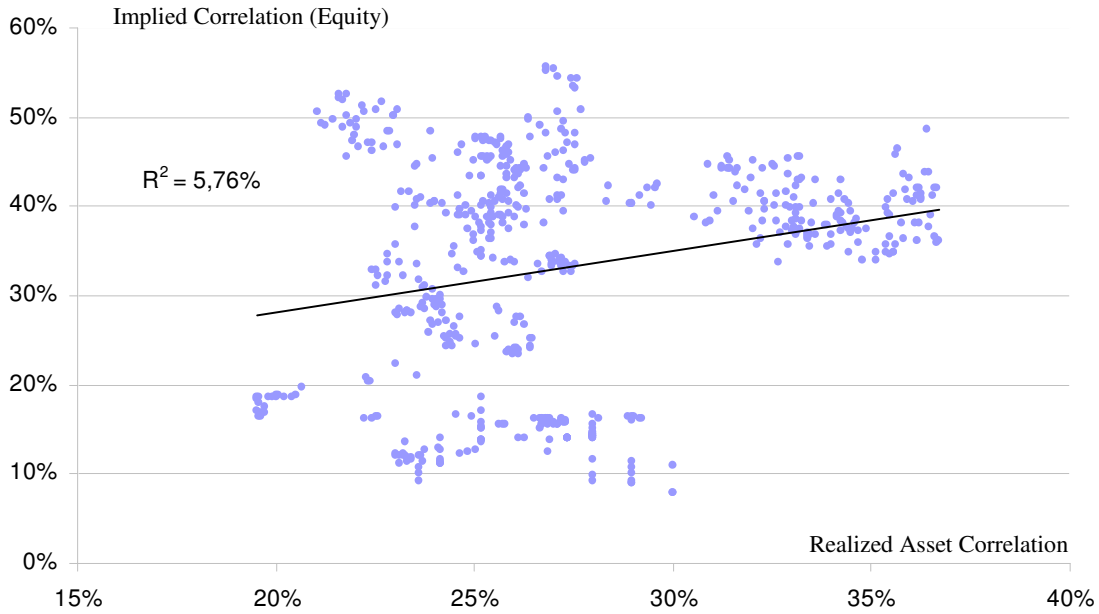


Figure 6: Realized Asset Correlation (90 days rolling) vs. Implied Correlation (Equity)  
(September 2006 - April 2009)

	<b>Euro Stoxx</b>	<b>Asset Correlation</b>	<b>Implied Correlation (Equity)</b>
<b>mean</b>	3552	27.36%	33.25%
<b>median</b>	3793	26.28%	37.20%
<b>maximum</b>	4558	36.70%	55.68%
<b>minimum</b>	1810	19.52%	7.88%
<b>standard deviation</b>	806	4.27%	12.32%
<b>N</b>	591	591	591

Table 3: Descriptive Statistics of relevant Market Parameters (September 2006 - April 2009)

	<b>EUROSTOXX</b>	<b>Asset Correlation</b>	<b>Implied Correlation (Equity)</b>
<b>EUROSTOXX</b>	100.00%	-78.36%	-55.54%
<b>Asset Correlation</b>		100.00%	24.00%
<b>Implied Correlation (Equity)</b>			100.00%

Table 4: Correlations between relevant Market Parameters (September 2006 - April 2009)

### 2.3 Risk Aversion and Implied Correlation

When the subprime crisis hit the world economy in summer 2007, a shift from idiosyncratic and sector specific components of credit risk to systematic or macroeconomic influence factors could have been observed. Before the financial crisis, CDS-Spreads were

mainly driven by idiosyncratic and sector specific issues. Based on this, the largest fraction of CDS-Spreads had been explainable (Longstaff et al., 2007).<sup>4</sup>

Since summer 2007 all three components of credit risk had increased drastically, whereas the risk of a systematic credit shock grew in a disproportionately strong way. This observation differentiated the subprime crisis from the very beginning from earlier credit crises.<sup>5</sup> Higher levels of CDS-index spreads in summer 2007 could be explained with an increase in firm specific risk of about 50%, but the fraction of macroeconomic credit problems almost tripled (Bhansali et al., 2008). Those systematic risk components are the driving force of positive default correlation and therefore especially important when analyzing implied correlations of index tranches on standardized credit indices such as the iTraxx Europe.

The fact that neither realized asset correlations nor the development of European stock markets could explain the (systematic risk sensitive) movements of implied base correlations during the financial crisis, leads to the analysis of further market parameters. It can be seen in this connection that the development of the gold price is able to explain the dynamics of the implied correlation of the equity tranche.

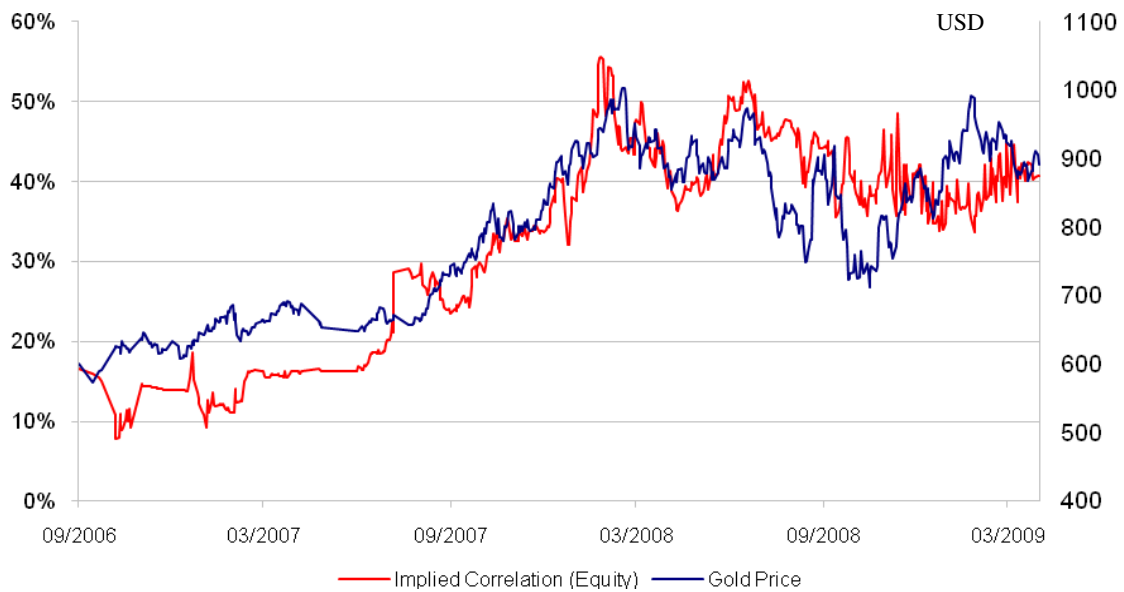


Figure 7: Gold Price and Implied Correlation during the Financial Crisis

Panic at the world's financial markets based on ongoing mark-to-market losses in fixed income securities, equities and structured products lead to an increase in the gold price from summer 2007 until the end of the relevant period. Investments and hectic regrouping

<sup>4</sup> Using a three-factor-model, Longstaff and Rajan could explain the spread of US CDX-Index with firm specific components (65%), sector specific risks (27%) and macroeconomic risk factors (8%) for the period October 2003 - October 2005.

<sup>5</sup> The downgrades of Ford and General Motors to non investment grade in May 2005 lead to a repricing of idiosyncratic and sector specific risk components in international credit markets. Premiums for exposure on systematic credit risk only increased slightly.

of financial assets into gold from large groups of financial market participants as well as private investors have made the gold price a surprisingly exact indicator of the level of risk aversion and anxiety due to growing macro risk. The specific characteristics of gold, in particular its high level of liquidity and price elasticity in times of a crisis (Demidova-Menzel et al., 2007), make it a rather good indicator for the macro risk sensitive movements of implied correlations of iTraxx tranches during the financial crisis. Fire sales of risky assets and the flight to quality also put pressure on the yields of medium- and long-term government bonds. Opposite effects due to an increase in credit spreads of industrialized economies make it impossible to explain the irrational risk averse behavior of professional market participants with government bond prices or yields. Respectively, the development of implied correlations of iTraxx tranches, which could be seen as a synonym for the market expectations of growing macro risk during the crisis could not be explained this way.

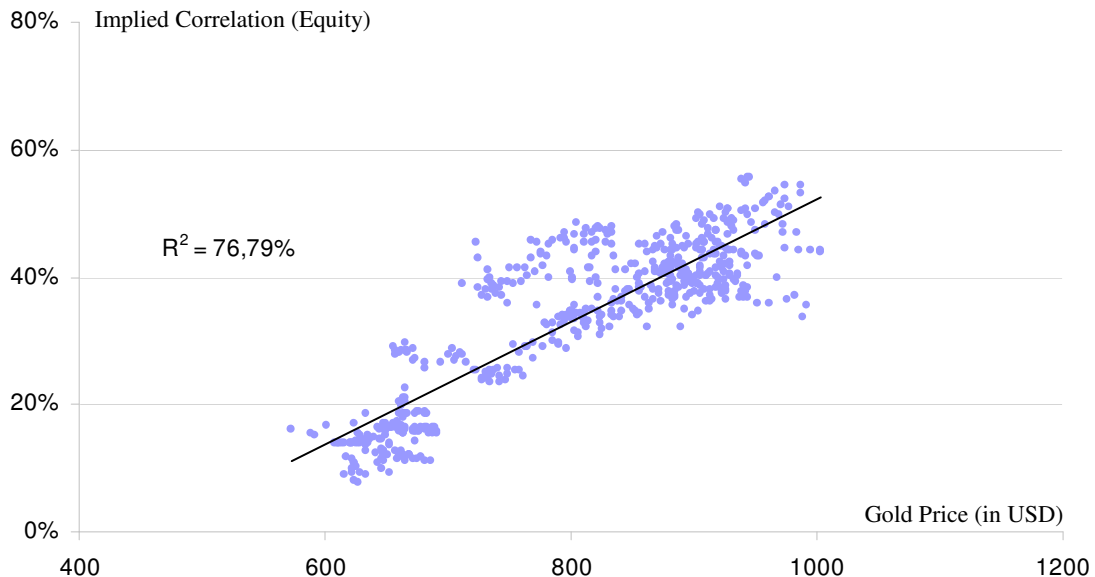


Figure 8: Gold Price vs. Implied Correlation (September 2006 - April 2009)

Moreover, it is assumed that the disrupted functionality of the interbank markets influenced implied correlations significantly. The increase of credit and liquidity risk of financial institutions could have had an impact on tranche implied correlations, because investments in STCDOs had been avoided and existing positions had been offset. The price for protection against systematic credit shocks therefore increased disproportionately high during the financial crisis. One indicator for systematic risk within the interbank market is the swap spread<sup>6</sup>, which contains both, credit and liquidity risk components (Longstaff et al., 2006). Due to the relatively low correlation with the explaining variable gold (55.82%), we

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<sup>6</sup> Difference between the swap rate and the yield of government bonds. We use the five year swap spread within the regression (source: Thomson Reuters).

use the swap spread within the empirical model to approximate the higher levels of credit- and liquidity risk components in the interbank market during the crisis.<sup>7</sup>

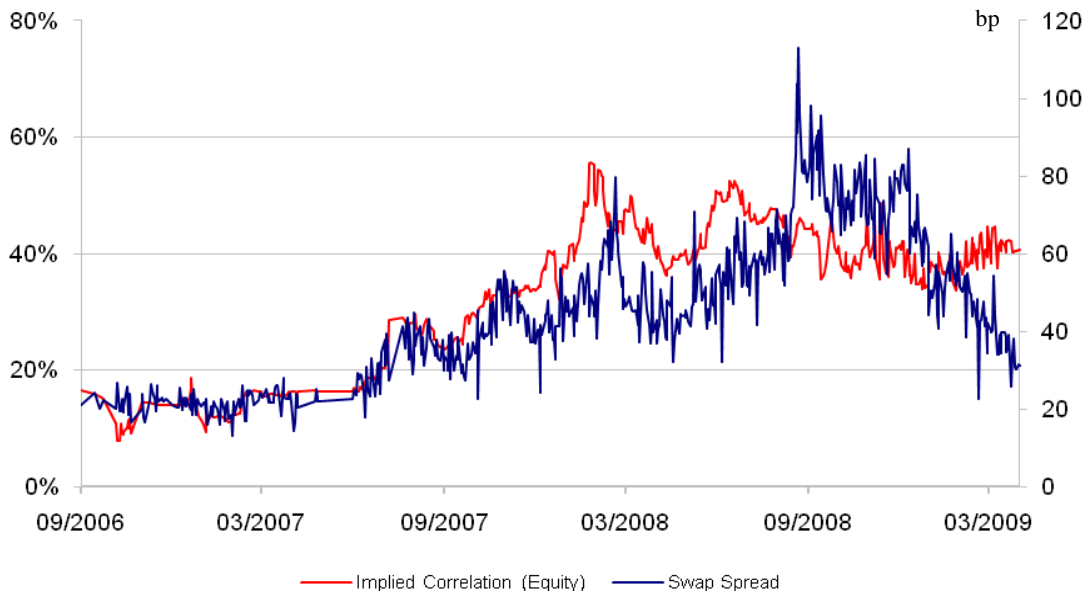


Figure 9: Swap Spread and Implied Correlation during the Financial Crisis

Due to the large fraction which the swap spread is able to explain with respect to the movements of implied correlations during the financial crisis, the following chapters will concentrate on how much this spread is driven by credit- and liquidity risk components.

---

<sup>7</sup> „Systematic risk is usually measured in terms of the widening of Libor swap spread and the CDS spreads of banks and financials. It is thus no surprise that the same period in which supersenior tranches have widened drastically in spread is accompanied by a sharp widening of swap spreads, financial sector spreads, increase in volatility and general reduction in liquidity” (Bhansali et al., 2008)

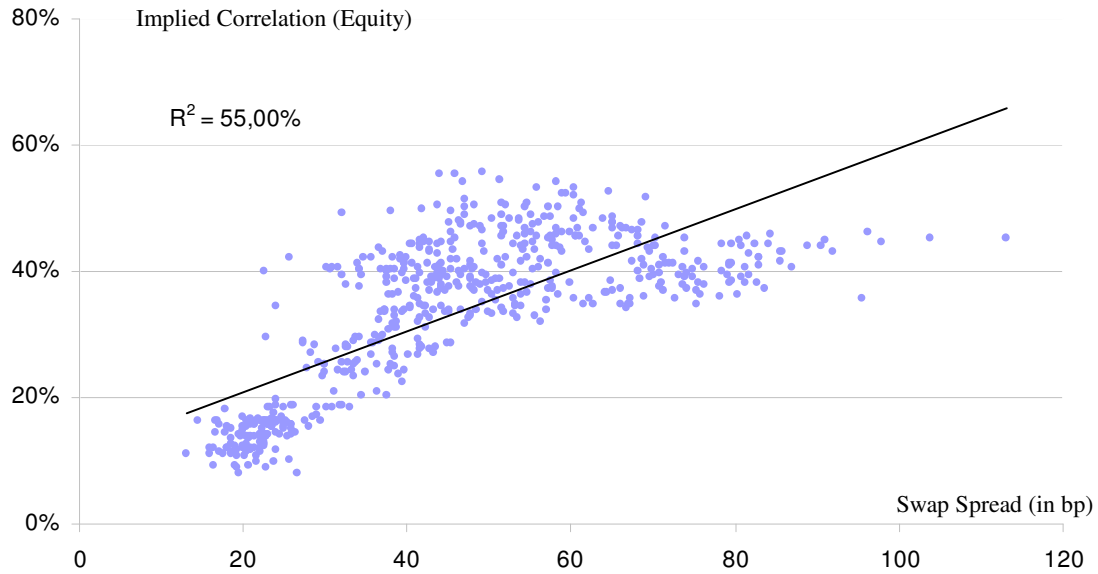


Figure 10: Swap Spread vs. Implied Correlation (September 2006 - April 2009)

## 2.4 Credit Risk and Implied Correlation

As mentioned before, the fraction of systematic risk components in CDS-Spreads increased during the financial crisis. The development of implied correlations of iTraxx tranches during the first months of the crisis can therefore be approximated quite well with the index spread. Nevertheless, it has to be taken into account that an increase in idiosyncratic risk components, or individual default probabilities (expected loss), had still been the major contributor to the levels of index spreads during the crisis (Bhansali, 2008). Using the index spread as an explanatory variable for the variance of the systematic risk factor implied correlation is problematic, because one would have to exclude idiosyncratic and sector specific risk components.

During the relevant period, tranche spreads are highly correlated with the spread of the iTraxx Europe.<sup>8</sup> This leads to the conclusion that the market did not differentiate between the various credit risk exposures related to the tranche’s level of subordination.

	<b>iTraxx Europe</b>	<b>Equity</b>	<b>Junior Mezz</b>	<b>Senior Mezz</b>	<b>Junior High</b>	<b>Senior High</b>
<b>iTraxx Europe</b>	100.00%	97.75%	96.62%	98.53%	98.52%	94.26%
<b>Equity</b>		100.00%	97.36%	97.91%	96.32%	89.09%
<b>Junior Mezz</b>			100.00%	98.83%	96.37%	84.92%
<b>Senior Mezz</b>				100.00%	98.14%	90.21%
<b>Junior High</b>					100.00%	94.26%
<b>Senior High</b>						100.00%

Table 5: Correlations between Tranche Spreads and iTraxx Spread (September 2006 - January 2009)

<sup>8</sup> Reliable data for tranche spreads are available until 01/30/2009 (source: Bloomberg).



Until September 2008 increasing index- and tranche spreads as well as implied correlations can be observed (see figure 11). The fact that index- and tranche spreads determine the level of implied correlation in a non-linear way (HPLGC-Model) highlights the problem to include index- and or tranche spreads as explanatory variables in the (linear) regression model.

The increase of expected losses in the reference portfolio was higher compared to the increase of expected losses in the equity tranche, because implied correlations also increased until summer 2008. Since September 2008 one can conclude that the increasing index- and tranche spreads neutralize themselves in correlation, which means that the probability density moves in a rather constant form so that correlation does not change (much). Consequently, the regression of index- and tranche spreads on the implied correlation does not deliver useful results for the period September 2008 - April 2009. On the other hand, the high explanatory power of index- respectively tranche spreads until September 2008 for implied correlation has to be mentioned ( $R^2 = 86.07\%$ ).<sup>9</sup>

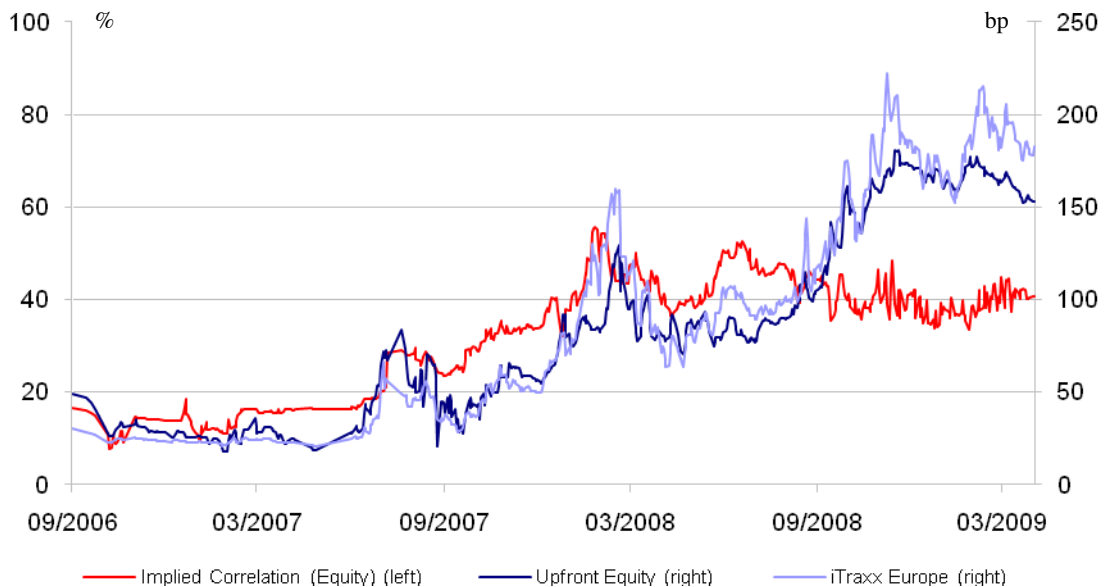


Figure 11: Implied Correlation, iTraxx Europe and Upront-Premium of the Equity Tranche

Due to the low explanatory power of the index spread for the development of implied correlations from September 2008 - April 2009 we instead use, as mentioned before, the swap spread within the empirical model in order to represent the growing systematic credit risk in the interbank market. Containing liquidity risk components on the one hand, the swap spread is on the other hand an indicator of AA Credit-Spreads (Kobor, 2005), which can be defined as the yield difference between government bonds and unsecured bank bonds and explains the strong increase of the swap spread until September 2008 almost completely.

<sup>9</sup> The Gold price shows almost identical explanatory power for the development of implied correlations until September 2008 ( $R^2 = 86.62\%$ )

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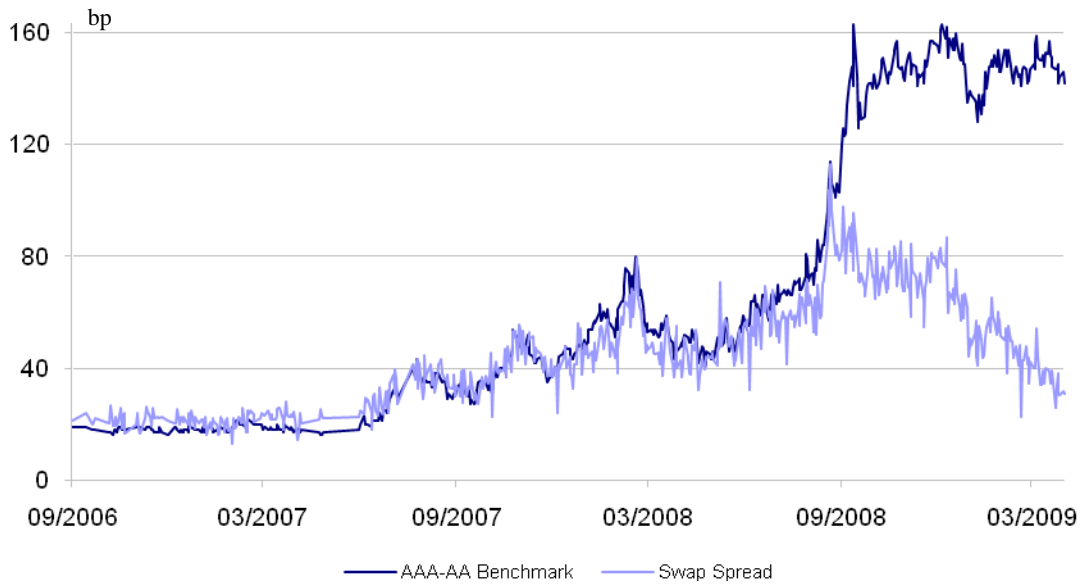


Figure 12: Swap Spread (5y) and AAA-AA Benchmark-Spread (5y) (Bundesbank, 2009)

If we regress the spread between the AA-AAA benchmark curves on implied correlation for the period September 2006 until September 2008, the explanatory power is almost identical compared to regressing the iTraxx spread on implied correlation. This is further evidence that credit spreads which differ in creditworthiness and industries have contained a larger fraction of macroeconomic risk factors since the start of the crisis.

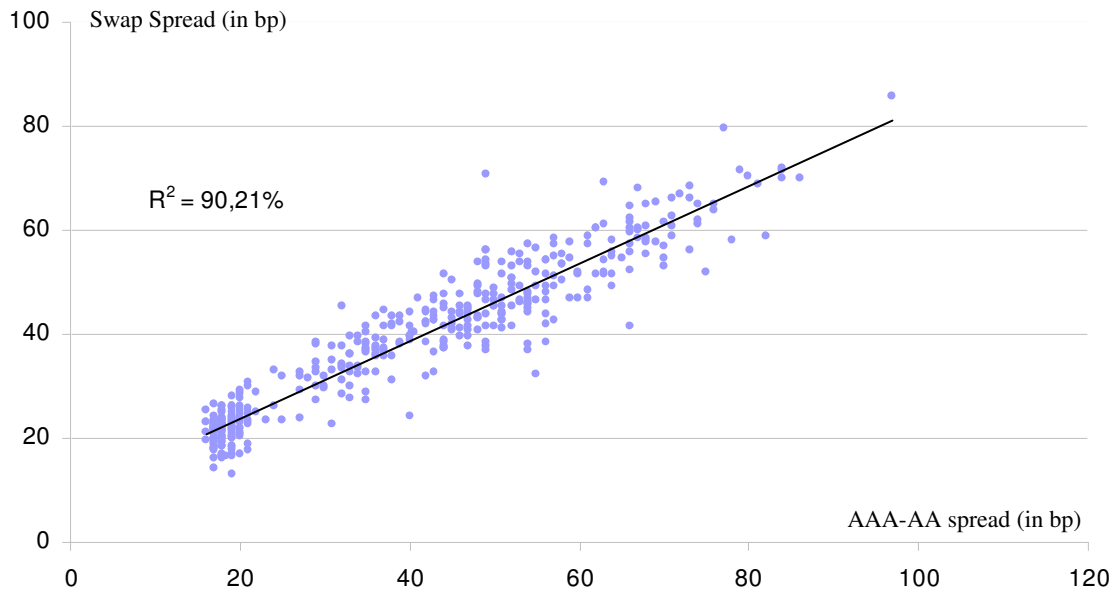


Figure 13: Swap Spread vs. AAA-AA Benchmark-Spread (09/20/2006 - 09/12/2008)

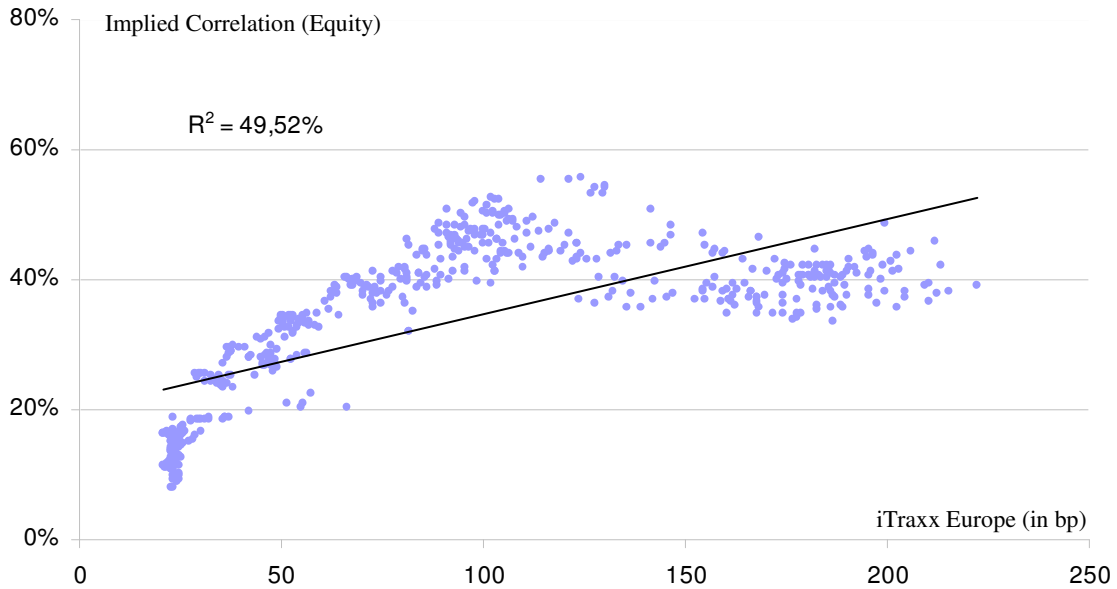


Figure 14: iTraxx Europe vs. Implied Correlation (September 2006 - April 2009)

## 2.5 Liquidity Risk and Implied Correlation

The influence of the dramatic decrease of market liquidity in the tranche market, which had been rather liquid before the subprime crisis (Bhan, 2008) on the quoted implied correlations will be the focus of the following analysis. In this connection, we first analyze classical indicators for the level of market liquidity, before connections of market and funding liquidity are discussed. Afterwards, it will be shown that the growing pressure on banks' refinancing conditions can explain the development of the swap spread from September 2008 - April 2009 and therefore the movements of implied correlations during the last months of the relevant period.

### 2.5.1 Market Liquidity and Implied Correlation

In general, one can distinguish between three different forms of market liquidity.<sup>10</sup> The Bid/Ask spread measures how much a trader loses if he buys an asset and immediately sells it. Market depth measures how much volume of an asset can be traded without affecting its market price. Market elasticity measures how long it takes an asset's market price to return to its previous level after a turnover. Market liquidity risk will be defined as a sudden variation in transaction costs (Acharaya et al., 2006) and therefore be approximated with the Bid/Ask spread. We suppose that the increase in systematic risk at the financial markets, which is represented by increasing implied correlations, can be explained with the illiquidity of iTraxx Europe index tranches.

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<sup>10</sup> "Market liquidity risk is the risk that a firm cannot easily offset or eliminate a position at the market price because of inadequate market depth or market disruption." (BIS, 2008)

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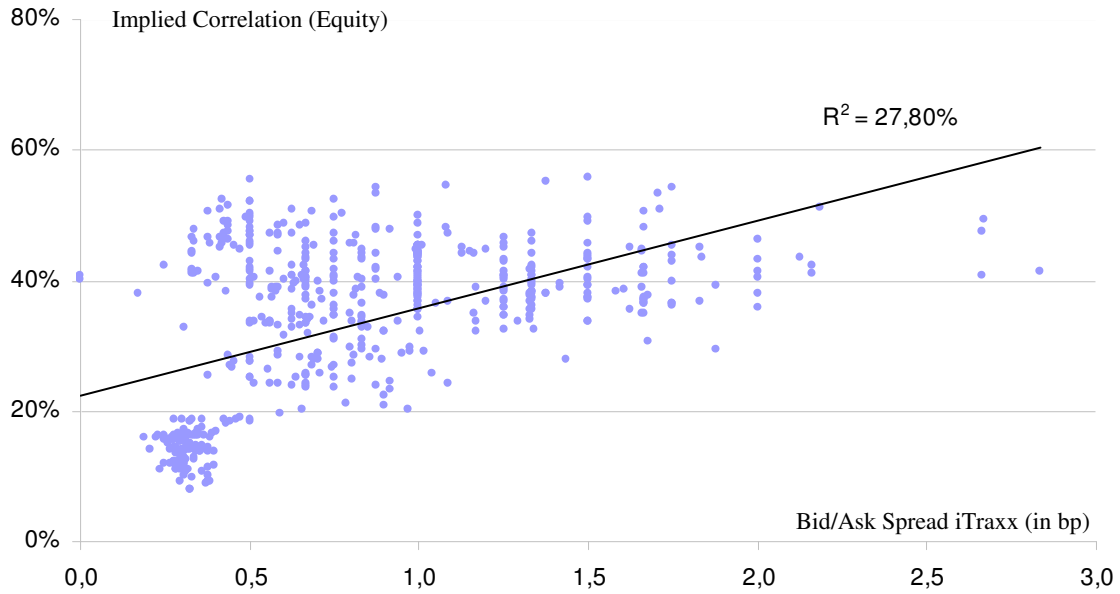


Figure 15: Bid/Ask Spread iTraxx vs. Implied Correlation (September 2006 - September 2009)

Figure 14 plots the Bid/Ask spread of iTraxx Europe, which can be interpreted as the general level of liquidity within the index tranche market (Scheicher, 2008) against implied correlation, whereas figure 15 shows the relationship between the Bid/Ask spread of the upfront premium of the equity tranche and the level of implied correlation.

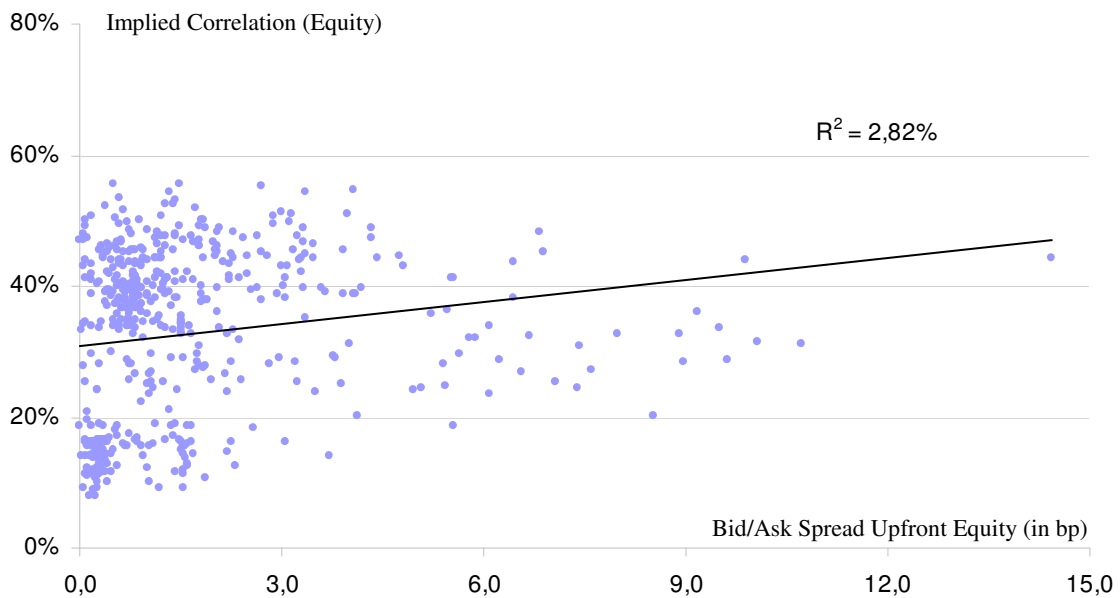


Figure 16: Bid/Ask Spread Upfront Equity vs. Implied Correlation (September 2006 - September 2009)

The explanatory power of classical indicators of market liquidity for the movements of implied correlations during the financial crisis is dissatisfying. The fact that the Bid/Ask-spread of the upfront premium (equity) decreases when implied correlation increases (Wagner, 2008) could not have been approved for the analyzed period.

### 2.5.2 Funding Liquidity and Implied Correlation

The link between market- and funding liquidity<sup>11</sup> are generally capital requirements of banks and collateral needs in interbank trading (Archaya et al., 2008). Market liquidity shocks are therefore often accompanied by funding liquidity shocks, because the conditions for traders to refinance themselves have an essential impact on their possibilities to provide market liquidity.

In times of falling asset prices the value of collaterals, which traders need for secured funding in the interbank repo markets, decreases as well. As a result, increasing haircuts have to be financed with the trader's capital (Brunnermeier et al., 2005). Liquidity shocks are therefore often caused by falling asset prices because secured funding of interbank market participants is limited due to capital and collateral limits so that traders cannot provide additional market liquidity. In those times market prices of financial assets are reduced for illiquidity. This reduction represents the cost of capital, which market makers have to pay for additional funding liquidity and are especially present in markets for derivatives and complex structured products because only a few market makers quote prices. In extreme cases, correlations between financial products are then driven by illiquidity, respectively by the pressure on banks' capital and collateral situation, and not by fundamentals (Archarya, 2006).

Moreover, the pro-cyclical impact of the leverage of investment banks and hedge funds, which have been the most important market participants in the index tranche market prior to the crisis, enforced the markets illiquidity (Duffie, 2008). When market values dropped, balance sheet volume had been reduced in order to keep leverages constant. Additionally, fire sales lead to a reduction in secured short-term funding which also put pressure on market- and funding liquidity (Adrian et al., 2008).

On European money markets, the problematic situation of short-term refinancing had been represented by widening spreads between cash and derivative instruments (Baba et al., 2008).

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<sup>11</sup> "Funding liquidity risk is the risk that the firm will not be able to meet efficiently both expected and unexpected current and future cash flow and collateral needs without affecting either daily operations or the financial condition of the firm." (BIS, 2008)

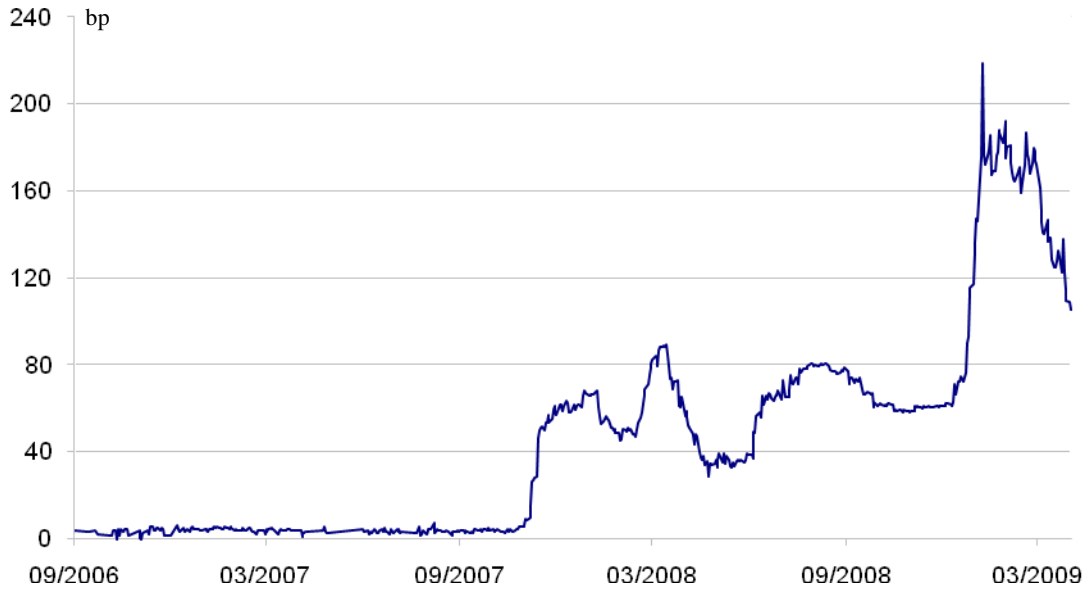


Figure 17: Spread between 3M EURIBOR and 3M EONIA Swap

The explanatory power of the money market spread for the development of implied correlations is lower than expected. A relationship with the swap spread is present, but prior analyses have shown that the swap spread could be explained (until September 2008) with increased credit risk in the interbank market. A liquidity risk premium for short-term funding had been demanded from the market since October 2007, which excludes the money market spread as an independent variable when regressing on the swap spread.

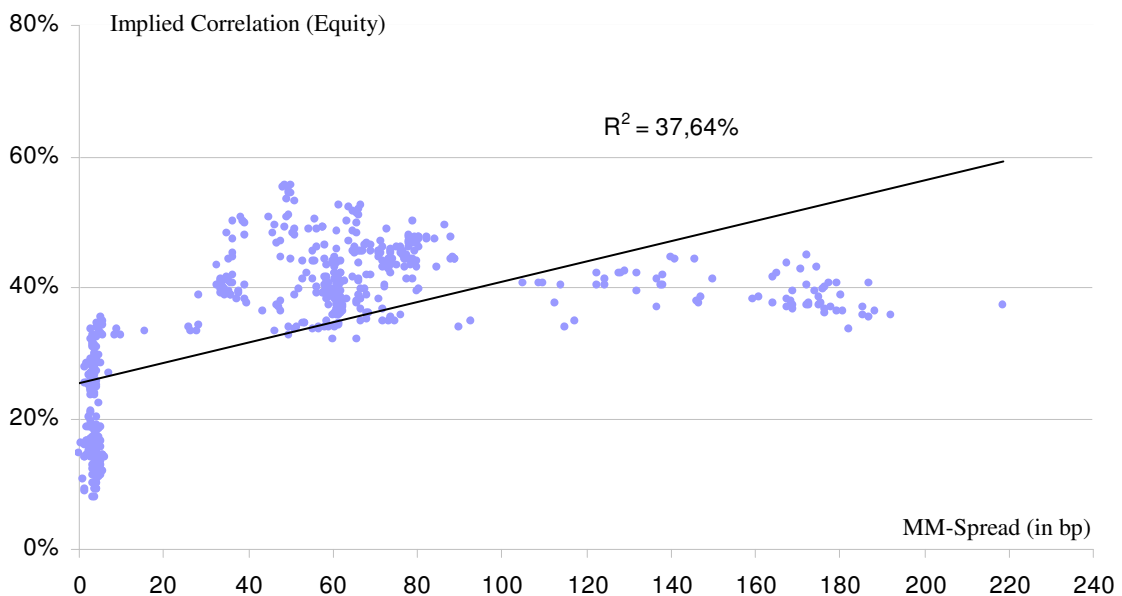


Figure 18: MM-Spread vs. Implied Correlation (September 2006 - April 2009)

As an argument that the swap spread contains, beside the credit spread of the interbank market (AA), further influence factors, one can argue that the credit risk of a bond is never completely comparable to the credit risk of a derivative (Haas, 2004). Therefore we suppose that liquidity risk premiums in medium- and long-term refinancing of banks, which could also be approximated with the spread difference of cash and derivative instruments, have been present in the swap spread.

The swap rate usually equals the rate on which interbank market participants have their lowest refinancing costs, because a swapped bond issue then costs EURIBOR-flat. After September 2008 the market has demanded a liquidity risk premium for banks' medium and long term refinancing, which we approximate with the spread between German Pfandbrief issues and the swap rate. The above mentioned pressure on short-term refinancing therefore spilled-over to medium and long-term refinancing with the September 2008 events. Banks tried to avoid long term funding in historical high liquidity spread environments, which put further pressure on short term money market rates. Interdependencies between short-term and medium-/long-term refinancing became especially present at the end of 2008.

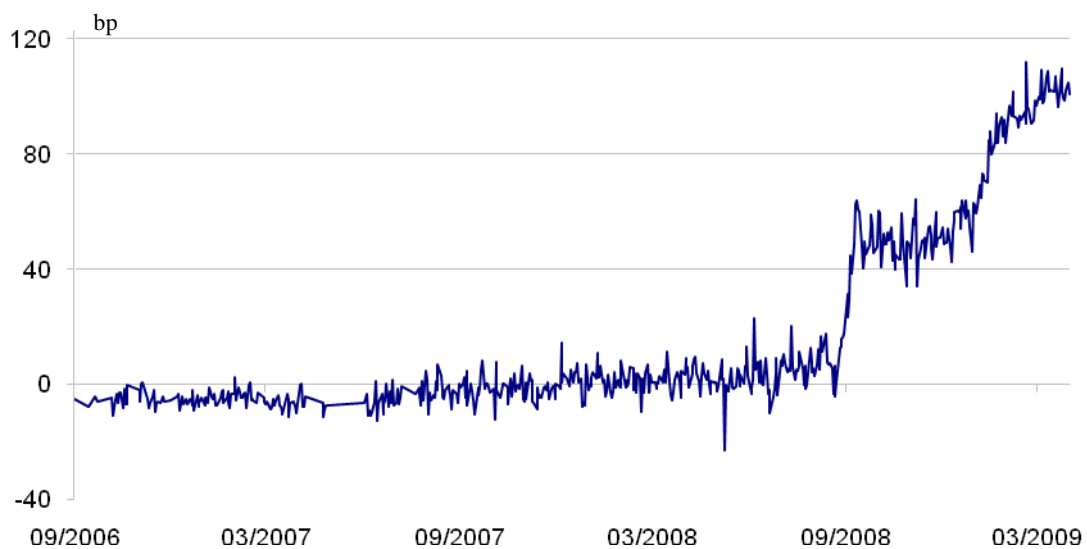


Figure 19: Pfandbrief/Swap-Spread (5y)

The sudden and extreme widening of the spread between German Pfandbrief yields and swap rates had been caused mainly by the development of swap rates since September 2008. In comparison to Bund and Pfandbrief yields, the swap spread decreased disproportionately when the market started to demand liquidity premiums for medium term refinancing (figure 19). Therefore, the swap markets, which are generally more liquid than the bond markets, had lost their benchmark and pricing status during the crisis, because bond

yields quote on a much higher level since September 2008.<sup>12</sup> The swap spread can therefore be explained quite well with liquidity risk premiums for medium term bank issues for the last months of the analyzed period. We use the average yield of public and mortgage secured Pfandbrief bonds with five years to maturity.

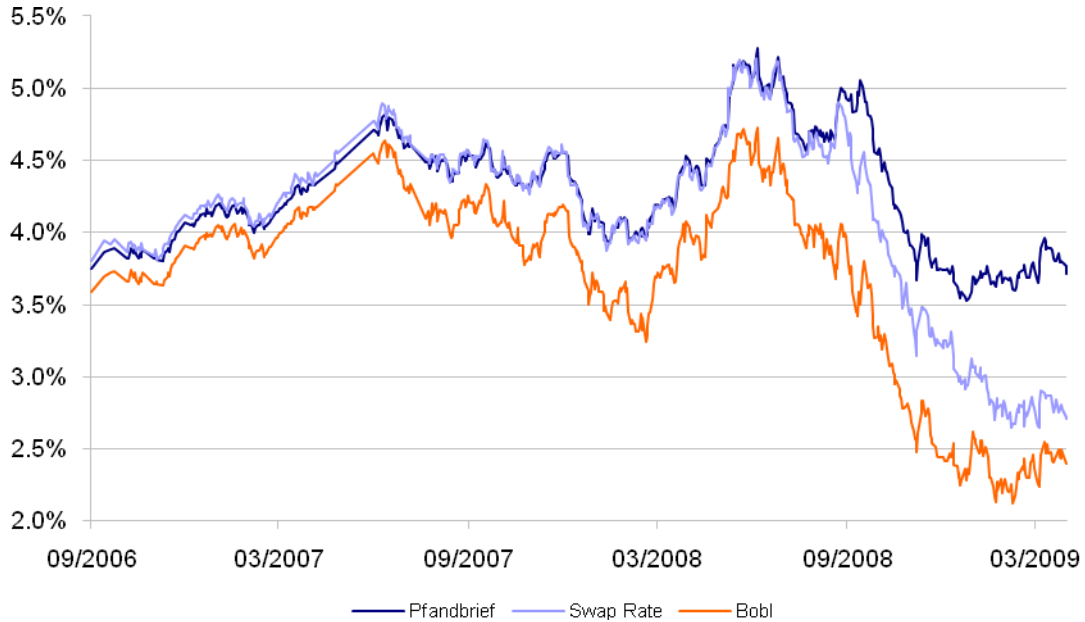


Figure 20: Development of Pfandbrief Yield, Swap Rate and Bobl Yield

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<sup>12</sup> If the liquidity risk premium is approximated with the spread between swap rates and unsecured bank issues, the impact for the regression is only marginal. Even if we differentiate between public- and mortgage secured or grandfathered issues, the regression is only influenced slightly.



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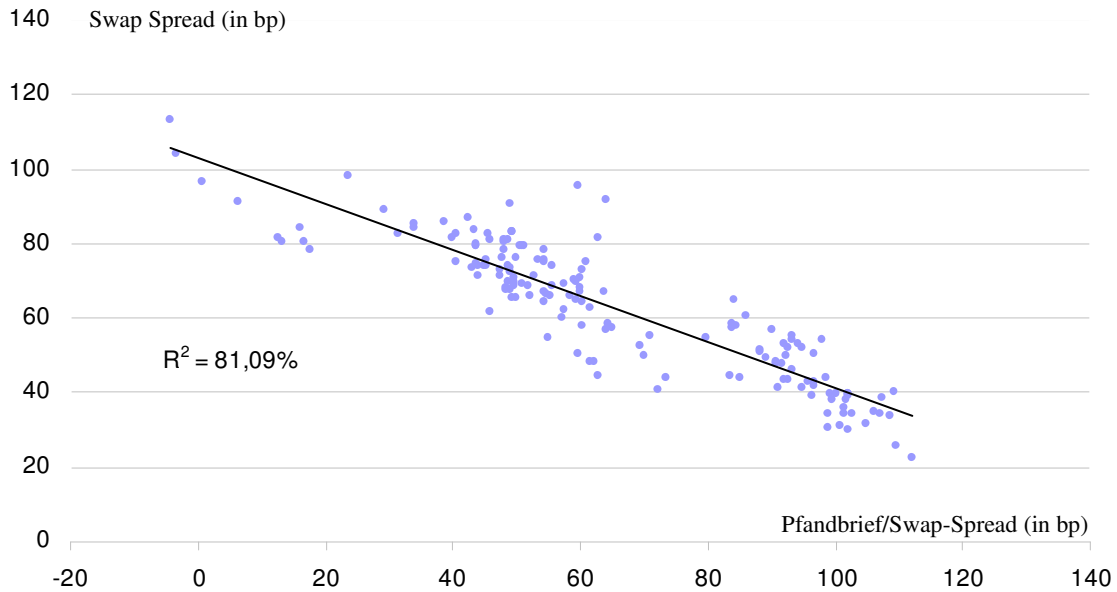


Figure 21: Swap Spread vs. Pfandbrief/Swap-Spread (09/15/2008 - 04/28/2009)

The inverse relationship between the swap spread and liquidity risk premiums indicates that despite growing credit risk within the interbank markets (increasing spread between AAA and AA-Benchmark bonds), the swap spread decreases at the end of the relevant period.

The reason for the over proportional tightening of the swap spread in comparison to bond yields is due to the pricing standards for interest rate swaps. The fix leg of the swap (Par-Coupon-Rate) is determined with the forward rates of the floating leg. Due to central banks interventions on international money markets, the floating leg decreased drastically (figure 21) in an environment of a flat yield curve. It follows a significant decrease in swap rates and the fact that bond yields decreased less strongly, shows the interdependence between short- and medium-term liquidity risk premiums on banks' refinancing operations and therefore its impact on market liquidity for index tranches and their implied correlations since September 2008.

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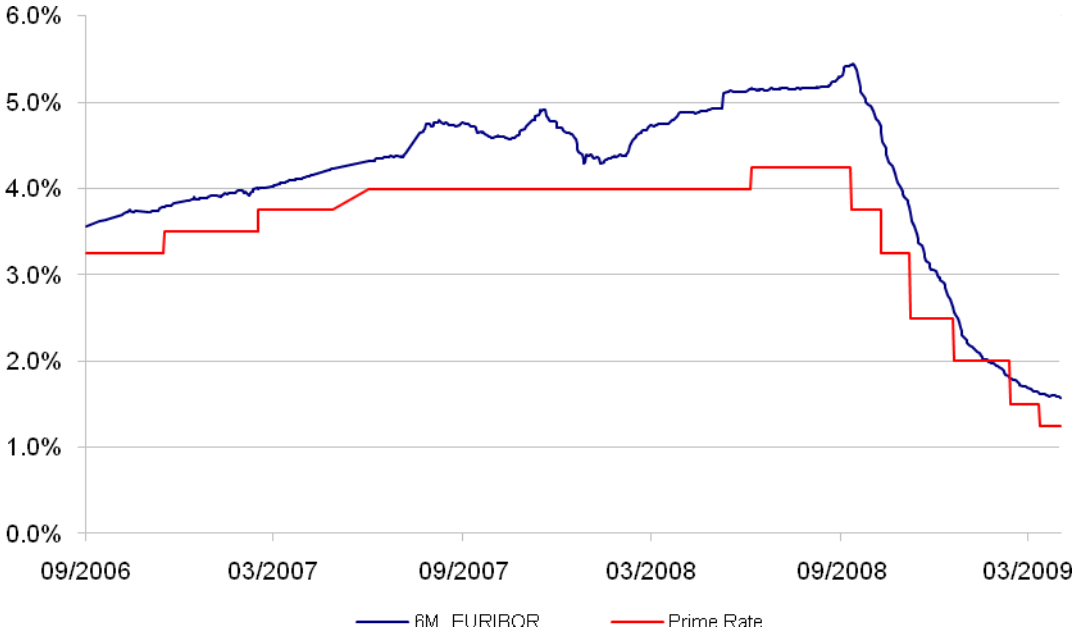


Figure 22: 6M Euribor and Prime Rate

### 3 Determinants of Implied Correlations of iTraxx Tranches during the Financial Crisis

#### 3.1 Results of the Regression Analysis

The highest explanatory power for the development of implied correlations of iTraxx-tranches during the financial crisis can be obtained when using the gold price and the swap spread as regressors. Adding any of the above discussed market parameters as independent variables, under the constraint to avoid multi-collinearity, does not add explanatory power to the multiple regression analysis.

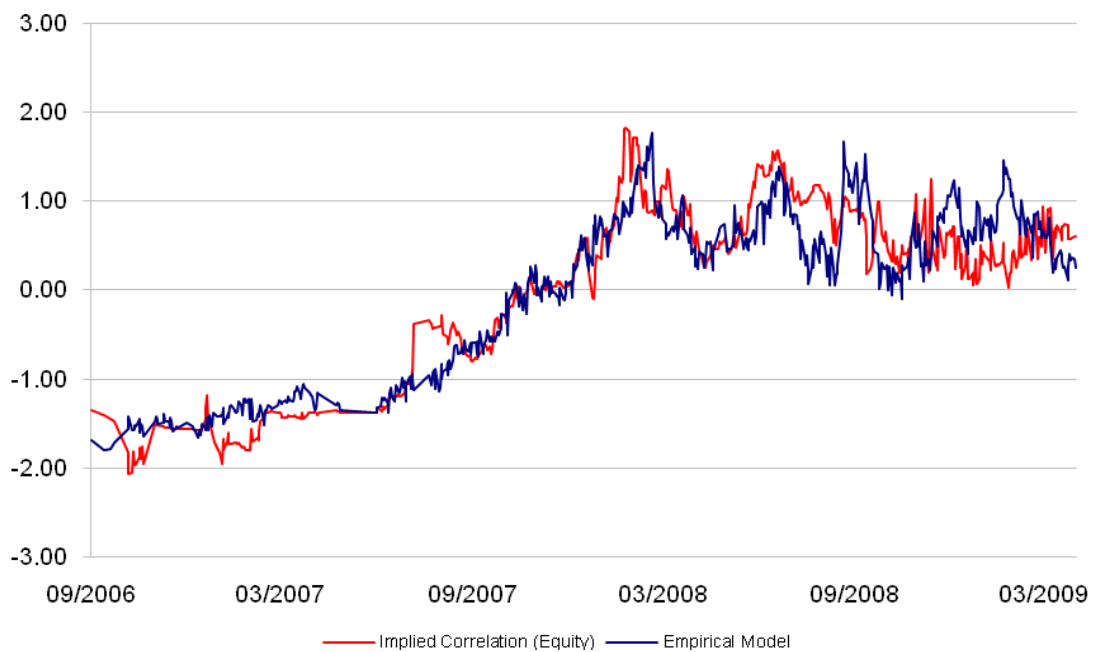


Figure 23: Implied Correlation and Empirical Model (standardized)

If we approximate the systematic credit risk component using the iTraxx spread within the regression and interpret it as the “main regressor”, we cannot add explanatory power using additional liquidity risk proxies. Moreover, using asset-correlations or the development of the EUROSTOXX (additionally) does not deliver good results. To explain the development of implied correlations of the entire capital structure, the regressors gold price and swap spread are statistically highly significant. The null hypotheses:

$$H_0 : \beta_{\text{Gold}} = 0$$

$$H_0 : \beta_{\text{Swap Spread}} = 0$$

$$H_1 : \beta_{\text{Gold}} \neq 0$$

$$H_1 : \beta_{\text{Swap Spread}} \neq 0$$

have to be rejected at  $\alpha = 0.01$  level of significance.

The development of the gold price explains almost 2/3 of the variations in implied correlations for all tranches, whereas the fraction becomes smaller for tranches of high subordination. The swap spread explains up to 45% (Senior-High) respectively (see table 6). The standard error of the estimate of the regression increases for high levels of implied correlations in comparison to the quoted correlations before the crisis (see figure 24). The complexity to parameterize the empirical model in a way, that it delivers good results for the entire period on the one hand, and that explains the strong variation of implied correlations at the end of the relevant period on the other hand, becomes obvious here.

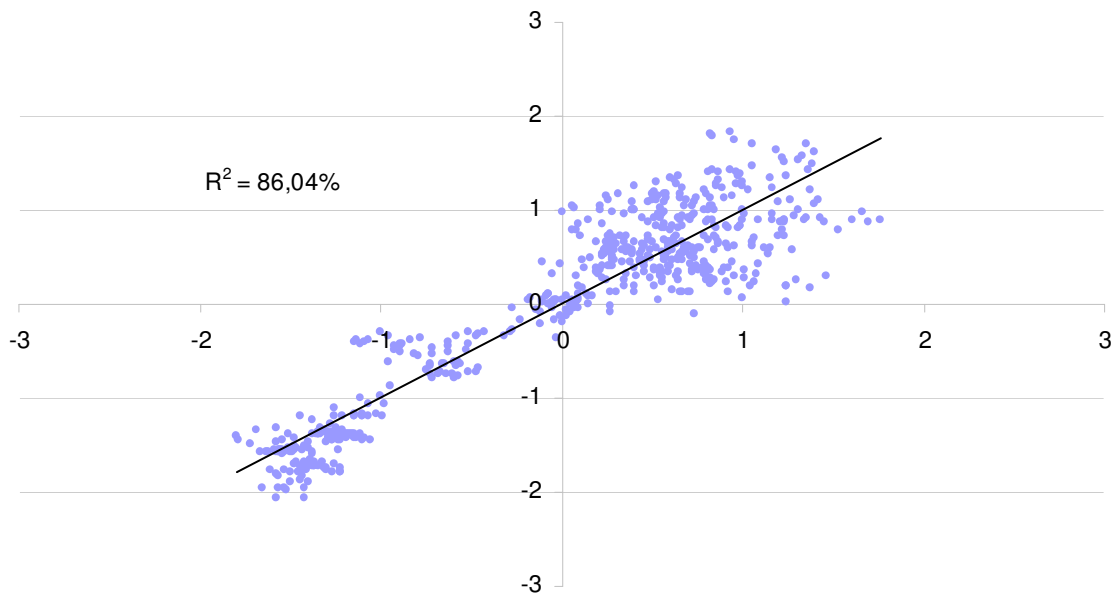


Figure 24: Explanatory Power of the Multiple Regression for the Implied Correlation (Equity)

Until Lehman faced bankruptcy in September 2008, the development of implied correlations could be explained using proxies which represent growing macro-risk in the market (gold price, swap spread, iTraxx spread). The goodness of fit of the model for realizations of implied correlations below its mean is therefore high. Since the peak of the financial crisis in autumn 2008, the extremely high levels of implied correlations could be predicted but the explained part of the implied correlations' variances decreases significantly. Therefore, increasing variances of the residuals could be observed for levels of implied correlations above their mean (see figure 24). Using the Goldfeld-Quant-Test we examine if heteroscedasticity is present. In order to test the null-hypothesis of homoscedasticity against the alternative hypothesis of heteroscedasticity within the residuals:

$$H_0 : \sigma_j^2 \leq \sigma_i^2$$

$$H_1 : \sigma_j^2 > \sigma_i^2$$

we divide the observations into two subsets:

$$N = 591 = I + J$$

I = 296 observations (09/20/2006 - 03/11/2008)

J = 295 observations (03/12/2008 - 04/28/2009)

The test statistic:

$$F = \frac{\sum_{j=1}^{295} \varepsilon_j^2 / (295 - K - 1)}{\sum_{i=1}^{296} \varepsilon_i^2 / (296 - K - 1)}$$

is F-distributed with (J-K) and (I-K) degrees of freedom if the null hypothesis is valid. The critical value for a level of significance of 0.05 is:

$$F_{293; 294; 0.05} \approx 1.50$$

For the entire capital structure the F-statistic is much higher (see table 6). We have to reject the null-hypothesis of homoscedasticity in favor of the alternative hypothesis (hetero- scedasticity) on the 5% level of significance. Moreover, the efficiency of the regressors is influenced by auto correlated residuals.

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	<b>Equity</b>	<b>Junior Mezz</b>	<b>Senior Mezz</b>	<b>Senior Low</b>	<b>Senior High</b>
R <sup>2</sup>	86.04%	73.80%	68.80%	72.07%	75.10%
<u>beta (standardized)</u>					
gold price	0.672	0.600	0.583	0.575	0.526
swap spread	0.367	0.351	0.326	0.372	0.435
<u>t-value</u>					
gold price	36.165	22.708	20.045	21.389	20.040
swap spread	19.749	13.283	11.203	13.824	16.558
<u>p-value</u>					
gold price	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
swap spread	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
<u>residuals</u>					
skewness	0.79	0.36	0.18	0.36	0.44
kurtosis	3.50	2.77	2.43	2.76	2.91
Goldfeld-Quandt	5.97	3.95	3.11	3.93	4.32
Durbin-Watson	0.33	0.16	0.16	0.15	0.17
N	591	591	591	591	591

Table 6: Results of the Regression Analysis on Implied Base Correlations

With a coefficient of determination of 93%, the determinants of the swap spread can be identified completely and consequently, the influence of increased systematic credit and liquidity risk in the interbank market on implied correlations of iTraxx-Tranches can be approximated.

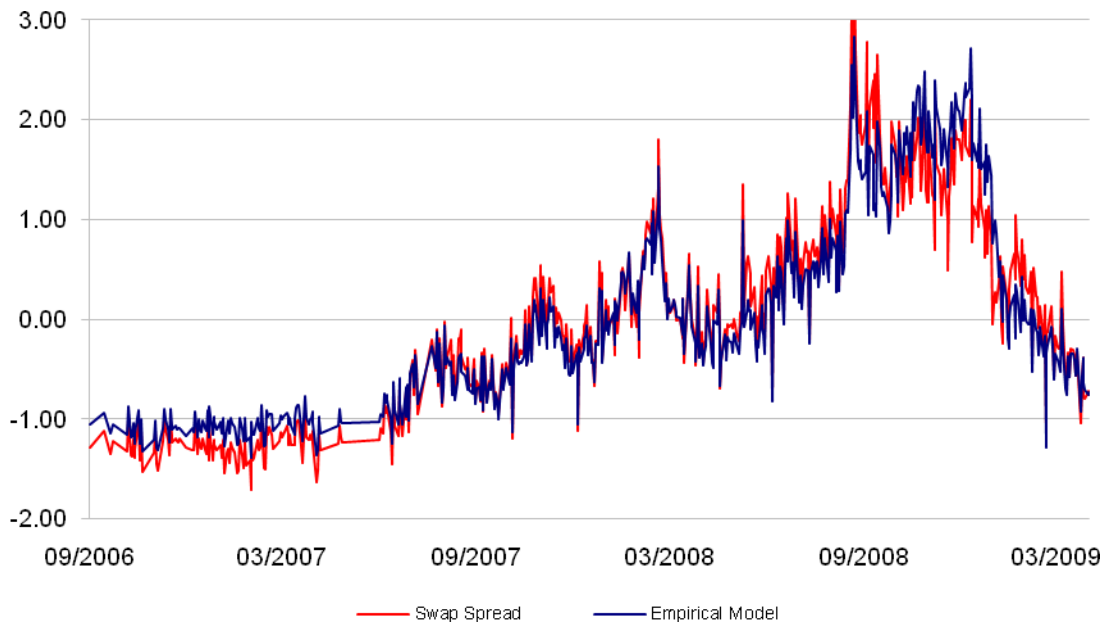


Figure 25: Swap Spread and Empirical Model (standardized)

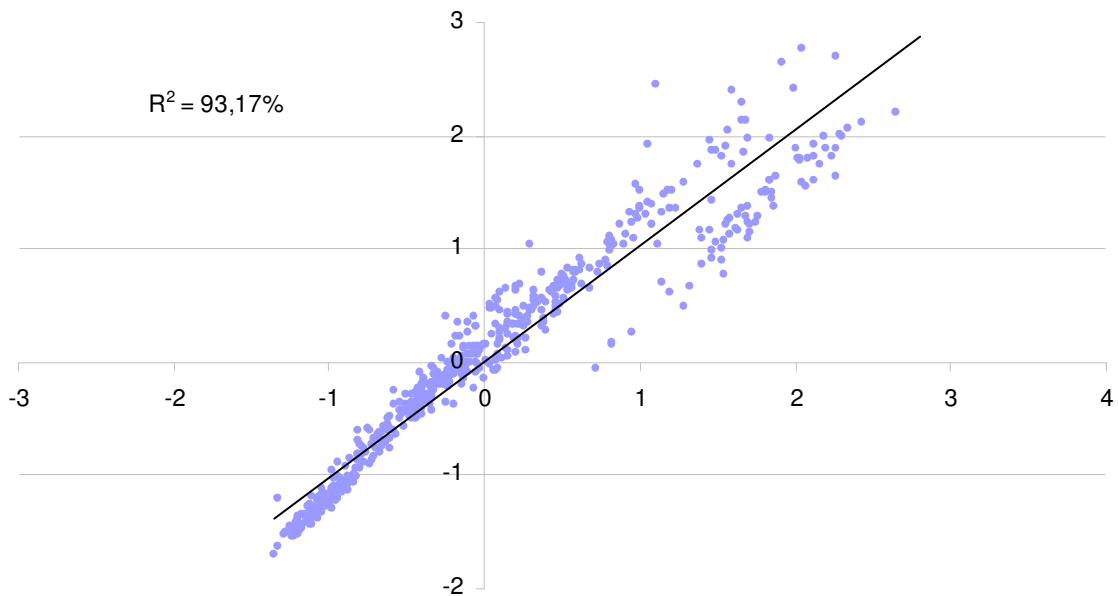


Figure 26: Explanatory Power of the Multiple Regression on the Swap Spread

Following that, the p-values of the independent variables AAA-AA Benchmark-Spread and Pfandbrief-Swap-Spread are very small. Hence, the statistical dependence is strong. Contrary to the results of the regression analysis for implied correlations, the possibility of non-observance of explaining variables is not given, even if heteroscedasticity and autocorrelation is also present within the residuals.

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	<b>Swap Spread</b>
R <sup>2</sup>	93.17%
<u>beta (standardized)</u>	
AAA-AA Benchmark-Spread	2.041
Pfandbrief/Swap-Spread	-1.473
<u>t-value</u>	
AAA-AA Benchmark-Spread	83.866
Pfandbrief/Swap-Spread	-60.168
<u>p-value</u>	
AAA-AA Benchmark-Spread	< 0.001
Pfandbrief/Swap-Spread	< 0.001
<u>residuals</u>	
skewness	-0.20
kurtosis	4.33
Goldfeld-Quandt	3.83
Durbin-Watson	0.18
N	591

Table 7: Results of the Regression Analysis on the Swap Spread

The strong correlation between the independent variables of 89.87% is not problematic with regard to multi-collinearity, because the regressors enter the model with opposite signs, which is economically reasonable and corresponds to the expectations formulated before.

### 3.2 Discussion and Remarks

That market implied parameters quote significantly above realized ones and that they react more sensitively to changing levels of risk aversion in times of a crisis is common and can also be observed for other asset classes. The fact that realized asset correlations of iTraxx Europe corporates have no explanatory power for implied correlations is surprising. Even until summer 2007, both correlation parameters seemed to be independent of each other.

The influence of the development of EUROSTOXX on implied correlations of iTraxx tranches has been confirmed but the relationship between equity markets and implied correlations is by far not as strong as the interdependence between the spread of iTraxx Europe and EUROSTOXX returns (correlation: -94.32%).

The simultaneous development of the gold price and implied correlations of iTraxx tranches shows the dimension of the global crisis because during former banking-, financial market- and economic crises, the gold price never moved as strongly as during the analyzed period. Even the Argentina Crisis at the end of the 90ies, which had been a desas-



ter for the national economy, did not have an impact on the gold price development. Therefore, two sensitive proxy variables for increasing global macro-risk and their interdependences have been shown.

The analysis of interrelationships between credit spreads (iTraxx Europe, AAA and AA Benchmark Curves) and their influence on implied correlation have shown that implied correlations could be explained with the growing fraction of systematic credit risk within credit spreads until September 2008. Since autumn 2008 the influence of the index spread on implied correlation is irreproducible. The reason is that implied correlations are determined by index- and tranche-spreads in a non-linear way. Moreover, implied correlations are influenced by a lot of economic factors which cannot be represented within the HLPGC-Model.

For this reason, liquidity risk in interbank markets, which suddenly appeared on banks' risk management agenda in summer 2007, has been analyzed. In this connection it was demonstrated that liquidity risk premiums have been present in the European money markets since summer 2007 when market participants started to hoard liquidity. For medium- and long-term capital market refinancing, the market demanded liquidity risk compensation since September 2008. Based on the interdependencies between market- and funding liquidity, it has been argued that the illiquidity of financial markets and especially of credit derivatives markets could explain the constantly high levels of tranche implied correlations since autumn 2008. In contrast, the results of the regression analysis show that the explanation of implied correlations' variance since Lehman's default and therefore the explanation of the quoted prices for taking systematic credit risk is not possible with standard instruments of economic analysis

Furthermore, it was shown that the swap spread is a very good proxy for the systematic component of credit risk in the interbank market and liquidity risk premiums of capital market refinancing. The spread between german government bonds and bank bonds determined the swap spread for the entire period, whereas liquidity risk aspects of medium-term refinancing operations influenced the development of the swap spread significantly since autumn 2008.

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