Credit Risk and Liquidity in Bond and CDS Markets

Inauguraldissertation zur Erlangung des akademischen Grades
eines Doktors der Wirtschaftswissenschaften
der Universität Mannheim

Monika Trapp

vorgelegt im Herbstsemester 2008

Dekan:	Prof. Dr. Hans H. Bauer
Referent:	Prof. Dr. Dr. h.c. Wolfgang Bühler
Korreferent	Prof. Dr. Peter Albrecht

Tag der mündlichen Prüfung 24. September 2008

Contents

List of Figures

List of Tables

Acknowledgments

This thesis evolved while I was a research assistant and PhD student at the Chair of Finance at the University of Mannheim; it was accepted as a dissertation by the Faculty of Business Administration.

None of this could have been accomplished without the help of many. First, I am greatly indebted to my advisor Prof. Dr. Dr. h.c. Wolfgang Bühler for his unrelenting support and encouragement. His critical advice has helped me to identify the what, why, and how of this thesis, his patience during our countless discussions to overcome the inevitable exasperations which accompany all academic work. I would also like to thank Prof. Dr. Peter Albrecht for co-refereeing the thesis.

Research support through the German Research Foundation (DFG) via the research group "Price, Credit and Liquidity Risks" is gratefully acknowledged, and I thank conference participants at the research group's meetings in Königsfeld for stimulating discussions. Many ideas in this work grew out of fruitful discussions at seminars and conferences.

My heartfelt thanks go out to my committed colleagues, now and formerly at the Chair of Finance, namely Jens Daum, Christoph Engel, Xuanlai He, Sebastian Herzog, Dr. Christoph Heumann, Prof. Dr. Olaf Korn, Prof. Dr. Christian Koziol, Dr. Jens Müller-Merbach, Raphael Paschke, Marcel Prokopczuk, Dr. Peter Sauerbier, Christian Speck, Volker Sygusch, and Volker Vonhoff, as well as our secretary Marion Baierlein, not only for constant after-lunch entertainment, but for countless comments, encouragement, support, and all the coffee anyone could turn into theorems.

Most of all, I thank my parents Anna-Maria and Horst Trapp, whose unfailing love and support have accompanied me through the years. You're the best!

> The credit default swap is
> probably the most important
> instrument in finance.
> Alan Greenspan, May 2006

Chapter 1

Introduction

Credit derivatives have revolutionized the way in which financial institutions, investors, regulators, and academics view credit risk. Single-name instruments such as credit default swaps (CDS), credit linked notes, or total rate of return swaps allow trading the default loss risk of an individual reference asset separately from this asset. Multi-name products which can be separated into basket and portfolio derivatives permit the transfer of a synthetic credit portfolio among the market participants. A common feature of all credit derivatives lies in their dependence on the general credit risk of a reference asset which may include rating downgrades, failure to pay, or bankruptcy. Due to the evolution and the standardization of the market for credit derivatives in general and CDS in particular, trading the derivative position has become a substitute for trades in the actual credit risk exposure. The Basel Committee on Banking Supervision (2004) reflects this development by recognizing CDS positions as credit risk mitigation for bond or loan exposures in the standardized and the internal ratings based approaches of the Basel II framework. However, the presumed correspondence between the reference exposure and its synthetic counterpart, the credit derivative, is only given if both instruments are subject to the same risk factors and exhibit an identical sensitivity to these risk factors.

The contribution of this thesis is to study the impact of different risk factors on bond prices and CDS premia and to explore the extent to which the different factors or sensitivities cause diverging price behavior. In particular, we focus on the contractual differences between bonds and CDS and on the instrument-specific liquidity as two potential reasons for divergence, and our results challenge the conventional wisdom of a simple one-to-one relation between the bond and the CDS market.

First, the bond and the CDS market are typically subject to a different liquidity. Even though investors in financial markets have a concise understanding of what constitutes liquidity, a theoretical definition of liquidity for arbitrary instruments is a daunting task. This is partly due to the complex nature of liquidity with its 4 dimensions time, price, magnitude, and regeneration. In addition, liquidity only plays a role if the market participants have a trading motive, an advantage from trading, and access to an alternative instrument which trades at a comparative advantage to the illiquid instrument. The approach to explain liquidity premia endogenously through market frictions and trading motives has been widely explored in the literature on equilibrium models, see e.g. Amihud and Mendelson (1986), Basak and Cuoco (1998), Duffie et al. (2000), and Sauerbier (2005).

All above models, however, suffer from the fact that the endogenous liquidity discount depends on parameters such as the endowments or the risk preferences of the agents. These are unobservable in practice and difficult to infer implicitly from prices. Most empirical work therefore avoids an explicit equilibrium modeling of liquidity and uses a purely econometrical or intensity-based reduced-form approach to determine the impact of illiquidity on asset prices.

For assets which are identical except for their liquidity such as on-the-run and off-the-run Treasury bond issues or Pfandbrief issues with different issue sizes, liquidity premia can directly be measured as the price differences. For default-risky assets such as corporate bonds, credit risk and liquidity have a *simultaneous* price impact and can interact with one another. Thus, the first contribution of this thesis is that we disentangle the simultaneous effect of credit risk and liquidity. This allows us to identify the different liquidity of the two markets as a cause for price divergence between the bond and the CDS market. We focus on the bond yield spread in excess of a default-free interest rate curve and on the CDS premia for a wide range of industry sectors and sovereign issuers with a rating between AAA and CCC. We employ two methods to explore this point. First, we demonstrate that bond yield spreads and CDS premia react differently to firm- and instrument-specific and market-wide measures of credit risk and liquidity in an econometric analysis. Second, we develop a reduced-form model that allows us to separate observed bond yield spreads and CDS premia into a credit risk and a liquidity premium component. We then analyze the estimated premia time series and identify the degree of co- and countermovement in the two markets. Our results show that bond and CDS liquidity premia move in opposite directions if we correctly adjust for the impact of credit risk. Consequently, ignoring either bond or CDS liquidity leads to overestimates of the two markets' correspondence.

Our second contribution is that we explore the price divergence between the bond and the CDS market caused by the impact of the delivery option on CDS premia. A CDS contract typically specifies an issuer and a debt type, e.g. senior or subordinate, instead of a single reference asset. If an event such as bankruptcy or failure to pay occurs for this issuer and debt type, the investor who has used the CDS contract to lay off credit risk (the protection buyer) has the option to choose one of the bonds on which default has occurred and deliver it to the investor who has taken on credit risk through the CDS contract (the protection seller). In return, the protection buyer obtains a fixed payment. This choice option constitutes an additional risk source for the protection seller which is not incurred by a direct investment in a specific bond, and the delivery option value is reflected in a higher CDS premium. We extend the existing literature on the CDS delivery option by developing an explicit representation of the minimal post-default bond price. We estimate the parameters of its distribution from a unique sample of defaulted bonds from the Euro area. Subsequently, we extend our reduced-form model for strategic delivery of the cheapest bond and determine the resulting decomposition of bond yield spreads and CDS premia into a credit risk, a liquidity, and a delivery option component. Our results show that the delivery option has a significant impact on CDS premia and, if ignored, becomes subsumed in the credit risk premium. Therefore, neglecting the delivery option also leads to overestimates of the two markets' correspondence.

The outline of this thesis is as follows. Chapter 2 describes the payment structure and the contractual features of a standard CDS and discusses the market organization and the evolving standardization. Chapter 3 introduces the data used in our empirical analysis, explores the relation between bond yield spreads and CDS premia and documents their different sensitivities to firm- and instrument-specific as well as market-wide measures of credit risk and liquidity. Chapter 4 presents the reduced-form model that allows us to separate bond yield spreads and CDS premia into a credit risk and a liquidity component, and Chapter 5 extends the model to a formal covariance structure for credit risk and liquidity and to the impact of the delivery option. Chapter 6 contains concluding remarks.

Chapter 2

Credit Default Swaps

A CDS is a bilateral contract which allows two counterparties to trade the credit risk of at least one underlying reference obligation. The counterparty who buys credit protection agrees to make periodic fee payments over the life of the swap. These fixed payments constitute the fixed leg of the swap. In return, the counterparty who sells credit protection agrees to make a payment if a "credit event" occurs for the reference obligations. This contingent payment is the floating leg of the swap.

In this chapter, we discuss the payment structure and the standard features of a CDS contract in Section 2.1. We give an overview over the organization of the CDS market and the main counterparties in Section 2.2. The standardization which the market has undergone and legal issues are described in Section 2.3. In each case, we focus on issues that affect the valuation of CDS contracts.

2.1 Payment Structure, Standard Contract Features, and Valuation

Due to its simple structure, the single-name CDS is the most frequently traded credit derivative contract. It allows the protection buyer and seller to trade the credit risk of the underlying reference entity, typically a company or a country, separately from other risk sources which affect bonds.

The basic contract form is as follows. At date t_0, the protection buyer and seller agree on a fee s, called the CDS premium,[1] which the buyer pays to the seller. Payments take place on fixed dates $t_1, \ldots, t_n$ if no credit event on the underlying reference obligations occurs until the maturity of the CDS contract at t_n.[2] In this case, the protection buyer receives nothing.

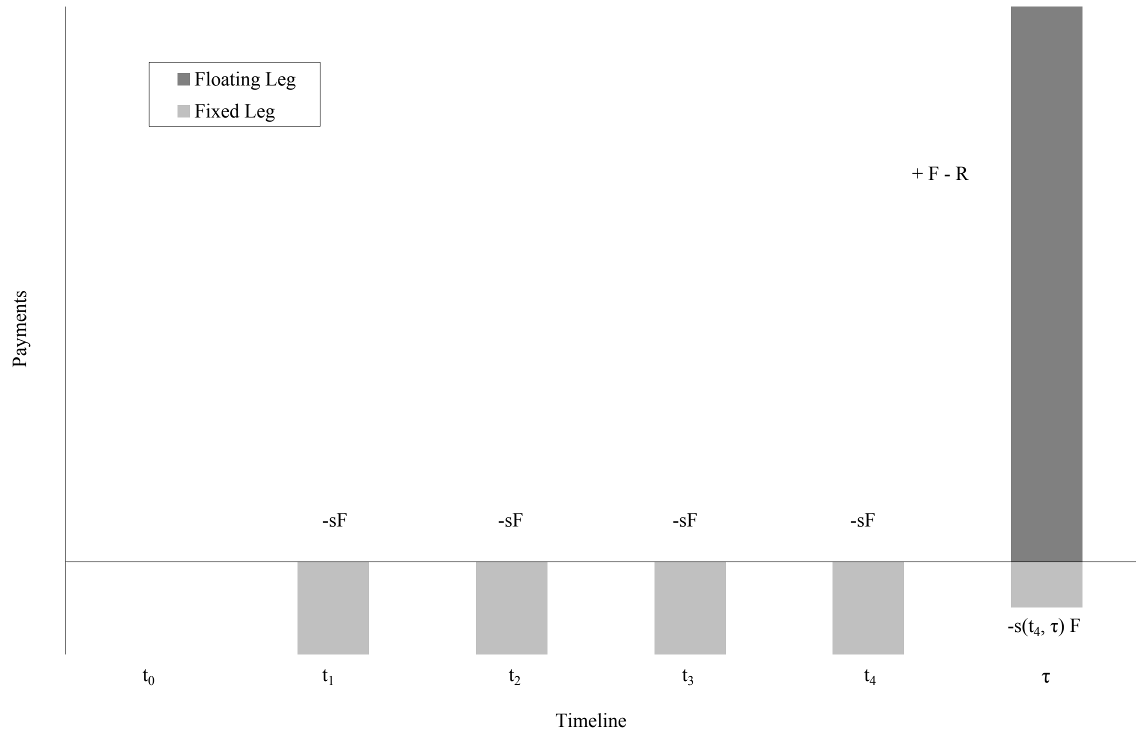
[1] The premium is quoted annualized and in basis points (bp) per unit of nominal value for which the credit protection applies.

[2] Payments are usually made in arrears, only for contracts with very short maturities or for very high

Credit events include events such as bankruptcy by the reference entity and failure to pay on or restructuring of specified reference obligations such as bank loans or bonds. If a credit event occurs at time $\tau < t_n$, the credit event is documented by a legal notice, and the CDS automatically terminates. As her termination payment, the buyer pays the premium accrued since the last payment date t_i to the seller. She announces which asset from the delivery basket she will transfer to the seller through a "Notice of Physical Settlement", transfers her claim on the asset to the seller, and obtains its face value in cash.[3] The equivalent value in cash of the protection seller's payment obligation therefore equals the face value F minus the post-default market price of the delivered asset R. The cash flows of a credit default swap are illustrated in Figure 2.1.

Figure 2.1: **Credit Default Swap Cash Flows**

The figure shows the cash flows in a CDS contract from the protection buyer's perspective. The inception date is denoted by t_0, the payment dates by $t_1, \ldots, t_4$, and the default date by τ. s is the CDS premium, F the face value of the contract, and R the market value of the delivered asset after default.



As in a standard interest rate swap contract, the CDS premium s is generally determined such that the value of the CDS contract at t_0 equals 0 both for the protection buyer and

CDS premia a single upfront payment is made at the inception date t_0.

[3] The British Bankers' Association estimates that 73% of CDS contracts specify physical delivery, see British Bankers' Association (2006). As an alternative to physical settlement, about 23% of CDS contracts specify cash settlement. We further discuss this settlement procedure in Section 2.3.

the protection seller. Therefore, the buyer and seller need to determine the expected present value of the fixed and the floating leg in order to find this value of s. Since τ and R are unknown at t_0, the value of s contains information regarding how the buyer and seller price the probability and severity of a credit event. For only about 3% of all contracts, the CDS contract specifies "Binary" or "Digital Settlement" where the contingent payment is fixed as a predetermined amount. This specification allows buyer and seller to exclusively price the probability of a credit event.

After the inception date, changes in the credit quality of the reference entity typically change the market value of the CDS. Unwinding the existing position through early termination then involves payments from the buyer to the seller if the credit quality has increased and from the seller to the buyer if the credit quality has decreased. Alternatively, the counterparties can assign their contract leg to a third counterparty or enter into an offsetting transaction. Usually the buyer and seller will not be default-risk free themselves. The counterparty risk may affect both the initial value of s and the payment upon early termination. In the following, we abstract from this feature.

In short, the standard CDS contract can be thought of either as an insurance contract against the credit risk for a given reference entity or as a synthetic vehicle for taking on this risk. The simple structure also facilitates the pricing of a CDS, i.e. the determination of the premium s. Duffie and Singleton (2003) argue that in a frictionless market (costless short selling, no transaction costs, no taxes, immediate payments, termination of all contracts upon default), the spread of a default-risky floating rate note issued at par over a default-free floating rate note also issued at par with the same maturity must equal the CDS premium of a contract written on that note if there is no arbitrage. Shorting costs and transaction costs can be integrated, but bonds with fixed coupons or trading away from par cannot be priced in the simplified no-arbitrage setting. An excellent overview of CDS valuation models which avoid this issue is given by Das and Hanouna (2006).

2.2 Market Organization, Size, and Participants

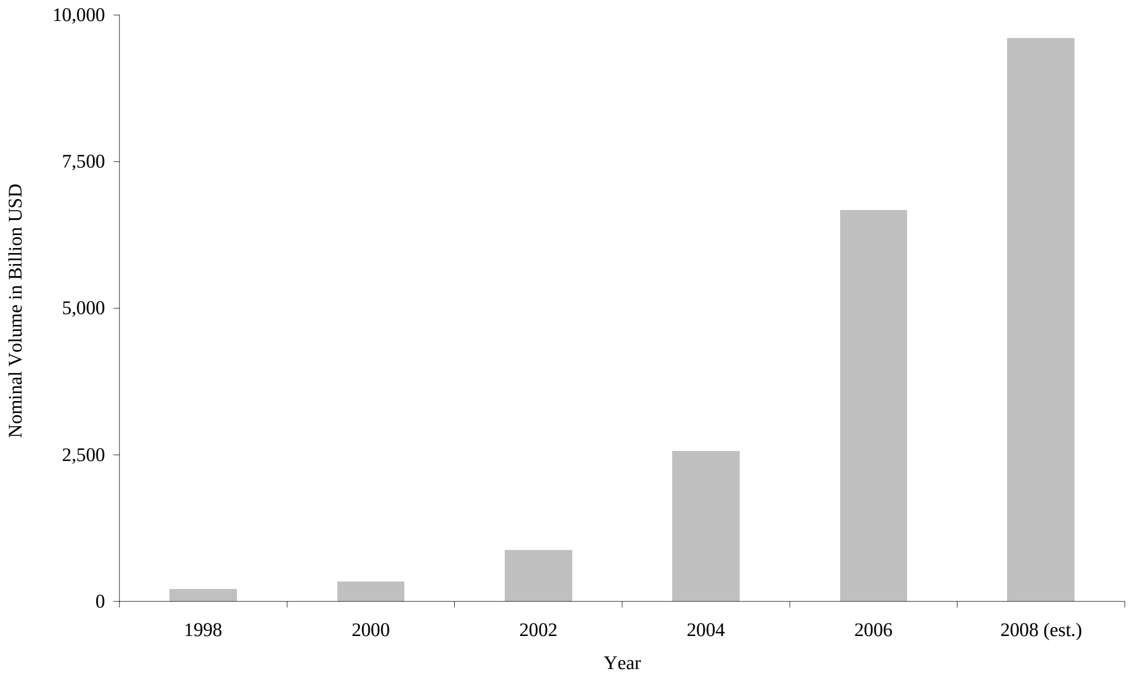
CDS contracts are mainly traded in the over-the-counter (OTC) market, see Gündüz et al. (2007). In particular, Meng and ap Gwilym (2006) claim that existing electronic trading platforms such as those distributed by Creditex or MarketAxess are mostly used for setting quotes. Traders usually set indicative bid and ask quotes via these systems, and actual trading takes place over the telephone with the contracts subsequently confirmed by the legal departments. This makes it difficult to obtain reliable data on the CDS market.

A particular problem refers to measuring the size of the CDS market. Due to its contractual nature, there is a risk of double-counting when a market participant effectually terminates her exposure as buyer or seller by entering into an offsetting contract with a third counterparty. The most frequently used sources are the British Bankers' Association's (BBA) surveys. They have been published since 1998 every second year and describe the evolution of the credit derivatives markets. In the following we refer to the market data compiled in British Bankers' Association (2004) and British Bankers' Association (2006).

Figure 2.2 shows the outstanding end-of-year nominal volume for the single-name CDS market.

Figure 2.2: **CDS Market Volume**

The figure shows the outstanding end-of-year nominal volume for the single-name CDS market in billion USD. Data Source: British Bankers' Association (2004) and (2006).

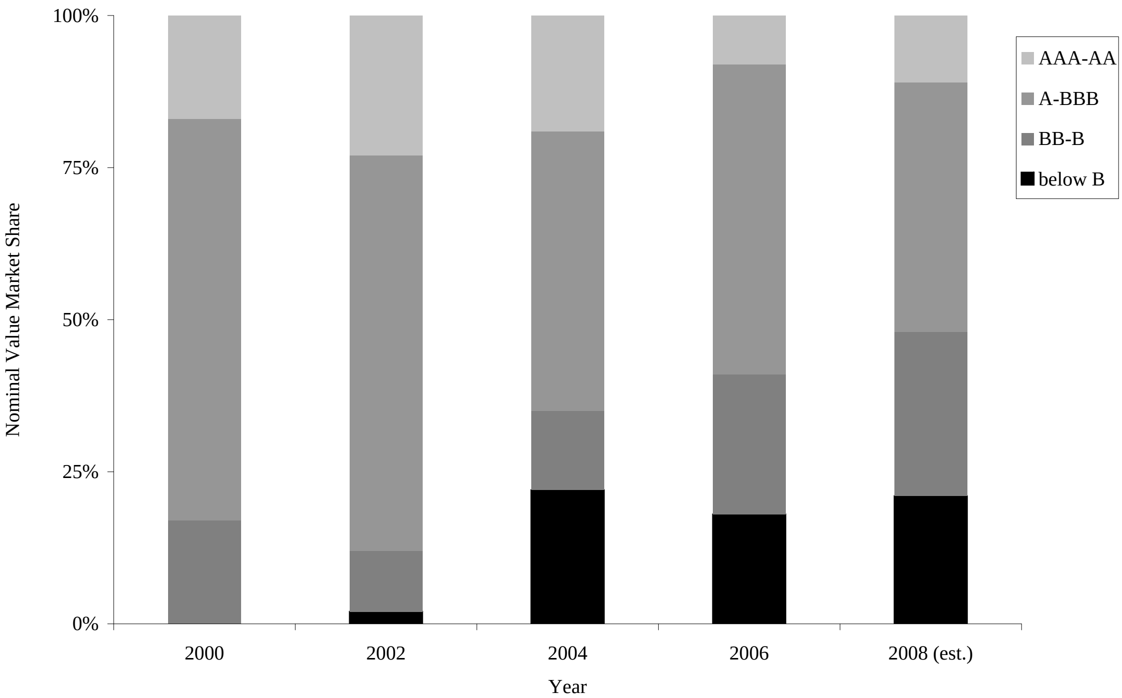


From an initial volume of 210 billion USD, the single-name CDS market has grown to 6,668 billion USD at the end of 2006. The BBA estimates a further increase to 9,600 billion USD for 2008. The entire market for credit derivatives is estimated to grow to 33,120 billion USD, and synthetic Collateralized Debt Obligations (CDO) which consist of a CDS portfolio are projected to amount to another 5,300 billion USD. If we contrast these numbers with the International Swaps and Derivatives Association's (ISDA) estimate of 15,000 billion USD for the nominal volume of the cash bond market in 2006, it becomes clear that single name CDS are of similar importance in trading credit risk as the secondary bond market.

Geographically, credit derivatives trading is concentrated in London at slightly below 40% of all trades by volume. The next-largest trading place is New York while Europe excluding London has a market share of 10%. With regard to the underlying reference entities, trading has historically been concentrated in investment grade entities with a rating between A and BBB. We present the evolution of the underlying obligation's rating distribution in Figure 2.3.

Figure 2.3: **Rating Distribution**

The figure shows the distribution of CDS across the rating of the underlying assets by market share relative to the outstanding nominal volume. Data Source: British Bankers' Association (2004) and (2006).



Overall, the average rating of the underlying assets has migrated downwards. The percentage of assets in the investment grade segment has fallen from 65% in 2004 to 59% in 2006 and is estimated to fall further to 52% in 2008. In contrast, the BB-B rating segment has grown from 13% to 23% and is expected to increase to 27% in 2008.

In Table 2.1, we summarize the distribution across the market participants in the credit derivatives market for 2006. We separate positions as protection buyer and seller, i.e. long and short credit risk positions.

Table 2.1: **Market Participants**

The table shows the percentages of market share in the credit derivatives market with regard to nominal volume for different participants who act as protection sellers (long risk), protection buyers (short risk), and the net risk position as of the end of 2006. A negative value suggests that the market participant is a net protection buyer. Data Source: British Bankers' Association (2006).

Market Participant		Seller (Long %)	Buyer (Short %)	(Net %)
Banks	Trading Book	35	39	-4
	Loan Portfolio	9	20	-11
Insurers	Mono-line	8	2	6
	Reinsurers	3	2	1
	Other	4	2	2
Corporates		1	2	-1
Hedge Funds		32	28	4
Pension Funds		4	2	2
Mutual Funds		3	2	1
Others		1	1	0

As Table 2.1 shows, banks are the largest participants in the credit derivatives market. On average, they operate as net protection buyers. The loan book in particular is combined with credit risk protection which allows banks to transfer credit risk to another counterparty. The banks' trading book remains the most important single participant, and this is probably due to the banks' dual role as intermediary in the OTC market and as end user. Insurers are the largest net protection sellers, they use the credit derivatives market to take on credit risk synthetically. Second only to banks, hedge funds have become a major participant in the credit derivatives market with high volumes in both buying and selling credit risk protection. In particular, they demand more credit risk protection than banks do for the loan book. Due to their different strategies, however, they are engaged more symmetrically. An example are basis trades where hedge funds enter in opposite positions in the CDS and the bond market if CDS premia and bond yield spreads, respectively asset swaps, differ sufficiently. Bühler and He (2007) show that these strategies are especially profitable when CDS premia exceed bond yield spreads. Pension and mutual funds as well as non-financial corporates are less heavily engaged in the credit derivatives market. As the Deutsche Bundesbank Monthly Report December 2004 finds, the increasing trading activities of hedge funds have caused fluctuations in single-name CDS premia. Pension and mutual funds mostly invest in CDS indices and CDO and therefore have no direct impact on the single-name CDS market.

2.3 Market Standardization, Accounting, and Legal Issues

Apart from the advantages which are associated with credit derivatives, some problematic issues arise. In particular in the early phase of the CDS market, market opacity due to the OTC nature raised concerns regarding the functioning of the CDS markets. These were partly redressed through the ISDA publication of the "1999 ISDA Credit Derivatives Definitions" jointly with the "1999 ISDA Master Agreement" and the 2003 definitions update which was published on February 11, 2003 and adopted with effect from June 20, 2003. The definitions are used in almost all single-name CDS contracts, leading to a high degree of standardization and thus liquidity in the CDS market. They provide standard answers to structural credit considerations including the reference entity, the credit event, the reference obligations, the protection period, the deliverable obligations, and the settlement procedure.[4]

Reference Entity In spite of its apparent simplicity, defining the appropriate reference entity whose credit risk is transferred can be intricate. A large corporate conglomerate can consist of subsidiaries who each have different debt issues outstanding. CDS contracts often specify either the subsidiary or the ultimate parent firm only, suggesting that the default risk and the post-default market value of the defaulted obligation may deviate significantly from the required credit risk profile. An example given by Pollack (2003) is the default of the US-based firm Armstrong World Industries, Inc. Armstrong World Industries filed for bankruptcy under chapter 11 in December 2000 while its parent firm Armstrong Holdings did not default. Market participants were holding CDS contracts which listed Armstrong Holdings as the reference entity but specified an obligation of Armstrong World Industries as the reference obligation. The protection sellers argued that a credit event had not occurred since Armstrong Holdings did not file for bankruptcy or default on the reference obligation.

At a more fundamental level, CDS contracts can also be written on reference entities which have no deliverable debt outstanding, making the standard protection virtually worthless. Concerns regarding this situation were raised in April 2006 when investors speculated about a buy-back of Air France's convertible bonds. Since this was the only

[4] For examples, we refer to Francis et al. (2004).

bond issue outstanding, no bonds would have been deliverable under the CDS contract after the buy-back. Consequently, CDS premia significantly decreased, see Scott (2006).

Provisions for mergers, demergers, and other corporate restructuring events were added by the ISDA in reaction to the National Power PLC demerger in 2000. To put it simply,[5] the provisions state that a successor holding 75% or more of the original debt becomes the sole successor of the original reference entity. If each successor holds less than 25% of the original debt and the original reference entity still exists, the contract provisions are unchanged. If the original reference entity has been dissolved, the new entity which holds the largest amount of original debt becomes the sole successor. If the fraction of debt lies between 25% and 75% for at least one reference entity, a new CDS is assigned to each successor.

Credit Event A credit event is triggered by:

- "Bankruptcy", including insolvency and the appointment of administrators, liquidators, and creditor arrangements,
- "Failure to Pay" on one or more obligations within a certain defined grace period and subject to a materiality threshold,
- "Restructuring" of claims due to deterioration of creditworthiness or the financial condition of the reference entity.[6]

The grace period which may be contained in the failure to pay credit event definition ensures that payments which are missed because of administrative or technical errors do not automatically trigger a default. The standard grace period is usually adopted from the prospectus of the obligation on which the failure to pay has occurred.[7] If the obligation does not specify a grace period, the ISDA definitions assume a grace period of three business days. Restructuring constitutes the most strongly discussed credit event. The current market convention excludes restructuring events which do not result from a deterioration in the creditworthiness of the reference entity. Standard criteria which lead to a credit event through restructuring encompass a reduction of the interest rate, the principal amounts, the seniority of the debt issue, or a postponement of payment dates. In addition, restructuring

[5] For a detailed discussion, see Richa (2007).

[6] The credit events obligation acceleration, obligation default, and repudiation/moratorium are also potential credit events. However, since April 2002, it has become market convention for corporate contracts on G7 reference entities not to use these credit events. Obligation default in particular is almost never included as a credit event.

[7] For senior unsecured bonds, the standard is a 30 calendar day grace period for coupon payments and a 15 calendar day period for principal payments.

of bilateral loans is excluded from the definitions by requiring more than three holders of the reference obligation and consent to restructuring by two thirds in order to qualify as a restructuring event.

Reference Obligation CDS contracts can be written on almost any financial instrument. In practice, ISDA gives 6 obligation categories. The broadest is “Payment” under which any present, future, or contingent payment is summarized, whether borrowed or not. Other categories are “Borrowed Money”, “Bond”, “Loan”, “Bond or Loan”, and “Reference Obligation Only”. The exclusion of undrawn credit facilities from the 2003 definitions ensures that a restructuring of undrawn facilities does not trigger a credit event. Overall, borrowed money which includes deposits and reimbursement obligations is the most widely used category. Obligation characteristics such as “Not Subordinated”, “Specified Currency”, or “Listed” further restrict the number of obligations which can trigger a credit event, but these are not customarily specified, see Francis et al. (2004).

Protection Period The 2003 ISDA definitions have changed the standard effective starting date of the credit protection from three business days after the trade date[8] to the first calendar date after the trade date. Credit events on the trade date remain uncovered by the CDS contract. The termination of the CDS contract can be either due to the scheduled termination date, early termination through a credit event, or early termination by bilateral agreement. March, June, September, and December 20 have evolved as the standard quarterly scheduled termination dates as of mid-2003. The time between the effective date and the next reference date is added to the quoted contract maturity. Therefore, a CDS contract entered into on a non-reference date with the standard 5-year maturity can effectually provide credit protection for up to $5\frac{1}{4}$ years.[9] The above-mentioned grace period decreases the value of credit protection since the standard contract specifies that the grace period for a “potential” failure to pay must have elapsed until the termination date of the CDS contract to trigger a credit event. If the termination date lies within the grace period, the “potential” failure to pay does not constitute a credit event except when a grace period extension is included in the contract provisions. Francis et al. (2004) argue that this inclusion is rare for standard contracts and mostly observed for emerging markets CDS.

[8]The trade date is the date on which the CDS contract was first orally or in writing agreed upon.

[9]CDS contracts with a 1-, 3-, 7-, and 10-year maturity are also traded, but the 5-year maturity constitutes the most liquid segment, see e.g. Meng and ap Gwilym (2006) and Gündüz et al. (2007).

Deliverable Obligation With regard to the basket of deliverable obligations, for a typical European corporate CDS all obligations are deliverable which rank pari passu or senior to the reference obligations that can cause a credit event. If no reference obligation is specified, the deliverable obligations must not be subordinate to any unsubordinated debt of the reference entity. In addition, the obligations must usually be denominated in EUR or one of the G7 currencies and be fully transferable from one holder to another, i.e. not a consent-requiring loan or a government savings bond. Contingent obligations such as callable bonds are usually excluded while non-mandatory convertible exchangeable bonds are deliverable,[10] and the maximum maturity is mostly specified at 30 years. Under the restructuring credit event, the maximum maturity is even shorter. The "Modified Restructuring" which prevails in the US and the European "Modified Modified Restructuring" specifications limit the final maturity date of the deliverable obligations to no later than 30 months for all deliverable obligations (US), respectively 60 months for restructured bonds and loans (Europe), after the maturity date of the restructured obligation. The modifications were added as a consequence of the 2000 Conseco, Inc. restructuring of its short-term credit facilities, see Pollack (2003). Only a single loan with a maturity of less than one year fell under the reference obligations, thus triggering a credit event, but the delivery of long-term debt with low market values was technically allowed under the ISDA agreement.

Settlement The standard physical settlement consists of three steps. When a credit event occurs, both buyer and seller may deliver a "Notification of a Credit Event" to the other counterparty. The legal limit until which this notice can be delivered is 14 calendar days after the scheduled termination date of the CDS contract - potentially years after the credit event has taken place. Additionally, the counterparty who serves the credit event notice may also have to deliver a "Notice of Publicly Available Information", confirming the source of information for the credit event. In the second step, the protection buyer delivers a "Notice of Physical Settlement" to the seller within 30 calendar days from the credit event notice in which she specifies which instrument she will deliver. The delivery of the physical settlement notice is the beginning of the physical settlement period which may last up to 30 calendar days. The third step consists of the actual delivery no later than 5 business days after the end of the physical settlement period. As an alternative to physical settlement, the CDS

[10] The ISDA supplement on convertible, exchangeable, or accreting obligations specifies that any determination of whether an obligation is not-contingent should focus on whether the right to receive principal is contingent. The supplement was added following the 2001 Railtrack default when Nomura attempted to deliver convertible Railtrack bonds and Credit Suisse First Boston declined to accept the bonds under the CDS contract. A detailed discussion is given by Pollack (2003).

contract can specify cash settlement. In this case, buyer and seller conduct either a market auction or a dealer poll to determine the market value R for a given deliverable asset. After the market auction, the seller pays the difference between the price at which the asset is sold and the face value to the buyer. For the standard dealer poll, a calculation agent has to poll one or more dealers for quotes on the reference obligation and determines the value from the quotes.[11] Harding (2004) notes that the seller usually acts as the calculation agent, but the buyer or a third party can also be specified in the CDS contract.

The standardization of the CDS market in general and the credit events in particular has directly affected the financial reporting of CDS contracts. We only discuss the reporting procedure for CDS under the International Financial Reporting Standard (IFRS); the GAAP treatment is similar. The premium payments on a CDS qualify as interest payments for the buyer and are treated as interest income for the seller. Until 2005, a CDS could either fall under IAS 39 as a financial instrument or, according to the exceptions stated with regard to financial guarantee contracts or insurance contracts, under IAS 37 or IFRS 4, see Felsenheimer et al. (2006). Since the 2005 IFRS novation, all CDS contracts are reported as financial derivatives or financial guarantees under IAS 39. The impact on the balance sheet and on the profit-and-loss account, on the other hand, depends on the contract's status as derivative or guarantee.

As a derivative, a CDS contract has to be reported as either an asset or a liability and must be disclosed at fair value. It thus enters the balance sheet at its initial value (which equals 0), and changes in the fair value must be recognized in the income statements in the period in which they occur. This fair value can be determined either through published price quotations if these are available for the CDS (i.e., if the maturity is a standard maturity) or through a valuation technique. If there is an asset against which the CDS is used as a hedging instrument, then changes in the fair value of the CDS contract are offset by changes in the asset. However, Hurdal and Yarish (2003) argue that this proceeding leads to a problem if the hedged asset is a bank loan or a comparable asset which is valued under accrual accounting rules. These assets enter the balance sheet at the origination value and are typically only revised immediately prior to a default. Therefore, if the CDS contract gains value as the creditworthiness of the reference entity deteriorates while a deterioration of the market value of the loan is not recognized. These net gains or, in the case of an

[11] Depending on the specification, the determination can either be "Market Value" (arithmetic mean of all quotes except for lowest and highest) or "Highest Value" (highest quote). If more than one date or deliverable obligation are specified, arithmetic means across the dates and the obligations are computed.

increase in the creditworthiness, net losses would further increase earnings volatility due to the accounting rules only, which firms typically want to limit.

If, on the other hand, the CDS contract is recognized as a financial guarantee, this mismatch does not arise. For a financial guarantee, IAS 39 states that valuation occurs in accordance with IAS 37 such that changes in the fair value are not reflected in the balance sheet. Instead, the reported value equals 0 if the probability of a credit event is smaller than or equal to 50% and, upon an impending default, the amount most likely to be paid by the protection seller.[12] This accounting procedure reasonable matches the standard for bank loans since impairments for the hedged exposure can be implicitly netted against the CDS contract.

The decision whether a CDS is a financial guarantee or a financial derivative is directly linked to the standard contract features. The general rule is that a CDS is classified as a financial guarantee if in the case of a credit event, (1) the protection buyer incurs a loss in the reference obligation, (2) the CDS payoff profile compensates for the loss on the reference obligation, and (3) the CDS contract is only triggered if due payments on the reference obligation do not take place. Therefore, Auerbach and Klotzbach (2005) argue that since almost all CDS contracts specify bankruptcy and restructuring as additional credit events, CDS contracts must in general be treated as financial derivatives. Felsenheimer et al. (2006), on the other hand, suggest that all three standard credit events should be recognized under the above conditions, excluding only obligation default, obligation acceleration, repudiation, and moratorium. Therefore, protection sellers in general and protection buyers who use CDS contracts to hedge an existing credit risk exposure in an economically meaningful way should be allowed to treat CDS contracts as financial guarantees.

In spite of the far-reaching market standardization, a number of issues regarding the processing of CDS contracts within an institution, selling CDS contracts from one counterparty to another, and contract settlement have arisen since the adoption of the 2003 definitions update. Instead of an even more detailed standard framework for CDS contracts, most of these issues have either been resolved through private efforts of the involved counterparties or directly by the ISDA via the publication of "Protocols". These documents provide a uniform set of rules for the protection buyer and seller which allows them to amend the existing contract to a situation where the standard contract features result in unexpected difficulties detrimental to both counterparties. By adhering to the

[12] In most cases, this amount equals the expected payment of the protection seller conditional upon the credit event.

protocols, the participants announce that they accept the protocols as an addendum to the master agreement.

As described by the Committee on Payment and Settlement Systems (2007), the New York Federal Reserve Bank urged 14 major banks in September 2005 to solve issues relating to the backlog of CDS contract confirmations from the legal departments. This action had been caused by complaints that banks were unable to process the credit derivatives confirmation documents; it took more than 40 business days to confirm a basic CDS transaction in a legally binding way. The issue was resolved by the banks without further actions from the regulating authorities by the strengthening of back offices and the development of electronic confirmation platforms such as Deriv/Serv.

A second issue relates to the early termination of a CDS contract through sale by one counterparty to a third counterparty. Numerous financial institutions had used this way to offset credit risk exposures in 2003 and 2004, leading to a situation where the eventual counterparty was unknown to the remaining original counterparty. This resulted, as documented by the Counterparty Risk Management Policy Group II (2005), in uncertainty regarding the counterparty risk and thus in disagreements about collateral requirements, and belated payments on the CDS contracts. The 2005 ISDA "Novation Protocol" has resolved this issue as described by the Committee on Payment and Settlement Systems (2007) through specifying that written consent for assigning contract positions to a third counterparty has to be obtained from the original counterparty by the end of the business day on which the transfer takes place.

A third and final issue regards the physical settlement procedures. If the volume of the outstanding CDS contracts is large relative to the volume of the deliverable obligations, price distortions are likely to arise. For specific cases such as the Delphi, Inc. and the Dana, Inc. default, the ISDA has published ad hoc protocols which allowed buyer and seller to switch to cash settlement in a standardized way in spite of the original contract provisions.

Chapter 3

CDS Premia, Bond Yield Spreads, and the Basis - An Econometric Approach

The purpose of this chapter is to explore the empirical relationship between bond yield spreads and CDS premia on the same reference entity. As Duffie (1999) shows, there is a clear theoretical link between CDS premia and yield spreads if the two quantities are viewed as a pure measure of credit risk. If they are affected by additional risk sources – such as liquidity – these risk sources may partially obscure the relationship. Many studies provide evidence that other factors than credit risk affect yield spreads and CDS premia. As an extreme case for the corporate bond sector, Elton et al. (2001) and Collin-Dufresne et al. (2001) find that only 25% of the yield spread can be attributed to default risk or explained by financial variables associated with it.

For the CDS market, Aunon-Nerin et al. (2002) and Tang and Yan (2007) explore the determinants of corporate CDS premia other than default risk. While the former authors claim that stock market liquidity measured as market capitalization does not matter, the latter study finds a liquidity premium in CDS transaction premia between 4 and 17 bp that accounts for approximately 26% of the entire CDS premium. Jankowitsch et al. (2007) provide an analysis of the impact of the delivery option on CDS premia and argue that its effect is about half as large as that of default risk. Dunbar (2007) develops a reduced-form model that includes a risk factor for market liquidity. He argues that neglecting liquidity risk when pricing CDS leads to an underestimation of the issuer-specific credit risk component.

In order to determine whether the link between the bond and the CDS market is similarly clear-cut as the argument of Duffie (1999) implies or whether, as above studies suggest, a more complex model is warranted, we analyze the relationship between CDS premia and yield spreads. Since the premia are not stationary, we cannot employ the standard ordinary least squares (OLS) regression framework. We instead focus on the cointegration relationship between the time series in the first part of our analysis. In the second part of our analysis, we show that both mid CDS premia and bond yield spreads are systematically affected by measures of market-wide and firm-specific credit risk and liquidity. Since the sensitivity of the two variables to the market-wide and firm-specific measures differs, the basis, defined as the difference between the mid CDS premium and the yield spread, also shows a significant sensitivity to credit risk and liquidity. Therefore, even though a combined position in a CDS and a bond is theoretically default-free, the position can be subject to significant credit-risk and liquidity induced variations in the market value.

3.1 Data

In this section, we describe the data set. Further details regarding the data collection procedure are given in Appendix 3.5.

3.1.1 Default-Free Reference Interest Rates

We first specify a proxy for the default-free interest rate. Obvious candidates are government rates or the interest rate swap rate. Grinblatt (1995) and Duffie and Singleton (1997) analyze the differences between the US Treasury and the swap rate term structure of interest rates and attribute these to a higher liquidity of Treasury bonds and different reactions to credit risk shocks. Hull et al. (2004) estimate that the default-free interest rate which makes CDS premia and yield spreads comparable lies between the Treasury and the swap rate with an average of 10 bp below that of the swap rate. They argue that bond traders often regard the Treasury zero curve as the appropriate zero curve while derivatives traders use the swap zero curve since it corresponds to their opportunity costs of capital. As there is no clear agreement in the literature regarding which interest rate to use, we have collected data both for the German government rate and the Euro swap rate. For the German government rate, we compute the interest rate curve for maturities between 1 day and 10 years using the estimates provided by the Deutsche Bundesbank on a daily basis. These estimates are determined by means of the Nelson-Siegel-Svensson method from prices of German government bonds which represent the benchmark bonds in the Euro area for most maturities. To compute the Euro swap rate curve, we collect daily interest rate swap rates for the Euro area from Bloomberg with maturities from 1 to 10 years and apply a cubic spline interpolation scheme. As the standard default-free interest rate, we use the German government rate. Since the differences to the results using swap rates were limited, we only discuss them in selected cases.[13]

3.1.2 CDS Premia

All CDS and bond data is collected from Bloomberg. CDS ask, bid, and mid premium quotes for reference entities from 9 industry sectors and the sovereign sector were made available to us through the Bloomberg system by a large international bank. As the starting and end point, we use June 1, 2001 (there were no CDS quotes available prior to this date) and June 30, 2007 which yields a total of 1,548 trading days.

We only choose Euro-denominated CDS with a 5-year maturity in order to obtain a sample which is homogenous with regard to the delivery option and highly liquid. This homogeneity has been discussed by Meng and ap Gwilym (2006) and Gündüz et al. (2007). In total, we obtain a set of 458 reference entities on which CDS contracts fulfilling the above criteria exist. For these reference entities, we determine the effective maturity between 5 and $5\frac{1}{4}$ years, see Section 2.3, as described in Appendix 3.5.

3.1.3 Bond Yield Spreads

For each reference entity, we collect the coupon, payment, and maturity dates of all senior unsecured Euro-denominated[14] straight bonds which were outstanding between June 1, 2001 and June 30, 2007. We exclude all bonds with more than 10 years to maturity at a given date since the modified-modified restructuring clause only allows for delivery of restructured assets with a time-to-maturity of up to 5 years in excess of the maturity of the restructured asset that triggered the credit event (see Section 2.3). We then download the time series of daily mid price quotes and the yields computed from mid price quotes for each of these bonds from June 1, 2001 to June 30, 2007. If the matched time series of CDS premia and bond yields has less than 20 observation points with one CDS bid and one ask quote and at least two bond quotes on consecutive trading days, we exclude the reference entity from the sample. The final sample consists of CDS contracts on 171 reference entities and 1,308 bonds for which mid price quotes, respectively yields from mid price quotes, are observed. The average length of the observation time series equals 806 trading days with a total of 137,816 CDS ask, bid, and mid quotes each and 552,399 bond yields. We determine the

[13]The resulting term structures were very similar. The swap rates were on average 12.46 bp higher than the government rates, the mean absolute difference equals 13.39 bp. A graph of the constant 1-year maturity and constant 5-year maturity time series is provided in Appendix 3.5.

[14]We limit the currency to EUR for bonds issued after January 1, 2002, and to the currency of countries with a fixed exchange rate between their national currency and EUR from June 1, 2001 to December 31, 2001 for bonds which were issued earlier.

yield spreads over the default-free interest rate as described in Appendix 3.5 to obtain a synthetical maturity which is identical to that of the CDS (5 to $5\frac{1}{4}$ years).

3.1.4 Firm-Specific Measures

As firm-specific measures of credit risk, the reference entity's rating and variables derived from traded stocks and stock options are explored. First, we use Standard&Poor's (S&P) and Moody's ratings. In their empirical analysis, Aunon-Nerin et al. (2002) find that the rating is the major determinant of CDS premia. Its explanatory power lies at 40% for their entire sample and increases to 66% for their sovereign subsample. However, the use of rating data as a dynamic measure of credit risk can also be problematic. First, rating agencies claim that their ratings are a through-the-cycle evaluation, and second, information on a borrower's creditworthiness may be reflected in CDS premia before the rating is adjusted. An example supporting this concern by Hull et al. (2004) shows that CDS premia partly anticipate rating changes while only reviews for rating downgrades contain information that significantly affects the CDS market.

Equity data is used in two ways. First, we directly employ stock returns as a measure of the individual firm's financial perspectives. While Kwan (1996) observes that bond yield changes are explained up to 60% by Treasury yield and stock return changes, Collin-Dufresne et al. (2001) find that the explanatory power decreases to only 5% when yield spread changes are the dependent variable. The impact of stock return changes is negative in both studies. Campbell and Taksler (2003) also analyze the relation between yield spreads and stock returns and find that mean daily excess stock returns have a negative impact on yield spreads.

Second, we use the historical volatility of stock returns and the option-implied volatility to measure credit risk as an alternative to a firm's rating. Even though we do not necessarily expect all these variables to have a simultaneous effect, the volatilities may provide more accurate information on changes in a firm's creditworthiness in the short run. If possible, we employ both the stock return volatility and the option-implied volatility since the former is a backward-looking measure of credit risk while the latter is forward-looking. The option-implied volatility may thus be associated more closely with yield spreads and CDS premia. This hypothesis is supported by Cremers et al. (2004) and Benkert (2004) who show that implied volatilities have an additional explanatory power in excess of historical volatilities and the rating. Overall, we obtain 233,780 daily stock return and 54,099 option-implied volatility data points.

3.1.5 Market-Wide Measures

We also explore the effect of the state of the economy, market-wide credit risk, and market-wide liquidity to analyze whether CDS premia, yield spreads, and the basis are affected more strongly by the general state of the economy than by firm-specific conditions.

Interest Rates

It is a well-documented finding that the level and slope of the interest rate curve have a significant impact on the level and the changes of CDS premia and yield spreads. From a technical point of view, Longstaff and Schwartz (1995) argue that a higher spot rate increases the risk-neutral drift of the firm value and thus decreases the default probability and yield spreads. In contrast, Leland and Toft (1996) discuss that if leverage and the default boundary are determined optimally, credit spreads can also increase if the default-free interest rate increases. With regard to the slope of the term structure of interest rates, Litterman and Scheinkman (1991) and Chen and Scott (1993) show that most of the variation of the term structure of Treasury bonds can be captured in changes of the level and the slope of the term structure. Therefore, both may affect the firm value and thus credit spreads.

Empirically, Duffee (1998) documents that yield spread changes react negatively to increases in the level and the slope of the Treasury curve. CDS premia also depend negatively on the interest rate level and slope as Aunon-Nerin et al. (2002) and Benkert (2004) show. Joutz et al. (2001) present evidence that the relation between credit spreads and the term-structure variables depends on the time-to-maturity and the rating. In addition, their cointegration analysis shows that Treasury yields are negatively related to credit spreads in the short run while the relation in the long run is positive.

Economically, the direction in which the interest rate variables affect CDS premia and yield spreads is not clear since contrary effects prevail. On the one hand, the effect described by Longstaff and Schwartz (1995) leads to a negative correlation with the level of the interest rate. In addition, default-free interest rates function as key rates in monetary policy. In recession phases, central banks lower interest rates to boost the economy and increase them in booms to prevent an overheating of the economy. Therefore, low interest rates coincide with recession phases which are marked by high CDS premia and yield spreads. Collin-Dufresne et al. (2001) also argue that a higher Treasury slope provides a measure of uncertainty about the economy and about the expected future short rates.

On the other hand, Leland and Toft (1996) demonstrate that increases in the default-free interest rate have an intricate effect on the optimal default boundary. If the notional debt value and the debt coupon are chosen optimally, the optimal default boundary can increase for a higher interest rate, and the credit spreads increase for intermediary maturities. In addition, higher interest rates make financing for firms more costly, and in particular firms who depend on short-term financing such as commercial papers or, like financial companies, have a higher interest expenditure ratio, may be more sensitive towards their financing cost due to the fact that they have mostly short-term liabilities and long-term assets which are both subject to interest rate risk.[15] This effect causes a positive association between CDS premia, respectively yield spreads, and interest rates.

Instead of the government or swap rate, we use the European Interbank Offered Rate (EURIBOR) as the "risk-free" interest rate in order to avoid endogeneity in the empirical analysis. We obtain the official daily EURIBOR interest rates from the International Capital Markets Association (ICMA) website. Overall, the time series of interest rates with maturities of 1 to 4 weeks and 1 to 12 months at a daily frequency from June 1, 2001 to June 30, 2007 contains 23,103 observations.

Corporate Bond Indices

The use of corporate bond indices as a measure of bond-market-wide credit risk is motivated by the flight-to-liquidity and the flight-to-quality effect described by Longstaff (2004) and Vayanos (2004). If market-wide credit risk increases, investors tend to move funds out of more risky and into virtually default-free investments, thus increasing the latter's price and lowering the price of default-risky debt.

Empirical evidence for the relation between market-wide indices and the bond yield spreads for a single firm is given by Collin-Dufresne et al. (2001) who document a positive association between changes in the implied volatility of the S&P 500 index and yield spread changes. Gebhardt et al. (2005) demonstrate that market-wide bond index returns, determined from price changes, coupon payments, and accrued interest, are among the most important determinants for the variation of individual bond returns. Ericsson et al. (2008) extend the evidence regarding the impact of market-wide indices to CDS bid and ask quotes. The results of Schueler and Galletto (2003) suggest that not only CDS premia and yield spreads are affected by bond and stock market indices, but that these also have an impact on the basis.

In order to extend the authors' anecdotal evidence, we include the JPMorgan Aggregate Index Europe, and the S&P Global Corporate Bond Indices which are available for all rating

[15] The Deutsche Bundesbank reports that the outstanding nominal lending volume to banks increased from EUR 2,239.71 billion in June 2001 to EUR 3,043.27 billion in June 2007.

classes between AAA and B with a constant 5-year maturity. We describe the indices in more detail in Appendix 3.5.

Financial Market Liquidity Indicator

As a measure of market-wide liquidity, we use the European Central Bank (ECB) Financial Market Liquidity Indicator which aims at simultaneously measuring the liquidity dimensions price, magnitude, and regeneration by combining 8 individual liquidity measures for the Euro area. The time series was made available to us by the ECB, and we describe the index in more detail in Appendix 3.5.

3.2 Descriptive Data Analysis

Before we analyze the relationship between CDS premia and yield spreads, we provide a basic description of the properties of our data set.

3.2.1 Distribution Across Rating Classes and Industry Sectors

The majority of studies on the relationship between CDS premia and yield spreads either focusses on sovereign or corporate reference entities. Andritzky and Singh (2007) perform a case study for CDS premia and bond yield spreads for the default of Brazil, Chan-Lau and Kim (2004) analyze the relation between sovereign bond indices, sovereign CDS premia, and national stock indices. Longstaff et al. (2005), Blanco et al. (2005), and Zhu (2006) only consider corporate names. Even for the corporate sector, many studies only differentiate between rating classes and not between financial and non-financial reference entities.

We believe that this distinction is relevant since financial firms are the major counterparties in the CDS market. Acharya and Johnson (2007) show that there is evidence of informed trading of banks in the CDS market. Because the trader's information regarding a financial underlying is better than for a non-financial one, CDS premia from the two sectors are likely to have a different level and a different sensitivity to the explanatory variables. Düllmann and Sosinska (2007) explore this hypothesis and find that changes in CDS premia for financial reference entities are positively related to changes in default-free interest rates. In addition, they present anecdotal evidence for a weak link between CDS-implied default probabilities and expected default frequencies for banks. A potential explanation is that financial firms are typically much more closely monitored by the regulators, causing a different behavior as the firm value deteriorates than for non-financial corporate reference entities. This effect should also be reflected in the bond market.

In addition, none of the above studies analyze subinvestment grade instruments because data on CDS on lower grade debt has traditionally been scarce. An exception is Ericsson et al. (2005), but the authors do not differentiate by industry sectors. Due to our large data set, we are able to analyze sovereign, financial, and non-financial corporate reference entities from 8 different industry sectors and partition the sample into investment and subinvestment grade debt. Table 3.1 presents the distribution of the reference entities and the observations across the different rating classes and industry sectors. For ease of exposition, we first compute the time series average numerical rating of a reference entity across all days with sufficient observations. We then map the numerical value to the S&P rating and use this as the column heading.

Table 3.1 shows that most reference entities have an average investment grade rating if time series averages are considered; only 13 lie in the subinvestment grade range. Nevertheless, we observe 8,993 CDS mid premia and 19,906 bond yields for these 13 reference entities which suffices for the following empirical analyses. In addition, many reference entities exhibit a subinvestment grade rating at some date in the observation interval.

The largest industry sector, both regarding the number of reference entities and the number of observations, is the financial sector with 54 reference entities and 175,870, respectively 38,046, bond yield and mid CDS premium observations. These numbers amount to 32% of the bond yield observations and 28% of the mid CDS premium observations. Moreover, financial firms are among the top-rated ones, constituting 34% of the investment grade reference entities.

Regarding the sovereign sector, Table 3.1 shows that there is both a significant variation in the average rating and a relatively high number of observations. 5 out of the 6 AAA-rated and two out of the three B-rated reference entities are sovereigns. This rating diversity in conjunction with the 6,594 CDS premia suggests that it is possible to treat the sovereign sector separately in the empirical analyses as well. This is of particular interest because the study of Packer and Suthiphongchai (2003) implies that corporate ratings have a different informational content than sovereign ratings.

As described in Section 3.1.3 and in Appendix 3.5, the bond yield observations for each reference entity are converted into synthetical yield spreads with the same time-to-maturity as the CDS contracts on the reference entity. We can therefore directly compare the CDS premium to the yield spread and compute the basis as the difference between these two quantities. In the next sections, we present the descriptive statistics of the CDS premia,

Table 3.1: **Reference Entities by Industry Sector and Rating Class**

The table shows the number of reference entities in each rating class and industry sector. Ratings are averages for the firm over all dates on which both CDS ask and bid premia and at least two bond prices were observed. The last columns and rows show the number of mid bond prices and mid CDS premia for each industry group and rating class in our sample between June 1, 2001 and June 30, 2007. The number of synthetical bond yields matched to the CDS contract maturity equals the number of CDS observations and is therefore suppressed.

	AAA	AA	A	BBB	BB	B	All	# Obs. Bonds	# Obs. CDS
Basic Materials	-	2	4	7	2	1	16	33,393	13,079
Communication	-	1	7	8	3	-	19	73,211	20,481
Cycl. Cons. Goods	-	2	3	9	2	-	16	47,497	15,634
Diversified	-	-	2	2	-	-	4	6,536	3,096
Financial	-	22	28	4	-	-	54	175,870	38,046
Industrial	-	-	4	5	-	-	9	40,624	9,531
Noncycl. Cons. Goods	-	-	5	8	1	-	14	40,519	12,319
Sovereign	5	1	3	3	2	2	16	55,145	6,594
Utility	1	5	13	4	-	-	23	79,604	19,036
All	6	33	69	50	10	3	171	552,399	137,816
# Obs. Bonds	40,414	137,702	193,195	161,182	16,399	3,507	552,399		
# Obs. CDS	2,946	29,129	55,221	41,527	7,962	1,031	137,816		

the interpolated yield spreads computed with regard to the different default-free reference interest rate, and the resulting basis.

3.2.2 Mid CDS Premia

In contrast to Table 3.1, Table 3.2 is compiled for the actual rating at each observation date instead of the time series average rating, i.e. the time series for which the statistics are computed is allowed to fluctuate between the rating classes, and observations are assigned to the rating class which contained the reference entity at the observation date.

As Table 3.2 shows, the mean and median CDS premia for the entire sample increase monotonously as the rating deteriorates. For each rating step, the mean and median premia approximately double within the investment grade segment, and as the rating goes down to subinvestment grade, they increase by almost 400%. From the BB to the B rating class, the increase is approximately 160%. This finding supports the notion that the difference between CDS premia for the lowest investment grade and the highest subinvestment grade rating class is larger than between two rating classes from the same segment. Default insurance for subinvestment grade debt becomes much more costly than for investment grade debt.[16] The standard deviation also increases across rating classes starting from the AA rating segment in absolute terms, but relative to the mean and median premia, it is much higher for the investment grade segment. The values of 193% (AAA), 72% (AA), 90% (A), and 118% (BBB) versus 93% (BB), 49% (B), and 13% (CCC) relative to the mean premia imply that the variation in CDS premia may be too high to be explained by default risk alone.[17]

Comparing financial to non-financial corporate reference entities, we find that mean and median CDS premia for financial entities are consistently lower than for non-financial ones in the same rating class. This is especially pronounced for AAA-rated entities and those in the subinvestment grade sample. At first, this seems surprising since a default within the financial sector would have severer consequences than in other corporate sectors because of systemic risk and a potential spillover into the real economy. As CDS could then be used as default insurance against the firm-specific and the market-wide risk, premia ought to be *higher*, not lower, for the financial sector. A first economic explanation draws on

[16] The only exception is the CCC rating class, but since we only have 171 observations, the lower value of 289.81 bp may not be representative. A similar behavior is reported by Ericsson et al. (2005), but they obtain the maximal CDS premia for the BB rating class.

[17] The numbers are compiled both across reference entities and over time. The standard deviation for a single reference entity over time is typically much lower than that across the entire sample in one rating class.

Table 3.2: **Descriptive Statistics of Mid CDS Premia**

The table shows the mean, median, standard deviation, minimum, maximum, and number of observations for the CDS mid premia. The values are determined row-wise cross-sectionally across reference entities in the industry sector and column-wise over time across reference entities which have the column-heading rating on a given date. All values are in basis points.

		AAA	AA	A	BBB	BB	B	CCC	All
All	Mean	6.27	15.23	35.00	71.64	275.77	437.34	289.81	54.82
	Median	3.25	12.09	25.88	46.22	171.25	375.97	287.67	28.75
	Std. Dev.	12.11	11.00	31.68	84.31	257.31	216.40	38.92	98.80
	Min.	1.00	2.50	5.20	9.00	38.50	121.67	225.40	1.00
	Max.	90.00	183.33	368.50	1,393.75	1,874.88	1,158.33	416.25	1,874.88
	# Obs.	3,085	29,661	57,745	40,641	4,621	1,892	171	137,816
Financial	Mean	8.06	13.07	23.20	46.29	104.31	-	-	19.03
	Median	8.03	10.60	18.33	39.67	99.00	-	-	14.17
	Std. Dev.	1.80	7.94	20.77	31.08	27.46	-	-	18.25
	Min.	5.53	3.00	5.22	18.33	71.67	-	-	3.00
	Max.	10.67	127.50	260.00	310.00	171.25	-	-	310.00
	# Obs.	106	19,749	16,473	1,657	61	-	-	38,046
Non-Financial	Mean	48.49	21.34	40.66	72.82	279.72	396.38	289.81	70.30
	Median	49.88	17.25	29.75	46.69	168.45	353.69	287.67	37.93
	Std. Dev.	20.21	14.46	34.42	85.86	263.52	188.61	38.92	110.15
	Min.	18.75	5.33	5.62	9.00	38.50	121.67	225.40	5.33
	Max.	90.00	183.33	368.50	1,393.75	1,874.88	1,158.33	416.25	1,874.88
	# Obs.	192	8,724	39,254	38,798	4,362	1,675	171	93,176
Sovereign	Mean	3.29	6.26	21.12	51.76	241.37	753.48	-	42.48
	Median	3.12	6.38	14.50	43.25	236.00	780.00	-	6.25
	Std. Dev.	1.53	1.68	14.05	23.02	67.49	144.49	-	140.54
	Min.	1.00	2.50	5.20	25.00	113.00	228.00	-	1.00
	Max.	20.52	12.75	60.75	105.50	380.00	992.50	-	992.50
	# Obs.	2,787	1,188	2,018	186	198	217	-	6,594

the asymmetric information effect explored by Acharya and Johnson (2007), a second on the contract-specific counterparty risk which may be higher given the default of a financial reference entity. A third potential explanation lies in the fact that a bank may effectually be too big to fail. As lender of last resort, a central bank provides additional financial resources to banks in distress. Under this assumption, the only relevant default event of the CDS contract is restructuring which leads to lower average CDS premia. As argued above, defaults are also effectively prevented by a closer monitoring. Since this behavior is unique to the financial sector, it may be difficult to compare the creditworthiness implied by a rating for a financial and a non-financial institution. Following the above argument, the rating of a financial institution may not measure the probability of bankruptcy or failure to pay, but rather be aimed at the soundness of the institution's overall economic health.

The standard deviation is also lower for the financial sector on an absolute level, but relative to the mean and median, there do not seem to be any systematic differences in the standard deviations. We take this as further evidence that non-credit risk related factors affect CDS mid premia.

For the investment grade segment, CDS premia on sovereign reference entities are slightly lower than for financial reference entities. For the subinvestment grade rating classes, however, CDS premia are much higher than for financial or non-financial corporate reference entities. This can be attributed a lack of cross-country bankruptcy regulations. For a sovereign default, an investor holding debt securities will have difficulties in even filing her claims against the defaulted country, let alone recover a significant proportion. On the other hand, if a foreign firm defaults to whose firm-specific risk the investor is exposed, the investor will be able to file her claims under the local bankruptcy code. Consequently, the potential loss given default to an individual investor is likely to be smaller for the corporate sector. Therefore, CDS protection sellers will charge higher premia for sovereign reference entities.

3.2.3 CDS Bid-Ask Spreads

The descriptive statistics of the CDS bid-ask spreads are presented in Table 3.3.

As Table 3.3 shows, the bid-ask spread level increases as well as the mid premium as the rating deteriorates. From a mean value of 2.54 bp and a median of 2.00 bp for the AAA rating class, the maximal mean and median of 29.16 bp, respectively 23.22 bp, are attained for the B rating class. This holds both for the entire sample and for each industry sector. For the relative bid-ask premia, however, we observe the reverse effect: the mean and median values

Table 3.3: **Descriptive Statistics of CDS Bid-Ask Spreads**

The table shows the mean, median, standard deviation, minimum, and maximum of the absolute CDS bid-ask spread (ask - bid) and of the relative CDS bid-ask spread ($\frac{\text{ask}-\text{bid}}{\text{mid}}$). The values are determined row-wise cross-sectionally across reference entities in the industry sector and column-wise over time across reference entities which have the column-heading rating on a given date. The absolute bid-ask spreads are in basis points, the relative bid-ask spreads in percentage points. The number of observations is as in Table 3.2.

		Level								Relative to Mid							
		AAA	AA	A	BBB	BB	B	CCC	All	AAA	AA	A	BBB	BB	B	CCC	All
All	Mean	2.54	4.21	5.70	7.48	27.43	29.16	8.96	6.89	71	31	20	12	9	7	3	21
	Median	2.00	3.33	4.36	5.00	13.00	23.22	8.80	4.50	63	30	18	11	7	6	3	17
	Std. Dev.	1.56	2.38	4.27	10.82	50.46	19.67	2.20	12.56	34	12	09	6	5	3	1	15
	Min.	0.01	-2.33	1.00	0.02	0.00	5.33	4.67	-2.33	0	-21	0	0	0	1	2	-21
	Max.	12.50	55.00	80.00	327.33	552.75	160.00	20.00	552.75	65	160	159	67	42	38	7	165
Financial	Mean	3.30	3.77	4.91	6.32	8.81	-	-	4.38	41	32	25	14	9	-	-	28
	Median	2.97	3.00	4.00	5.33	10.00	-	-	3.50	41	30	23	13	9	-	-	27
	Std. Dev.	0.93	1.99	3.32	4.98	2.09	-	-	2.90	6	11	10	5	3	-	-	11
	Min.	2.00	-2.33	1.84	1.00	5.00	-	-	-2.33	28	-21	0	3	3	-	-	-21
	Max.	5.33	20.00	40.00	120.00	12.50	-	-	120.00	50	60	96	67	14	-	-	160
Non-Financial	Mean	7.63	5.46	6.08	7.50	27.66	26.92	8.96	8.01	16	30	17	12	9	7	3	16
	Median	8.50	4.71	4.67	5.00	13.00	21.00	8.80	5.00	16	27	16	11	7	7	3	13
	Std. Dev.	2.80	2.80	4.61	11.01	51.80	18.80	2.20	14.80	4	14	8	5	5	3	1	9
	Min.	2.50	1.00	1.08	0.02	2.60	5.33	4.67	0.02	6	5	0	0	1	1	2	0
	Max.	12.50	55.00	80.00	327.33	552.75	160.00	20.00	552.75	27	107	59	65	42	38	7	159
Sovereign	Mean	2.16	2.37	4.71	14.64	28.26	46.41	-	5.57	76	40	24	33	12	6	-	49
	Median	2.00	2.25	3.50	15.00	30.00	45.00	-	2.33	64	36	22	33	13	6	-	39
	Std. Dev.	0.41	0.51	2.97	1.42	14.32	17.58	-	9.94	32	14	9	13	5	2	-	33
	Min.	0.01	0.00	1.00	10.00	0.00	20.00	-	0.00	0	0	0	9	0	3	-	0
	Max.	3.50	5.00	12.00	17.50	80.00	112.50	-	112.50	65	100	69	55	26	12	-	165

decrease with the rating. Again, this holds for the entire sample and each industry sector. If we take the bid-ask spread as a proxy for liquidity, this implies that absolute liquidity premia increase with credit risk while relative liquidity premia per basis point decrease. This finding has been explored for corporate bonds by Ericsson and Renault (2006) in a theoretical setting. In the CDS market, evidence on the behavior of bid-ask spreads is somewhat less conclusive. Acharya and Johnson (2007) do not find a significant relationship between CDS mid premia and bid-ask spreads, but Tang and Yan (2007) show that for a broader sample of traded contracts, bid-ask spreads relative to the mid premium seem to decrease with rating. They attribute this to a higher interest in credit protection for the lower-rated reference entities and, as a result, more active trading.

Comparing absolute and relative bid-ask spreads for the different industry sectors, we find that sovereign and, for the BBB rating class, financial reference entities exhibit the lowest absolute bid-ask spread for the investment grade segment. In the subinvestment grade segment, absolute bid-ask spreads are somewhat lower for non-financial corporate reference entities. With regard to the relative bid-ask spread, the sovereign sector exhibits the highest values while those for non-financial corporate reference entities are lowest. This finding is in contrast with the informational asymmetry argument by Acharya and Johnson (2007). Tang and Yan (2007) also argue that CDS contracts on non-financial corporate reference entities are traded at a higher frequency. This implies a shorter time until a protection buyer or seller can unwind her position, leading to lower search costs and lower bid-ask spreads. This market microstructure argument is supported for our data set by the fact that mean and median bid-ask spreads are low when the number of observations is high.

3.2.4 Bond Yield Spreads

The descriptive statistics of the synthetical 5-year yield spreads over the default-free interest rates are presented in Table 3.4.

As the minimal values show, we obtain partly negative yield spreads. For the entire sovereign and the financial sector in the AAA rating class, the negative values are caused by interpolating negative yield spreads. These surprisingly large negative values also cause the negative mean for the sovereign sector in the A rating class. We have carefully checked each bond for which we obtained a negative yield spread and were unable to identify contractual differences or a specific time interval that could have caused these negative values. For the remaining financial rating classes and the entire non-financial corporate sector, we only obtain negative values when we extrapolate the observed yield spreads.

Table 3.4: **Descriptive Statistics of Synthetical 5-Year Bond Yield Spreads**

The table shows the mean, median, standard deviation, minimum, and maximum of the synthetical 5-year bond yield spreads over the German government bond interest rate. The values are determined row-wise cross-sectionally across reference entities in the industry sector and column-wise over time across reference entities which have the column-heading rating on a given date. All values are in basis points. The number of observations is as in Table 3.2.

		AAA	AA	A	BBB	BB	B	CCC	All
All	Mean	6.23	64.12	64.87	144.67	276.28	472.25	253.96	99.90
	Median	4.41	30.57	45.19	106.74	149.10	386.76	247.19	55.51
	Std. Dev.	35.89	144.28	84.72	142.76	302.35	292.44	41.05	149.51
	Min.	-260.17	-63.85	-207.20	-89.27	-48.82	-58.39	178.45	-260.17
	Max.	223.23	1,380.78	1,243.50	2,442.06	2,288.17	2,231.71	334.49	2,442.06
Financial	Mean	17.98	72.22	41.29	94.70	84.01	-	-	59.68
	Median	19.10	31.18	34.94	91.62	85.02	-	-	33.83
	Std. Dev.	9.13	170.63	37.51	47.27	12.18	-	-	126.85
	Min.	-3.55	-39.56	-75.71	14.29	56.63	-	-	-75.71
	Max.	34.02	1,380.78	621.45	235.44	107.94	-	-	1,380.78
Non-Financial	Mean	67.03	47.64	78.59	147.12	284.17	456.00	253.96	121.02
	Median	75.26	29.13	55.55	110.91	149.54	375.97	247.19	77.72
	Std. Dev.	22.07	61.64	95.81	145.29	309.09	302.71	41.05	155.01
	Min.	10.71	-63.85	-79.17	-89.27	11.17	-58.39	178.45	-89.27
	Max.	109.96	800.44	1,243.50	2,442.06	2,288.17	2,231.71	334.49	2,442.06
Sovereign	Mean	1.60	50.44	-8.43	84.75	163.15	596.55	-	34.34
	Median	1.79	16.75	-2.06	43.41	160.19	622.62	-	12.65
	Std. Dev.	33.27	67.46	43.63	69.42	61.49	146.28	-	122.32
	Min.	-260.17	-1.21	-207.20	17.04	-48.82	264.58	-	-260.17
	Max.	223.23	320.28	138.62	214.34	295.06	832.55	-	832.55

Table 3.4 demonstrates that in spite of the similarities, there are also clear differences between CDS mid premia and yield spreads. Even though the mean and median of the yield spreads increase for the lower rating classes, the difference between the mean and the median is larger than for mid CDS premia, pointing at outliers in the right-hand tail of the distribution. Ericsson et al. (2005) report slightly higher mean values but a similar deviation between mean and median.

The differences between the rating classes for the entire sample seem to be not quite as clear-cut for the mean yield spreads as for the mid CDS premia, in particular the differences between the AA and the A rating class are almost negligible. This is mostly caused by the low yield spreads for A-rated sovereign reference entities. In comparison to the mid CDS premia, we find that the average yield spread is higher than the CDS premium, and the difference is more pronounced for the intermediate rating classes and the sample means. This results in a pronounced basis smile as described by Schueler and Galletto (2003). The median values differ less strongly, and in particular for the subinvestment grade segment, the mid CDS premia almost coincide with or exceed the yield spreads.

Comparing the yield spreads for the different industry sectors, we find that sovereign reference entities tend to display the lowest yield spreads while non-financial corporate reference entities have the highest yield spreads. The higher liquidity of sovereign bonds may be one explanation for this finding, our choice of the default-free interest rate a second one.[18] But since we observe a similar relation between the financial, non-financial, and sovereign sector CDS premia, it could be argued that the yield spreads reflect different recovery rates for the sovereign sector, and possibly a different default definition for financial entities.

A comparison of the yield spreads over the government yield curve and the swap curve reveals that both samples only exhibit limited differences in their descriptive statistics. Since the swap rates are slightly higher than the government rates, the mean and median yield spreads are lower by approximately 10 bp to 20 bp. The differences decrease as the rating deteriorates,[19] and are almost negligible for subinvestment grade financial and sovereign reference entities.

[18] In fact, it is difficult to judge whether it is appropriate to compare the yield of traded sovereign bonds to the Nelson-Siegel-Svensson curve computed for German government bonds.

[19] Since we first determined the yield spreads for each bond as described in Appendix 3.5 and then interpolated the yield spreads to a synthetical 5-year maturity, the difference is not constant cross-sectionally.

3.2.5 Basis

To conclude this section, we exhibit the descriptive statistics of the basis, computed as the difference between the mid CDS premium and the yield spreads, in Table 3.5.

Overall, we see from Table 3.5 that the basis mostly takes on negative values. This is a sign that yield spreads are higher than if credit risk were the only priced factor.

Across the rating classes, the mean and median basis values display a slight U-shape. For all except the CCC rating class, the median value exceeds the mean value which implies outliers in the left tail of the distribution. If the mean basis is taken relative to the CDS mid premium, the pattern is not clear. The ratio fluctuates between -321% for the AA rating class and +1% for the AAA rating class. If anything, we can differentiate between the investment grade and the subinvestment grade segment in the sense that the impact of credit risk becomes more dominant than other risk factors both for CDS mid premia and bond yield spreads for the lower rating classes.

With regard to the differences between the industry sectors, we find that except for the AA rating class, the mean basis is less strongly negative in each rating class for the financial than for the non-financial corporate sector. The smaller absolute difference suggests that the factors which increase yield spreads compared to CDS premia are less important for financial reference entities. Taking the basis relative to the mid CDS premium, we again observe that the absolute values are much higher for the investment grade segment than for the subinvestment grade segment both for the financial and the non-financial corporate sector.

The sovereign sector presents a very different picture. The sign of the mean and median basis changes with each rating step until the subinvestment grade segment is reached. From then on, the mean and median are positive, suggesting that CDS premia are on average too high in comparison to yield spreads. Relative to the CDS mid premium, our above finding holds; the effect of factors other than credit risk compared to that of credit risk is lower for the subinvestment grade segment. Both of these findings could be the result of a higher liquidity of sovereign bonds.

3.3 Time Series Properties

We now explore the connection between the time series of yield spreads and CDS premia for each reference entity. As in the previous section, we differentiate between rating classes and

Table 3.5: **Descriptive Statistics of Basis**

The table shows the mean, median, standard deviation, minimum, and maximum of the basis, defined as the difference between the CDS mid premium and the synthetical 5-year bond yield spread. The values are determined row-wise cross-sectionally across reference entities in the industry sector and column-wise over time across reference entities which have the column-heading rating on a given date. All values are in basis points. The number of observations is as in Table 3.2.

		AAA	AA	A	BBB	BB	B	CCC	All
All	Mean	0.05	-48.89	-29.87	-73.03	-0.50	-34.91	35.85	-44.95
	Median	0.82	-18.22	-18.82	-39.32	5.83	-5.04	15.54	-21.08
	Std. Dev.	32.10	144.30	80.05	137.07	182.60	223.60	52.95	122.45
	Min.	-221.11	-1,375.71	-1,203.62	-2,420.42	-1,041.11	-1,462.31	-20.07	-2,420.43
	Max.	262.29	416.90	825.93	854.18	726.41	830.24	237.80	854.18
Financial	Mean	-9.92	-59.14	-18.08	-48.40	20.30	-	-	-40.61
	Median	-9.10	-19.58	-15.43	-48.21	11.03	-	-	-18.17
	Std. Dev.	10.02	171.40	38.77	41.45	22.03	-	-	127.93
	Min.	-27.47	-1,375.71	-596.33	-190.44	-11.94	-	-	-1,375.71
	Max.	9.30	416.90	793.21	118.96	73.40	-	-	793.21
Non-Financial	Mean	-18.54	-26.30	-37.94	-74.30	-4.45	-59.61	35.85	-50.53
	Median	-20.49	-14.67	-22.45	-38.19	2.97	-41.48	15.54	-25.60
	Std. Dev.	11.11	53.99	91.84	139.88	186.79	224.83	52.95	122.48
	Min.	-39.06	-761.77	-1,203.62	-2,420.42	-1,041.11	-1,462.31	-20.07	-2,420.42
	Max.	15.54	83.18	825.93	854.18	726.41	830.24	237.80	854.18
Sovereign	Mean	1.69	-44.18	29.55	-33.00	78.23	156.94	-	8.44
	Median	2.58	-10.16	30.69	-3.62	83.19	130.67	-	2.33
	Std. Dev.	33.14	67.96	35.52	52.51	54.44	66.29	-	59.81
	Min.	-221.11	-316.15	-88.62	-141.35	-29.70	-36.58	-	-316.15
	Max.	262.29	7.04	246.70	18.16	257.82	322.57	-	322.57

industry sectors. If credit risk is the main priced factor, we should find a close and positive cross-sectional and time series relation between the CDS premia and yield spreads. The theoretical relationship between these quantities has first been explored by Duffie (1999), and numerous studies such as Hull et al. (2004) and Blanco et al. (2005) have documented its existence empirically. The relation should still hold if the factors which lead to differences between CDS premia and the yield spreads do not exhibit a high amount of variation over time, e.g. if they are characteristics of the market on which the instrument is traded or of the reference entity. If, on the other hand, we do not find a positive association between CDS premia and yield spreads, it is natural to ask which factors can obscure the credit-risk induced relationship. The latter analysis is undertaken in Section 3.4.

For all analyses in this section, it is important to obtain a long time series without gaps. We therefore use the average rating of the reference entity as in Section 3.2.1 and not the actual observed rating to avoid gaps in the time series to segment the data. Details are given in Appendix 3.5

3.3.1 Stationarity

To explore whether the underlying data generating process of the time series has a unit root, we apply the augmented Dickey-Fuller test. The analysis is conducted on a daily, weekly, and monthly basis with 5 lags on the daily, 4 on the weekly and 2 on the monthly level in order to capture higher-order autocorrelation. The results at the 5% significance level are given in Table 3.6.[20]

Table 3.6 shows that the null hypothesis of a unit root can only be rejected for a relatively minor part of the time series. Comparing the test results for data on the daily, weekly, and monthly level, we find that the null hypothesis can be rejected most often on the daily level. This result is sensible since deterministic trends in the time series are more difficult to detect given the higher fluctuation on the daily level. CDS premia tend to be stationary less often than yield spreads. If credit risk were the only priced factor, either both or neither CDS premia and yield spreads would be stationary. Therefore, this finding is a sign of different risk factors affecting the two quantities at the daily level. At the monthly frequency, on the other hand, short-term deviations may be more difficult to detect if CDS premia and bond yield spreads react quickly to new information.

Regarding the basis time series, the low number of stationary time series at the daily, weekly, and monthly frequency demonstrates that - and this even holds at the 10%

[20]The results for the 1% and the 10% significance level are similar.

Table 3.6: **Unit Root Test for Level of CDS Premia, Bond Yield Spreads, and Basis**

The table shows the percentage of reference entities in each rating class and industry sector for which the augmented Dickey-Fuller test can reject the null hypothesis of a unit root at the 5% significance level. The test is performed on the daily (D), weekly (W), and monthly (M) level. Ratings are time-series averages for the reference entity. CDS denotes the mid CDS premium, ys the synthetical 5-year bond yield spread over the German government bond interest rate, and b the basis, defined as the difference between the mid CDS premium and the bond yield spread. All values are in percentage points.

		AAA			AA			A			BBB			BB			B			All		
		D	W	M	D	W	M	D	W	M	D	W	M	D	W	M	D	W	M	D	W	M
All	CDS	33	17	17	24	21	15	25	19	19	28	12	10	0	10	20	0	0	0	24	16	15
	ys	33	0	0	36	12	12	23	15	7	24	14	4	20	20	20	0	0	0	26	13	8
	b	17	17	17	21	18	15	25	19	17	26	12	8	0	10	20	0	0	0	22	16	14
Financial	CDS	-	-	-	27	23	18	29	32	18	0	50	50	-	-	-	-	-	-	26	30	20
	ys	-	-	-	50	14	14	11	14	4	0	25	0	-	-	-	-	-	-	26	15	7
	b	-	-	-	5	23	18	29	32	14	0	50	50	-	-	-	-	-	-	24	28	15
Non-	CDS	100	0	0	10	20	10	24	11	21	33	9	7	0	13	25	0	0	0	25	11	14
Financial	ys	0	0	0	10	10	10	29	16	11	28	12	5	25	13	13	0	0	0	26	13	8
	b	0	0	0	20	20	10	24	11	21	30	9	5	0	13	25	0	0	0	24	11	13
Sovereign	CDS	20	20	20	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	1	6
	ys	40	0	0	0	0	0	67	0	0	0	8	0	0	25	25	0	0	0	26	13	6
	b	20	20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6	6

significance level - for less than 50% of the reference entities CDS premia and bond yield spreads can be exclusively determined by credit risk.

For the different rating classes, no clear pattern emerges. At the daily frequency, approximately 25% of CDS premia are stationary for the investment grade segment, and no CDS premia are stationary at all for the subinvestment grade segment. The results are similar at the weekly and monthly frequency. Yield spreads are also more often stationary at the daily frequency for the investment grade segment. With regard to the basis, the results do not seem to depend on the rating. At the daily frequency, the basis tends to be stationary only if both CDS premia and yield spreads are stationary. At the weekly frequency, a stationary basis can also be observed for non-stationary CDS premia and yield spreads at the weekly level. This implies that differences between the bond and the CDS market do not persist as strongly at a lower data frequency.

Comparing the results for the different industry sectors, we observe that stationary CDS premia, yield spread, and basis time series are more prevalent in the financial sector, especially at the weekly and monthly level. This finding supports our initial hypothesis that CDS premia and yield spreads for financial reference entities are less affected by dynamic non-credit risk related factors. The effect can be documented across all investment grade rating classes. A conclusive analysis of the sovereign sector is slightly more difficult since we only observe 16 sovereign reference entities. The fact that only one or, at the 10% level, two reference entities, had a stationary basis seems to point at a fairly high effect of discriminating factors for the sovereign sector.

3.3.2 Cointegration

Since some CDS premia and yield spread time series were stationary and some non-stationary, we employ the Phillips-Ouliaris cointegration test which implicitly differentiates between stationary and non-stationary time series and computes a comparable cointegration vector. For jointly stationary time series, we compute a simple correlation coefficient. For non-stationary time series, we first check the degree of integration for both time series. If the degree is identical, we perform a standard cointegration test. If the degrees are different, the we determine whether a linear combination of the CDS premia, yield spreads, and a simple time-trend is stationary.[21]

In order to adjust for different means and linear time series trends, we simultaneously

[21] Theoretically, we could also explore how changes in the yield spread level are associated with CDS premium levels or vice versa if the degree of integration differs. This procedure, however, is unusual, and there is no straightforward economic intuition for such an association.

estimate the cointegration coefficient, a constant mean, and the coefficient of the linear time series trend of the difference between the CDS premia and the yield spread. The results of the test at the 5% level are displayed in Table 3.7.

As we see from Table 3.7, the difference between the daily, weekly, and monthly level becomes easier to grasp than in Table 3.6. The average estimated cointegration coefficient for the entire sample is equal to 1.00 at the weekly and the monthly frequency, and the standard deviation of the 171 significant coefficients is 0.00 when rounded to two decimal places.[22] At the daily frequency, only for 82% of the reference entities, CDS premia and yield spreads are significantly cointegrated, and the lower coefficient of 0.31 in conjunction with the high standard deviation of 0.41 across all significant estimates shows that this relation is not identical across the reference entities. At the 10% significance level, the results are unchanged at the weekly and monthly frequency. The average coefficient at the daily frequency declines to 0.29 for a total of 145 reference entities (85%).

Since all reference entities are cointegrated at the weekly and monthly frequency with a coefficient that is identical to 1.00 when rounded to two decimal places, differences across the rating classes and the industry sectors are only of interest at the daily frequency. Across the different rating classes, the proportion of significant relations increases as the rating deteriorates. This result suggests that the idiosyncratic fluctuations become dominated by the credit risk component as the rating deteriorates. Simultaneously, the size of the average coefficient estimate increases up to 0.69 for the BB rating class, and for this rating class only, the average is also significantly different from 0 as implied by the lower standard deviation in a simple t-test. For each investment grade rating class, we cannot reject the hypothesis that the average coefficient vector is equal to 0. As the high standard deviation suggests, we partly obtain individual coefficient estimates that are smaller than 0. This suggests that CDS premia and yield spreads move in the opposite direction, an effect that cannot be caused by credit risk.

For the different industry sectors, we observe that the average coefficients and their standard deviations are of a comparable size for financial and non-financial corporate reference entities. Financial reference entities have a lower percentage of significantly associated CDS premia and yield spreads than non-financial corporate ones. We attribute

[22] In Table 3.6, the maximum number of reference entities which *could* have been tested for correlation and cointegration would have been smaller. For example, 16 CDS premia time series were stationary, but only 14 yield spread time series. This suggests that the potential number of cointegration relationships is 169. In Table 3.7, the potential number of cointegration relations is 171. This is possible because the Phillips-Ouliaris test adjusts for potential time series trends which the augmented Dickey-Fuller test does not.

Table 3.7: **Cointegration Test for CDS Premia and Bond Yield Spreads**

The table shows the results of the cointegration test for the mid CDS premium and the bond yield spread, adjusting for a constant mean and a linear time-series trend of the difference. The rows give the percentage of reference entities for which the Phillips-Ouliaris test can reject the null hypothesis of no cointegration at the 5% significance level, and the average and the standard deviation of the cointegration coefficient across all reference entities for which the null hypothesis is rejected at the 5% level. The percentage of reference entities is given in percentage points, the mean and the standard deviation are determined from the coefficient estimates for mid CDS premia and bond yield spreads in basis points. The test is performed on the daily (D), weekly (W), and monthly (M) level. Ratings are time-series averages for the reference entity.

		AAA			AA			A			BBB			BB			B			All		
		D	W	M	D	W	M	D	W	M	D	W	M	D	W	M	D	W	M	D	W	M
All	% sign.	67	100	100	70	100	100	83	100	100	88	100	100	90	100	100	100	100	100	82	100	100
	Mean	0.02	1.00	1.00	0.06	1.00	1.00	0.25	1.00	1.00	0.46	1.00	1.00	0.69	1.00	1.00	0.57	1.00	1.00	0.31	1.00	1.00
	Std. Dev.	0.04	0.00	0.00	0.11	0.00	0.00	0.40	0.00	0.00	0.45	0.00	0.00	0.25	0.00	0.00	0.41	0.00	0.00	0.41	0.00	0.00
Financial	% sign.	-	-	-	77	100	100	68	100	100	75	100	100	-	-	-	-	-	-	72	100	100
	Mean	-	-	-	0.05	1.00	1.00	0.24	1.00	1.00	0.52	1.00	1.00	-	-	-	-	-	-	0.18	1.00	1.00
	Std. Dev.	-	-	-	0.09	0.00	0.00	0.50	0.00	0.00	0.50	0.00	0.00	-	-	-	-	-	-	0.39	0.00	0.00
Non-Financial	% sign.	0	100	100	50	100	100	95	100	100	88	100	100	100	100	100	100	100	100	87	100	100
	Mean	-	1.00	1.00	0.12	1.00	1.00	0.26	1.00	1.00	0.44	1.00	1.00	0.67	1.00	1.00	0.23	1.00	1.00	0.37	1.00	1.00
	Std. Dev.	-	-	-	0.18	0.00	0.00	0.35	0.00	0.00	0.40	0.00	0.00	0.27	0.00	0.00	-	-	-	0.38	0.00	0.00
Sovereign	% sign.	80	100	100	100	100	100	67	100	100	100	100	100	50	100	100	100	100	100	81	100	100
	Mean	0.02	1.00	1.00	-0.01	1.00	1.00	0.01	1.00	1.00	0.62	1.00	1.00	0.82	1.00	1.00	0.73	1.00	1.00	0.33	1.00	1.00
	Std. Dev.	0.04	0.00	0.00	-	-	-	0.04	0.00	0.00	0.99	0.00	0.00	-	0.00	0.00	0.42	0.00	-	0.55	0.00	0.00

this difference to a higher degree of dependence on market-wide factors than on firm-specific risk factors for financial reference entities. In contrast, the sovereign sector displays a very different behavior. For the rating classes AAA to A, the coefficient estimates are in the range from -0.05 to 0.02 and grow to 0.68 to 0.92% for the BBB to B rating classes. This result demonstrates that credit risk does not seem to be the only determinant of CDS premia and yield spreads for highly rated sovereign reference entities, whereas for reference entities with a higher default risk these two terms appear to be mainly determined by common factors.

In short, the stationarity and cointegration tests show that CDS premia and yield spreads partially display a very different time series behavior and that credit risk cannot be the only determinant. We also find that the relation is affected by the sampling frequency, i. e. whether daily, weekly, or monthly data is used, and by the degree of credit risk which is reflected in the two quantities. Our results imply that weekly and monthly CDS premia and yield spreads exhibit a high degree of comovement when we also adjust for different means and time-dependent trends. On the daily level, we do not find a similar comovement. The next section is concerned with the analysis of the impact of the difference between the bond yield spread and the CDS premium. In particular, we explore whether the comovement of the two quantities is simultaneous or whether changes in one of the time series precede those in the other. If this reaction mechanism occurs within one week, this could be a reason for the different behavior of the CDS premia and the yield spreads at the daily level and the high degree of comovement at the weekly and monthly level.

3.3.3 Vector Error Correction Model

In this section, we explore the time series dependence of CDS premia and yield spreads on one another. As the cointegration tests show, CDS premia and yield spreads sampled at a daily frequency do not necessarily move in unison and, in some cases, even exhibit reverse behavior. At the weekly frequency, the two quantities are almost perfectly cointegrated or, in the case of stationarity, correlated.

This different behavior could be caused by two effects. First, the daily CDS premia and yield spreads could be affected by uncorrelated idiosyncratic disturbances that mask the actual relation between the time series. Moving to the weekly frequency, the joint behavior becomes easier to detect as the idiosyncratic disturbances cancel out.

The second possibility is that one market leads the other in the context of price discovery, i.e. similar factors cause movements in CDS premia and yield spreads but at a different speed. If, as Blanco et al. (2005) argue, a time lag exists between the two markets, the simultaneous cointegration test performed in the previous section cannot pick up on this non-simultaneous changes at the daily frequency. At a weekly frequency, however, a difference in the adjustment speed cannot be fully detected if the adjustment occurs in both markets within a few days.

In order to explore whether the second effect can be detected in our sample, we perform a vector error correction model (VECM) analysis. In particular, we first determine for each reference entity whether the mid CDS premium and the bond yield spread time series are stationary. If the augmented Dickey-Fuller test cannot reject a unit root at the 5% level for each time series, we test whether the first differences of the mid CDS premium and the bond yield spread time series are stationary. If the augmented Dickey-Fuller test can reject a unit root in the first differences at the 5% level for each time series, we perform the Johansen test for cointegration[23] between the mid CDS premium and the bond yield spread. If the cointegration vector is significantly different from 0 at the 5% level, we estimate the following set of equations for each reference entity:

$$\begin{aligned} \Delta CDS_t &= v_1 \left(CDS_{t-1} - \beta y s_{t-1} \right) + \sum_{i=1}^{p} u_i \Delta CDS_{t-i} + \sum_{i=1}^{p} w_i \Delta y s_{t-i} + \varepsilon_{1,t} \\ \Delta y s_t &= v_2 \left(CDS_{t-1} - \beta y s_{t-1} \right) + \sum_{i=1}^{p} x_i \Delta CDS_{t-i} + \sum_{i=1}^{p} z_i \Delta y s_{t-i} + \varepsilon_{2,t}, \end{aligned} \tag{3.1}$$

where ΔCDS_t denotes the change of the CDS mid premium between $t-1$ and t, Δys_t the change of the yield spread between $t-1$ and t, p is the maximum lag order, v_1 and v_2 are the coefficients of the error correction term $CDS_{t-1} - \beta ys_{t-1}$ with regard to the CDS mid premium and the yield spread changes, β is the cointegration coefficient, u_i, w_i, x_i, and z_i are the coefficients of the lagged changes of the CDS mid premia and yield spreads, and $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are the error terms. The size and significance of v_1 and v_2 are used to infer whether a deviation of either the CDS mid premium or the yield spread from their long-run relation causes one of these quantities to change in a systematic way.

The results of the estimation are displayed in Table 3.8. We only report the coefficients of the error correction term for the lag order $p = 5$, the results for the lag orders 2 to 4 were similar.

We see from Table 3.8 that the error correction term affects yield spreads more often and more strongly than it does CDS premia. More than twice as many yield spreads react to deviations from the cointegration relationship, and the average coefficient for the yield

[23] See Johansen (1977).

Table 3.8: **Vector Error Correction Model for CDS Premia and Bond Yield Spreads**

The table shows the results of the VECM for the mid CDS premium and the bond yield spread in Equation (3.1). The rows give the percentage of reference entities for which the error correction coefficients are significant at the 5% level, and the average and standard deviation of the error correction terms across all reference entities for which the error correction coefficient estimates are significant at the 5% level. v_1 gives the error correction coefficient for the change in the CDS premium, v_2 the error correction coefficient for the change in the bond yield spread. The percentage of reference entities is given in percentage points, the mean and the standard deviation are determined from the coefficient estimates for mid CDS premia and bond yield spreads in basis points. Ratings are time-series averages for the reference entity.

		AAA		AA		A		BBB		BB		B		All	
		v_1	v_2	v_1	v_2	v_1	v_2	v_1	v_2	v_1	v_2	v_1	v_2	v_1	v_2
All	% sign.	17	0	12	24	8	38	18	32	0	40	33	33	12	28
	Mean	-0.01	-	-0.01	-0.28	-0.06	0.13	-0.01	0.05	-	0.05	-0.02	0.12	-0.03	0.05
	Std. Dev.	-	-	0.01	0.69	0.14	0.35	0.01	0.05	-	0.05	-	-	0.08	0.37
Financial	% sign.	-	-	14	32	4	18	0	0	-	-	-	-	7	22
	Mean	-	-	-0.01	-0.07	-0.02	0.09	-	-	-	-	-	-	-0.01	0.01
	Std. Dev.	-	-	0.00	0.38	-	0.11	-	-	-	-	-	-	0.01	0.30
Non-Financial	% sign.	0	0	0	10	13	32	21	37	0	38	100	100	15	33
	Mean	-	-	-	-1.74	-0.08	0.20	-0.01	0.05	-	0.04	-0.02	0.12	-0.04	0.06
	Std. Dev.	-	-	-	-	0.16	0.42	0.01	0.05	-	0.04	-	-	0.10	0.41
Sovereign	% sign.	20	0	100	0	0	66	0	0	0	50	0	0	13	19
	Mean	-0.01	-	-0.02	-	-	-0.19	-	-	-	0.10	-	-	-0.02	0.05
	Std. Dev.	-	-	-	-	-	0.16	-	-	-	-	-	-	0.00	0.29

spread is mostly higher than for the CDS premia. At the 1% level, the difference is even more pronounced with three times as many yield spreads affected by CDS premia than vice versa. This result suggests that price discovery first takes place in the CDS market and that yield spreads adjust more slowly. This finding is in line with Blanco et al. (2005). For all reference entities for which v_1 and v_2 are simultaneously significant, the sign of v_1 is the reverse of the sign of v_2. Since we obtain a positive cointegration coefficient β, a negative sign for v_1 and a positive one for v_2 or vice versa, both CDS premia and yield spreads revert to the cointegration relationship. For those reference entities for which either v_1 or v_2 is not significant, we observe positive values of v_1 and negative ones of v_2. These signs also imply a reversion to the long-run relation, but due to the averaging this is more difficult to infer from Table 3.8.

The results for the different rating classes suggest that the asymmetry regarding the CDS premia and yield spreads is most pronounced for the AAA, the A, and the BB rating class. We conclude that there is no clear link between the rating and the price discovery.

Regarding the differences between the industry sectors, we find that the non-financial sector tends to have the highest proportion of significantly affected CDS premia and yield spread changes. Across the rating classes, 15% of CDS premia changes are affected and 33% of the yield spread changes. The financial sector, on the other hand, exhibits significant estimates for v_1 for 7% of all reference entities and significant estimates for v_2 for 22%. These proportions show that the non-financial sector has a less pronounced asymmetry between the number of significantly affected CDS premia and yield spread changes than the financial sector, suggesting that both the bond and the CDS market react to deviations from the long-run equilibrium relationship. Price discovery in the financial sector seems to take place more frequently through the CDS than through the bond market. This finding agrees with the evidence for US financial reference entities analyzed by Blanco et al. (2005).

The behavior of the sovereign sector stands in contrast to both corporate sectors. For this sector, *either* the CDS premia *or* the yield spreads react to deviations from the cointegration relation, but never both.[24] This supports our notion that the CDS and the bond market for sovereign reference entities are less strongly interconnected bilaterally. For highly rated reference entities, the bond market leads the CDS market, and the reverse result holds for lower-rated reference entities.

To summarize, Table 3.8 demonstrates that even if CDS premia and yield spreads are cointegrated, the error correction term does not significantly affect CDS premia or yield

[24]Even for the AAA rating class at the 10% level, v_1 and v_2 never both significant for any reference entity.

spread changes for a high number of reference entities. This finding is robust with regard to the number of lags in equation (3.1). In addition, CDS premia seem to be affected by deviations from the cointegration relation less frequently than yield spreads, suggesting that information moves from the CDS market to the bond market more often than vice versa. This asymmetry decreases with the rating of the reference entity and is more pronounced for financial corporate reference entities. From these results, we draw the conclusion that we cannot reject the hypothesis that CDS premia and yield spreads reflect similar information but at a different speed.

We now turn to the core analysis of this chapter, the fixed-effects regression analysis of the CDS premia and yield spreads in the next section.

3.4 Explaining CDS Premia, Bond Yield Spreads, and the Basis

As the time series of CDS premia and yield spreads are frequently non-stationary, we cannot use standard OLS estimates to determine the significance of the impact of the explanatory variables. A standard way to cope with this problem is the use of first differences instead of levels since these are stationary in our setting. This procedure, however, has the drawback that the results become more difficult to interpret economically. Instead of using first differences, we analyze the impact of the explanatory variables on the mid CDS premia, the yield spreads, and the basis in a fixed-effects framework. This type of model is used to explore the impact of a time-invariant, unobserved effect that is potentially correlated with the explanatory variables, on the dependent variable.[25] Since the fixed-effects formulation allows us to pool the CDS mid premia and bond yield spread observations in levels across all reference entities, the size coefficient estimates are economically more intuitive.

3.4.1 Firm-Specific Factors

In this section, we explore how firm- and instrument-specific measures of credit risk and liquidity affect CDS premia, yield spreads, and the basis.

Explanatory Variables

Our results from Section 3.2 imply that while credit risk proxied by the rating is one of the main determinants of the level of CDS premia and yield spreads, the high variability within

[25] See e.g. Wooldridge (2002), p. 252.

a given rating class suggests that other factors also significantly affect them. Since it is likely that the rating of a reference entity constitutes only an inert proxy for the true credit risk, we use additional variables that may improve the explanation of the credit risk component in the dependent variables. In particular, we use the equity return and the historical and option-implied volatility as measures of credit risk.

It is natural to assume that the liquidity of the bond and the CDS market have an impact on the yield spreads and the CDS premia. For the CDS, we have a direct proxy of the liquidity in the bid-ask spread reported in Table 3.3. A priori, we expect the standard liquidity effect described by Amihud and Mendelson (1986): the higher the bid-ask spread, the higher the illiquidity and the CDS mid premium. Choosing an appropriate proxy for the bond is more difficult as we do not have access to historical transaction data or quotes and thus no direct liquidity measures. Instead, we follow Houweling et al. (2004) who identify the impact of a number of liquidity measures on the yields of corporate bond portfolios. The authors find that among potential liquidity proxies including issued amount, age, and number of quote contributors, the bond yield volatility on a given date across the portfolio is one of the most powerful explanatory variables for the portfolio's liquidity. As Shulman et al. (1993) and Hong and Warga (2000), their study shows that a higher yield volatility is associated with lower liquidity and higher yields. We therefore expect a positive association between the volatility across a reference entity's bond yields on a given date and yield spreads.

Regarding the cross-market liquidity impact, we cannot predict the sign of the coefficient estimates because the liquidity of the markets is linked both directly and indirectly. First, CDS premia are directly affected by bond liquidity since a lower liquidity of a reference asset will in general decrease its price. This increases the expected payment contingent upon default from the protection seller and the CDS premia. Second, credit risk can be taken on or sold of either directly by buying or selling the bond or indirectly by selling or buying protection in the CDS market. Therefore, it is possible that positions are taken in either one market or the other. Reversely, positions in the CDS and the bond market can be combined to arrive at a given risk exposure, e.g. buying the bond and subsequently buying credit risk protection yields a default risk-free position.

As the last explanatory variable, we include the value of the cheapest-to-deliver (CTD) option. As we currently have no theory for this value, we have to find an appropriate proxy. This proxy is somewhat difficult to define since there is no clear theoretical link between the bond prices of a firm prior to default and their post-default dispersion. Therefore, we make the following assumptions. First, the value of the CTD option is likely to be higher if a reference entity has more bonds outstanding. Second, the value of the CTD option is likely to be higher if the range of the prices of outstanding bonds issued by the same entity is larger. Given these assumptions, we use the product of the number of bonds outstanding with the difference between the highest and the lowest bond price at a given date as our proxy for the CTD option.

Model Specification

As shown in Table 3.6, for a single firm the time series of the CDS premia, the bond yield spreads, and the basis are only stationary for few reference entities. Therefore, we pool the time series data for our fixed effect analysis by concatenating the time series of observations for all reference entities.[26] In the industry-sector and rating-class-specific analyses, we concatenate the time series for the relevant subsamples.

The explanatory variables are concatenated in the same way, and for each of the reference entities, we include a different intercept term to capture the firm-specific fixed effects. The resulting system of equations which we estimate is given by

$$\begin{aligned}
CDS_{i,t} &= \alpha_{0,i} + \alpha_1 r_{i,t} + \alpha_2 \mu_{i,t} + \alpha_3 \sigma_{i,t}^{\text{hist}} + \alpha_4 \sigma_{i,t}^{\text{OI}} + \alpha_5 ba_{i,t} + \alpha_6 yv_{i,t} + \alpha_7 ctd_{i,t} + \varepsilon_{i,t}, \\
ys_{i,t} &= \beta_{0,i} + \beta_1 r_{i,t} + \beta_2 \mu_{i,t} + \beta_3 \sigma_{i,t}^{\text{hist}} + \beta_4 \sigma_{i,t}^{\text{OI}} + \beta_5 ba_{i,t} + \beta_6 yv_{i,t} + \beta_7 ctd_{i,t} + \eta_{i,t}, \\
b_{i,t} &= \gamma_{0,i} + \gamma_1 r_{i,t} + \gamma_2 \mu_{i,t} + \gamma_3 \sigma_{i,t}^{\text{hist}} + \gamma_4 \sigma_{i,t}^{\text{OI}} + \gamma_5 ba_{i,t} + \gamma_6 yv_{i,t} + \gamma_7 ctd_{i,t} + \nu_{i,t}.
\end{aligned} \tag{3.2}$$

$CDS_{i,t}$, $ys_{i,t}$, and $b_{i,t}$ denote the CDS mid premium, the yield spread, and the basis for reference entity i at time t where data is used at a daily, weekly, and monthly frequency. The fixed effects $\alpha_{0,i}$, $\beta_{0,i}$, and $\gamma_{0,i}$ are assumed to be time-invariant and can be correlated with the exogenous variables. $r_{i,t}$, $\mu_{i,t}$, $\sigma_{i,t}^{\text{hist}}$, and $\sigma_{i,t}^{\text{OI}}$ refer to the rating, equity return, historical, and option-implied volatility. $ba_{i,t}$ and $yv_{i,t}$ are the proxies for the CDS and the bond liquidity. In order to avoid endogeneity issues, we use the liquidity proxies two business days prior to t. $ctd_{i,t}$ is the proxy for the value of the CTD option defined above.

In order to check whether the coefficient estimates are robust against the inclusion of the potentially correlated explanatory variables, we estimate Equation 3.2 both univariately (using only one explanatory variable) and multivariately. We repeat the analysis for each industry sector and all rating classes separately.

We determine the significance of the coefficient estimates using the Newey-West

[26] For a similar pooling approach, see Timmreck (2006), pp. 139–144.

covariance estimate to adjust for autocorrelation and heteroscedasticity.[27] We also test whether the time series of the residuals is stationary for each reference entity. Due to the heteroscedasticity and the autocorrelation of the error terms, we use the Phillips-Perron test instead of the augmented Dickey-Fuller test.[28] For the CDS premia, the Phillips-Perron test can reject the null hypothesis of a unit root (for the full model specification) at the 10% significance level for 157 reference entities. The null hypothesis cannot be rejected at the 10% level for 7 investment-grade financial, 5 investment-grade non-financial corporate, and two subinvestment grade sovereign reference entities. For the bond yield spreads and the basis, the Phillips-Perron test can reject the null hypothesis of a unit root in the regression residuals (for the full model specification) at the 10% significance level for all but two investment grade and one subinvestment grade sovereign reference entities.

The results of the estimation are given in Table 3.9.

For the CDS premia, the bond yield spread, and the basis, we first discuss the estimation results for all reference entities, then the results by industry sector, and last the results by rating class.

CDS Premia

As Panel A of Table 3.9 shows, all credit risk and liquidity measures except for the stock return significantly affect mid CDS premia both in the univariate and in the multivariate setting. For the full sample, the explanatory variables all increase CDS premia at the 1% significance level. The adjusted R^2 is highest for the historical volatility with 12% among the credit risk variables and for *ba* with 68% among the liquidity variables. The bond-derived measures *yv* and *ctd* also affect CDS premia, but the lower adjusted R^2 of 9% and 1% suggests that the variation in CDS premia is less dependent on variations in these measures. μ is only significantly different from 0 in the full model specification and increases the CDS mid premium. The multivariate estimation which uses all explanatory variables simultaneously shows that there is some overlap between the explanatory variables in the univariate estimation since the value of all coefficients - except for *ba* - strongly decreases. The overall adjusted R^2 of 72% is high, but compared to the R^2 of the bid-ask spread the additional explanatory variables have a limited effect.

[27]See Campbell et al. (1997), pp. 234-235.
[28]See Enders (1995), pp. 239-240.

Table 3.9: **Impact of Firm-Specific Risk Factors**

The table shows the coefficients, significance level, and adjusted R^2 for the fixed effects model. The model is estimated for each variable univariately ("Single") and for the full multivariate specification ("Full"). r denotes the rating, μ the stock return, σ^{hist} the historical volatility, σ^{OI} the option-implied volatility, ba the CDS liquidity, yv the bond liquidity, and ctd value of the CTD option. Significance is determined using Newey-West heteroscedasticity and autocorrelation robust standard errors. ***, **, and * denote the 1%, 5%, and 10% significance level. Coefficients are determined for mid CDS premia, bond yield spreads, and the basis in basis points, the adjusted R^2 are given in brackets.

Panel A: Analysis by Industry Group

	Financial		Non-Financial		Sovereign		All	
	Single	Full	Single	Full	Single	Full	Single	Full
				Mid CDS Premia				
r	1.62***	1.57***	5.52***	4.57***	26.49***	22.34***	5.25***	4.40***
	(0.03)		(0.03)		(0.35)		(0.03)	
μ	2.65	4.61*	10.81	13.59**	-	-	8.88	11.55**
	(0.00)		(0.00)				(0.00)	
σ^{OI}	0.12**	0.05	2.40***	0.65***	-	-	2.00***	0.55***
	(0.00)		(0.00)				(0.00)	
σ^{hist}	0.47***	0.09***	2.09***	0.68***	-	-	1.66***	0.51***
	(0.18)		(0.15)				(0.12)	
ba	4.52***	4.33***	4.76***	4.31***	6.02***	4.74***	4.76***	4.45***
	(0.66)		(0.69)		(0.27)		(0.68)	
yv	-1.62***	-1.45***	64.23***	15.15***	12.63***	8.00***	38.64***	8.40***
	(0.00)		(0.15)		(0.01)		(0.09)	
ctd	0.11***	0.01	2.05***	0.23***	-0.26**	0.44***	1.27***	0.14***
	(0.00)	(0.69)	(0.01)	(0.74)	(0.00)	(0.51)	(0.01)	(0.72)
				Bond Yield Spreads				
r	-0.86***	-0.03	5.53***	4.34***	31.92***	28.64***	5.02***	4.14***
	(0.00)		(0.02)		(0.36)		(0.01)	
μ	38.36	48.16	28.13	29.69*	-	-	30.55**	33.01**
	(0.00)		(0.00)				(0.00)	
σ^{OI}	3.52***	2.94***	6.27***	3.24***	-	-	5.78***	3.37***
	(0.00)		(0.01)				(0.01)	
σ^{hist}	-0.12***	-0.19***	1.11***	0.10***	-	-	0.79***	-0.01
	(0.00)		(0.02)				(0.01)	
ba	1.13***	1.97***	3.58***	3.36***	5.43***	3.75***	3.55***	3.36***
	(0.00)		(0.19)		(0.15)		(0.14)	
yv	25.62***	26.26***	52.29***	19.72***	6.98***	0.10	39.63***	19.95***
	(0.02)		(0.05)		(0.00)		(0.03)	
ctd	0.03	-0.59***	-0.69***	-2.02***	-0.77***	-0.19*	-0.48***	-1.41***
	(0.00)	(0.02)	(0.00)	(0.22)	(0.00)	(0.43)	(0.00)	(0.17)
				Basis				
r	2.49***	1.62***	0.01	0.27**	-5.46***	-6.38***	0.25**	0.30***
	(0.00)		(0.00)		(0.02)		(0.00)	
μ	-35.78	-43.54	-16.93	-16.05	-	-	-21.39	-21.39
	(0.00)		(0.00)				(0.00)	
σ^{OI}	-3.40***	-2.89***	-3.89***	-2.61***	-	-	-3.81***	-2.84***
	(0.00)		(0.00)				(0.00)	
σ^{hist}	0.58***	0.28***	0.98***	0.59***	-	-	0.87***	0.52***
	(0.01)		(0.02)				(0.02)	
ba	3.39***	2.36***	1.20***	0.97***	0.61***	1.01***	1.23***	1.11***
	(0.01)		(0.03)		(0.00)		(0.02)	
yv	-27.17***	-27.69***	12.05***	-4.43***	5.68***	7.84***	-0.95**	-11.47***
	(0.02)		(0.00)		(0.00)		(0.00)	
ctd	0.09	0.60***	2.75***	2.25***	0.51***	0.62***	1.75***	1.55***
	(0.00)	(0.03)	(0.01)	(0.05)	(0.00)	(0.03)	(0.00)	(0.04)

Panel B: Analysis by Rating Class

	AAA		AA		A		BBB		BB		B		CCC	
	Single	Full	Single	Full	Single	Full	Single	Full	Single	Full	Single	Full	Single	Full
							Mid CDS Premia							
r	0.07**	1.03***	0.40***	0.09***	-0.93***	-0.08**	1.46***	-0.70***	-0.65	-2.40***	0.88	3.51***	0.00	4.39***
	(0.00)		(0.01)		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)	
μ	14.13	87.05***	0.69	1.68	9.40*	17.33***	-31.47*	7.59	162.68	54.74	-28.50	-120.13*	-90.37	137.17
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)	
σ^{OI}	-0.01	6.82***	-0.13***	-0.02	-0.08	0.09	2.28***	0.52***	-6.40***	-0.93	1.99	-0.01	8.33***	3.64**
	(0.00)		(0.00)		(0.00)		(0.00)		(0.01)		(0.00)		(0.42)	
σ^{hist}	0.00	-0.12***	0.21***	0.04***	0.71***	0.22***	1.95***	0.83***	7.79***	0.02	4.52***	1.40***	14.43***	-7.93***
	(0.00)		(0.12)		(0.17)		(0.17)		(0.33)		(0.20)		(0.13)	
ba	0.50***	1.38***	2.71***	2.60***	4.59***	4.29***	4.37***	3.89***	3.77***	4.01***	6.87***	4.80***	0.59	-1.97**
	(0.03)		(0.48)		(0.51)		(0.53)		(0.69)		(0.64)		(0.00)	
yv	1.38***	1.66***	-0.48***	-0.76***	5.94***	1.43***	43.64***	31.00***	90.36***	-13.14***	163.86***	77.61***	-19.84*	-128.21***
	(0.02)		(0.00)		(0.01)		(0.08)		(0.24)		(0.44)		(0.02)	
ctd	-0.05***	-0.01	-0.11***	-0.15***	-0.39***	0.38***	6.01***	0.41***	9.43***	-6.13***	27.69***	8.22***	3.90***	16.78***
	(0.01)	(0.12)	(0.00)	(0.50)	(0.00)	(0.53)	(0.07)	(0.59)	(0.01)	(0.72)	(0.24)	(0.79)	(0.05)	(0.64)
							Bond Yield Spreads							
r	0.04	1.02	1.30***	0.56	-0.36**	0.05	1.62***	-0.02	-1.08	-3.17***	1.82	6.82***	0.00	3.16***
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)	
μ	20.55	85.73	46.30	54.58	35.97	43.06**	24.45	52.61**	144.55	56.25	-178.91	-238.03	343.39*	60.10
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.02)	
σ^{OI}	-0.06	7.19	4.63***	3.52***	0.35**	0.58**	5.24***	5.20***	-0.82	-3.04	0.14	5.02	-0.81	0.63
	(0.00)		(0.00)		(0.00)		(0.01)		(0.00)		(0.00)		(0.00)	
σ^{hist}	0.00	-0.32	-0.40***	-0.35***	0.54***	0.32***	0.31***	-0.33***	7.07***	2.59***	4.15***	-1.16***	-3.24	-2.72*
	(0.00)		(0.00)		(0.01)		(0.00)		(0.31)		(0.07)		(0.00)	
ba	0.33	1.30*	0.17	1.58***	2.45***	1.71***	2.58***	3.09***	3.04***	3.15***	5.80***	1.07***	-8.97***	-2.47***
	(0.00)		(0.00)		(0.02)		(0.07)		(0.51)		(0.19)		(0.16)	
yv	10.82***	13.23***	31.11***	30.34***	12.72***	11.02***	21.37***	18.78***	66.10***	52.31***	243.54***	241.15***	143.38***	105.68***
	(0.02)		(0.02)		(0.01)		(0.01)		(0.15)		(0.39)		(0.78)	
ctd	-0.04	0.19**	0.16	-0.06	-1.08***	-0.86***	-1.50***	-4.65***	-5.32***	-1.80***	33.05***	14.32***	17.91***	5.85***
	(0.00)	(0.02)	(0.00)	(0.03)	(0.00)	(0.03)	(0.00)	(0.10)	(0.01)	(0.56)	(0.14)	(0.49)	(0.75)	(0.91)
							Basis							
r	0.03	0.10	-0.91**	-0.46	-0.57***	-0.14	-0.14	-0.65***	0.44	0.89	-0.90	-3.30**	0.00	0.78
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)	
μ	-7.14	7.02	-45.70	-52.93	-26.45**	-25.75**	-55.83**	-45.38*	17.70	-2.55	155.64	118.93	-444.76**	94.43
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.03)	
σ^{OI}	0.05	0.36	-4.76***	-3.54***	-0.44**	-0.49**	-2.97***	-4.69***	-5.58***	2.16	1.86	-5.02	9.13***	2.79*
	(0.00)		(0.00)		(0.00)		(0.00)		(0.01)		(0.00)		(0.30)	
σ^{hist}	0.00	0.17	0.61***	0.39***	0.17***	-0.09***	1.65***	1.16***	0.69***	-2.55***	0.35	2.57***	17.33***	-5.99***
	(0.00)		(0.00)		(0.00)		(0.05)		(0.01)		(0.00)		(0.11)	
ba	0.17	0.15	2.54***	1.03***	2.14***	2.57***	1.79***	0.81***	0.77***	0.90***	1.05***	3.73***	9.44***	-0.54
	(0.00)		(0.00)		(0.02)		(0.04)		(0.07)		(0.01)		(0.13)	
yv	-9.41***	-11.55***	-31.57***	-31.09***	-6.70***	-9.52***	22.56***	12.32***	24.15***	-65.45***	-79.47***	-163.80***	-165.99***	-230.42***
	(0.01)		(0.02)		(0.00)		(0.01)		(0.04)		(0.07)		(0.78)	
ctd	0.00	-0.20**	-0.26*	-0.09	0.68***	1.23***	7.56***	5.07***	0.68	11.73***	-5.16***	-6.05***	-14.25***	10.23***
	(0.00)	(0.01)	(0.00)	(0.03)	(0.00)	(0.03)	(0.04)	(0.09)	(0.00)	(0.11)	(0.01)	(0.21)	(0.36)	(0.87)

Industry Sectors Comparing the results for the different industry sectors in Panel A, we observe that the non-financial corporate sector exhibits the highest adjusted R^2 of 74% for the full model. The explanatory power is lowest for the sovereign sector, but since the stock-market dependent measures cannot be included, this may be an immaterial effect. The financial sector is less strongly affected by the option-implied than by the historical volatility. In the non-financial corporate sector, the reverse holds for the univariate setting and the same in the multivariate model. Overall, the explanatory power of all credit-risk related measures is similar for both private sectors.

An interesting difference of the financial to the non-financial sector concerns the impact of bond liquidity and the delivery option: *yv* negatively affects the CDS premium in the univariate and the multivariate specification for the financial sector. This indicates that CDS are not predominantly used as default insurance but that buying or selling credit risk through a CDS is a substitute for selling or buying credit risk through the bond. *ctd* significantly increases CDS in the univariate specification but becomes insignificant in the full model. Non-financial corporate reference entities, on the other hand, are affected more strongly and positively by *yv* and *ctd*.

As expected from our earlier analysis, the sovereign sector shows a different behavior to the corporate sectors. Even in the univariate specification, the high coefficient estimate for the rating and the adjusted R^2 of 35% suggests that credit risk is sufficiently captured in the rating. *ba* has the lowest adjusted R^2 for the sovereign sector, and *yv* also affects the CDS premia less strongly than for the non-financial corporate sector. The coefficient of *ctd* is negative in the univariate model but positive and larger than for the other sectors in the multivariate setting.[29] This is sensible when taking into account the high variability of bond prices for defaulted sovereign issuers.

Rating Classes Regarding the results for the different rating classes given in Panel B of Table 3.9, we see that the adjusted R^2 for the multivariate model increases monotonously up to the B rating class for which a value of 79% is attained. For the CCC rating class, the value is lower at 64%. For the AAA rating class, CDS premia are mostly unaffected by the stock and option-implied credit risk measures in the univariate specification. Only the rating, the bond- and CDS-specific liquidity, and the delivery option have a significant impact.

The remaining investment grade classes exhibit a mostly increasing sensitivity to the

[29] We further discuss the negative coefficient of *ctd* below.

explanatory variables in the univariate setting and an increasing adjusted R^2 both in the univariate and the multivariate setting. This increase suggests that the variation in the CDS premia can be explained better through credit risk and liquidity, the higher the credit risk is. In particular for the BBB rating class, the CDS premia are highly sensitive to yv as shown by the high coefficient estimates in the single and the full model and by the adjusted R^2 of 8%.

The impact of the stock and option-implied credit risk measures is also more pronounced for the subinvestment grade segment in the univariate model, only the rating has no impact on CDS premia. An interesting finding is the negative sign of the coefficients for yv in the BB and the CCC rating class. This again implies that CDS are not primarily used as default insurance, but as a substitute to a direct investment in the bond and that this effect is most pronounced for the subinvestment grade segment.

Bond Yield Spreads

In the following, we focus on the differences to the results we obtained for CDS premia. As Panel A of Table 3.9 shows, the yield spreads show a similar dependence on the explanatory variables as the CDS premia, but the adjusted R^2 are much lower. The lower coefficient estimates for the historical volatility for the entire sample imply that the option-implied volatility is a more appropriate measure for credit risk in the bond market than in the CDS market. This result contrasts with the finding of Cremers et al. (2004). As expected, we obtain a higher coefficient estimate for yv than we did for the CDS premia, but surprisingly, the adjusted R^2 is lower. The delivery option has a negative coefficient estimate. We attribute this to the fact that our proxy is positively related to bond liquidity as we multiply the price range by the number of available bonds to obtain the proxy. Houweling et al. (2004) show that an increasing number of available bonds is positively associated with liquidity. Therefore, ctd also proxies for higher liquidity and decreases yield spreads. Interestingly, this secondary effect of the delivery option is insignificant for financial reference entities.

Industry Sectors For yield spreads, the differences between the different industry sectors displayed in Panel A of Table 3.9 are more pronounced than for CDS premia, in particular with regard to the explanatory power. Yield spreads for financial reference entities are not affected strongly by the explanatory variables as measured by the adjusted R^2 even though all variables except for μ and ctd are significant. The coefficient for the historical volatility is negative both in the univariate and the multivariate model. The highest sensitivity of the yield spreads is with regard to *yv* which is shown by the high coefficient estimate and the largest R^2 in the univariate specification. The non-financial corporate sector is more sensitive to the explanatory variables, in particular *ba* has a high explanatory power in the univariate setting. This agrees with our earlier finding that spill-over effects between the CDS and the bond market are stronger for non-financial reference entities. In the multivariate model, we obtain an adjusted R^2 which is still much lower than that for the mid CDS premia but 11 times larger than for the financial sector. In contrast to the corporate sectors, the sovereign sector has the highest adjusted R^2 of 43% in the multivariate model specification which only slightly falls below that for the CDS market. This is due to the effect of the rating on the yield spreads which is sufficiently high to account almost entirely for the adjusted R^2 in the multivariate model.

Rating Classes For the coefficient estimates across the different rating classes depicted in Panel B of Table 3.9, our results resemble those for the CDS premia, but the adjusted R^2 are again much lower. The explanatory power remains higher for the subinvestment grade rating class. For the AAA rating class, only *yv* and, in the multivariate setting, *ctd* significantly affect yield spreads.

For the remaining investment grade rating classes, the coefficients are roughly of the same magnitude. As for the CDS market, we observe that the BBB rating class is most sensitive to the liquidity of the other market both in the univariate and the multivariate model which is shown by the higher coefficient estimate and the higher adjusted R^2.

The subinvestment grade rating classes again tend to be affected more strongly by the explanatory variables. The liquidity-driven link between the two markets is also stronger in the subinvestment grade segment, as is the impact of *yv*. For the CCC rating class, we observe the same negative dependence on the other market's liquidity which points at liquidity moving in opposite directions in the bond and the CDS market.[30]

Basis

The coefficient estimates for the basis in Panel A and B of Table 3.9 can be directly inferred from the results for the CDS premia and yield spreads. We therefore only discuss which effect prevails in the basis and the significance and explanatory power which these effects have.[31]

[30] The analysis of the yield spreads computed from swap rates yields similar results.

[31] Recall from Table 3.5 that the basis is mostly negative. Therefore, a basis increase means decreasing differences between the CDS premia and yield spreads.

For the full sample, credit risk affects the basis in two ways. Both the rating and the historical volatility tend to increase the basis, but the option-implied volatility decreases it. From our analysis of CDS premia and yield spreads, we can explain this finding by CDS premia being affected more strongly by the rating and the historical volatility while yield spreads are associated more closely with the option-implied volatility. The CDS bid-ask spread and the CTD option increase the basis, showing that the impact on CDS premia is higher than on yield spreads. The negative coefficient for the bond liquidity shows that its effect on yield spreads is stronger than on CDS premia.

Industry Sectors Regarding the differences between the industry sectors, Panel A of Table 3.9 shows that a deterioration in the rating leads to a decrease in the basis for sovereign reference entities while it increases the basis for financial and non-financial corporate reference entities. The remaining credit risk measures all have a similar effect as for the full sample, and so do *ba* and *ctd*. The explanatory power is rather low, the adjusted R^2 lies between 3% and 5% in the multivariate model specifications. This suggests that the differences between CDS premia and yield spreads are not entirely due to the reference entity's credit risk and the instrument-specific liquidity.

Rating Classes For the different rating classes, Panel B of Table 3.9 shows that the basis for the AAA rating class is, as the yield spreads, exclusively affected by *yv* and, in the multivariate model, *ctd*. Interestingly, the coefficient of *ctd* is negative. Since the negative coefficient for *yv* decreases in the multivariate model, we believe that the joint significance is only significant statistically and not economically meaningful. For the remaining investment grade rating classes, the impact of the option-implied volatility is negative whenever significant as for the entire sample. The historical volatilities have a positive impact which increases from the A to the CCC rating class. *ba* has a consistently positive impact and tends to be higher for the investment grade rating class, and *yv* and *ctd* exhibit the reverse behavior. In the univariate setting, the coefficients have a hump-shaped curve across the rating classes with the maximum attained in the BBB rating class. These findings lend support to our earlier notion that the impact of the bond liquidity on the CDS premia - and therefore on the basis - may be twofold and that it is not clear ex ante which effect dominates. The adjusted R^2 increases monotonously as the rating decreases, suggesting that CDS premia and yield spreads deviate because they reflect credit risk and liquidity differently in the subinvestment grade segment.

To summarize the results of the firm-specific fixed effects analysis, we find that CDS premia are affected by the credit risk and liquidity-related explanatory variables. The factors have a high explanatory power, most of all the bid-ask spread which seems to measure not only CDS-specific liquidity but also credit risk. Financial reference entities are affected less by the credit risk measures, the bond liquidity has a negative impact, and that of the CTD option is very limited. This suggests that the credit risk of a financial reference entity is reflected in CDS premia differently than in the rating, the stock market, and the options market. The rating has the highest impact in the sovereign sector, and the CTD option is also most important for this sector. The latter result agrees with evidence that the price range for sovereign defaulted debt tends to be wide. Across the different rating classes, we observe an increasing impact of credit risk and liquidity, in particular when comparing the investment grade to the subinvestment grade segment. Bond liquidity has the highest impact for the BBB rating class, suggesting that close to the subinvestment grade barrier, the connection between the two markets' liquidity is strongest. The negative coefficients for the bond liquidity in the BB and CCC rating class also suggests that positions as CDS protection seller are used for taking on credit risk.

Bond yield spreads exhibit a much lower adjusted R^2. Even though the same factors have an impact on the bond market, the spread variation is not largely due to these factors as in the CDS market. Overall, the bond market is more closely linked to the options market than the CDS market. The sign of the coefficient for *ctd* becomes negative as a higher value of the explanatory variable is associated with a higher bond liquidity. The lower adjusted R^2 in the multivariate model for financial reference entities implies that the same weaker relation between a reference entity's specific credit risk and liquidity and the premia holds in the bond market as in the CDS market. The sovereign bond market shows most similarity to the CDS market, and we trace this back to the impact of the rating by which both CDS premia and yield spreads are strongly affected. Across the different rating classes, we observe a much lower adjusted R^2 than for CDS premia, but the dependence structure is similar. The subinvestment grade rating classes are affected more strongly by credit risk and liquidity as shown by the higher coefficient values and higher adjusted R^2, and the BBB rating class exhibits the highest sensitivity to the CDS market's liquidity.

For the basis, we find that credit risk can have two effects. If we measure credit risk by the rating or the historical volatility, the basis increases with credit risk. If, on the other hand, credit risk is measured by the option-implied volatility, the basis decreases for higher credit risk. The impact of the liquidity measures across the different rating classes differs.

The bond liquidity and the CTD option coefficients have a hump-shaped curve, the one for the CDS liquidity is slightly U-shaped. In both cases, the extremal points lie in the BBB rating class. From this, we conclude that the change from investment to subinvestment grade also changes the impact of liquidity in the sense that CDS liquidity becomes more important while the bond liquidity and the CTD option have a smaller effect. The adjusted R^2 remains largest for the subinvestment grade segment. Even though the differences between the CDS and the bond market increase with regard to the level, they are also more closely associated with credit risk and liquidity. Therefore, the higher the credit risk - as measured by a lower rating - the larger is the pricing impact of the identical risk factors.

For brevity, we do not show the results at the weekly or the monthly data frequency. The major differences are that CDS premia, yield spreads, and the basis are less strongly affected by the equity and the equity options market and that the link between the CDS and the bond market does, in fact, become stronger as the results of Section 3.3 suggested.

3.4.2 Market-Wide Factors

In an extension of the firm-specific analysis, we now explore the dependency of the CDS premia, bond yield spreads, and the basis on the market-wide measures of credit risk and liquidity described in Section 3.1.5. Collin-Dufresne et al. (2001) find that a number of firm-specific variables that should in theory affect credit spread changes for individual bonds have very little explanatory power, and that the remaining variation is explained to a large extent by a single common but unknown factor. This evidence is also supported by Pedrosa and Roll (1998) who show that credit spreads of various bond indices are influenced by common underlying factors. We therefore analyze whether the explanatory power of these market-wide measures is similar to the explanatory power of the firm-specific measures of credit risk and liquidity and whether the sensitivity to the market-wide variables depends on the industry sector and the rating class.

Explanatory Variables

As interest rate variables, we include the level and the slope of the EURIBOR curve. We use EURIBOR as a timely and highly liquid benchmark interest rate in the Euro money market. The level is chosen as the longest available EURIBOR maturity which equals 12 months, the slope as the difference between the 12-month and 1-month level. Other studies such as Duffee (1998) or Bedendo et al. (2007) use longer maturities of up to 30 years in their empirical analysis of the determinants of bond yield spreads. However, their bond sample also consists of bonds with a much longer maturity than 5 years. We therefore believe that our choice of a shorter maturity is sensible. As discussed in Section 3.1.5, it is not clear ex ante in which direction the interest rate variables affect the CDS premia, bond yield spreads, and the basis.

As corporate bond indices, we use the JPMorgan Aggregate Index Europe and the rating-class specific S&P Global Bond Index which are described in more detail in Appendix 3.5. For these indices, we determine the yield spread over the 5-year swap rate. Assuming a constant price of credit risk, a higher index yield spread measures a higher market-wide credit risk which will in general translate into higher individual CDS premia and bond yield spreads. However, taking into account the flight-to-quality effect, we also surmise that yield spreads for highly rated debt may decrease if the index yield spreads increase.

As the last explanatory variable, we use the ECB Financial Market Liquidity Indicator which is also described in Appendix 3.5. A higher value of the indicator implies a higher overall market liquidity. As for the index yield spreads, we assume that a lower degree of liquidity translates into higher yield spreads, i.e. that the relation between the index and the CDS premia and bond yield spreads is negative. For very highly rated reference entities, on the other hand, the coefficient estimate may also be positive.

Model Specification

The system of equations which we estimate is given by

$$\begin{aligned} CDS_{i,t} &= \alpha_{0,i} + \alpha_1 l_t^{\text{eur}} + \alpha_2 s_t^{\text{eur}} + \alpha_3 MAGGIE_t + \alpha_4 SPWC_{i,t} + \alpha_5 FML_t + \varepsilon_{i,t}, \\ ys_{i,t} &= \beta_{0,i} + \beta_1 l_t^{\text{eur}} + \beta_2 s_t^{\text{eur}} + \beta_3 MAGGIE_t + \beta_4 SPWC_{i,t} + \beta_5 FML_t + \eta_{i,t}, \\ b_{i,t} &= \gamma_{0,i} + \gamma_1 l_t^{\text{eur}} + \gamma_2 s_t^{\text{eur}} + \gamma_3 MAGGIE_t + \gamma_4 SPWC_{i,t} + \gamma_5 FML_t + \nu_{i,t}. \end{aligned} \tag{3.3}$$

$CDS_{i,t}$, $ys_{i,t}$, $b_{i,t}$, $\alpha_{0,i}$, $\beta_{0,i}$, and $\gamma_{0,i}$ are defined as in Equation 3.2. l^{eur} and s^{eur} denote the EURIBOR level and slope. MAGGIE gives the JPMorgan Aggregate Index Europe yield spread, SPWC the rating-class specific S&P Global Bond Index yield spread, and FML the ECB Financial Market Liquidity Indicator.

The significance of the coefficient estimates is determined using the Newey-West covariance estimate to adjust for autocorrelation and heteroscedasticity. Stationarity of the residuals is determined via the Phillips-Perron test. For the CDS premia, we can reject the null hypothesis of a unit root (for the full model specification) at the 10% significance level for 148 reference entities. The null hypothesis cannot be rejected at the

10% level for 5 investment-grade financial, 16 investment-grade non-financial corporate, and two subinvestment grade sovereign reference entities. For the bond yield spreads and the basis, we cannot reject a unit root (for the full model specification) at the 10% significance level for the same three sovereign reference entities as in the firm-specific analysis.

The results of the estimation are given in Table 3.10.

As in the previous section, for each dependent variable we discuss the estimation results first for all reference entities, then the results by industry sector, and last the results by rating class.

CDS Premia

As Panel A of Table 3.10 shows, for the entire sample the market-wide explanatory variables have a high impact on CDS premia and yield spreads both in the univariate and the multivariate model as measured by the significance of the coefficients and the adjusted R^2. l^{eur} and s^{eur} have a negative impact in the univariate model as also found in Aunon-Nerin et al. (2002) and Benkert (2004).

Higher overall credit risk, reflected by a higher value of MAGGIE, also increases CDS premia both univariately and multivariately. The rating-specific default risk which we proxy by SPWC increases CDS premia, and a higher financial market liquidity which is proxied by higher values of FML decreases CDS premia. This finding suggests that mid CDS premia are affected by aggregate market liquidity.

The explanatory power of MAGGIE, SPWC, and the liquidity indicator are rather high. With an adjusted R^2 of 9% and 10% each in the univariate model specification, these market-wide variables have a similar impact on CDS premia as the firm-specific historical volatility in Table 3.9.

Industry Sectors Across the different industry sectors, we observe from Panel A of Table 3.10 that most explanatory variables have a higher explanatory power for CDS on reference entities from the financial sector. MAGGIE and the liquidity indicator affect CDS more strongly than any of the firm-specific variables except the bid-ask spread in Table 3.9. This result agrees with Ericsson et al. (2008) who document that the 10-year treasury yield has a higher explanatory power for CDS bid and ask quotes on US reference entities than the firm-specific stock return volatility.

Table 3.10: **Impact of Market-Wide Risk Factors**

The table shows the coefficients, significance level, and adjusted R^2 for the fixed effects model. l^{eur} and s^{eur} denote the EURIBOR level and slope, MAGGIE the JPMorgan Aggregate Index Europe yield spread, SPWC the rating-class specific S&P Global Bond Index Yield spread, and FML the ECB Financial Market Liquidity Indicator. The model is estimated univariately ("Single") and for the full multivariate specification ("Full"). Significance is determined using Newey-West heteroscedasticity and autocorrelation robust standard errors. ***, **, and * denote the 1%, 5%, and 10% significance level. Coefficients are determined for mid CDS premia, bond yield spreads, and the basis in basis points, the adjusted R^2 are given in brackets.

Panel A: Analysis by Industry Group

	Financial		Non-Financial		Sovereign		All	
	Single	Full	Single	Full	Single	Full	Single	Full
				Mid CDS Premia				
l^{eur}	-4.35***	75.89***	-3.73***	236.60***	-1.75**	73.44**	-3.81***	194.30***
	(0.05)		(0.00)		(0.00)		(0.00)	
s^{eur}	-30.21***	-5.98***	-74.50***	-20.21***	-30.90***	-42.50***	-61.35***	-18.25***
	(0.22)		(0.06)		(0.02)		(0.05)	
$MAGGIE$	1.44***	1.46***	3.90***	3.40***	1.34***	-1.99***	3.17***	2.85***
	(0.33)		(0.10)		(0.02)		(0.09)	
$SPWC$	15.19***	13.22***	40.65***	33.88***	13.72***	12.98***	32.67***	26.94***
	(0.05)		(0.12)		(0.07)		(0.10)	
FML	-27.47***	-5.63***	-72.83***	13.48***	-38.68***	-39.72***	-60.40***	5.38***
	(0.30)	(0.40)	(0.09)	(0.20)	(0.05)	(0.13)	(0.09)	(0.17)
				Bond Yield Spreads				
l^{eur}	16.58***	405.08***	-0.37***	47.42**	8.48***	63.77	4.88***	143.35***
	(0.02)		(0.00)		(0.01)		(0.00)	
s^{eur}	48.94***	42.30***	-29.88***	-9.24***	-21.83***	-53.60***	-9.47***	2.57
	(0.01)		(0.00)		(0.01)		(0.00)	
$MAGGIE$	-1.32***	-1.54***	1.78***	1.56***	0.27**	-1.23**	0.94***	0.59***
	(0.01)		(0.01)		(0.00)		(0.00)	
$SPWC$	21.22***	18.80***	23.84***	22.70***	9.15***	10.21***	19.65***	18.81***
	(0.00)		(0.02)		(0.02)		(0.01)	
FML	8.74***	-44.06***	-32.14***	10.03***	-26.54***	-40.68***	-22.01***	-9.86***
	(0.00)	(0.04)	(0.01)	(0.03)	(0.02)	(0.12)	(0.00)	(0.02)
				Basis				
l^{eur}	-20.93***	-329.19***	-3.33***	189.14***	-10.23***	10.62	-8.67***	50.97***
	(0.02)		(0.00)		(0.03)		(0.00)	
s^{eur}	-79.11***	-48.29***	-44.43***	-10.92***	-8.95***	11.11**	-51.72***	-20.78***
	(0.03)		(0.01)		(0.00)		(0.02)	
$MAGGIE$	2.76***	3.00***	2.12***	1.84***	1.07***	-0.76*	2.23***	2.26***
	(0.02)		(0.02)		(0.02)		(0.02)	
$SPWC$	-6.27***	-5.60**	16.75***	11.09***	4.48***	2.61***	12.91***	8.03***
	(0.00)		(0.01)		(0.01)		(0.01)	
FML	-36.20***	38.41***	-40.81***	3.36	-12.14***	0.98	-38.46***	15.16***
	(0.01)	(0.06)	(0.02)	(0.03)	(0.01)	(0.08)	(0.02)	(0.03)

Panel B: Analysis by Rating Class

	AAA		AA		A		BBB		BB		B		CCC	
	Single	Full	Single	Full	Single	Full	Single	Full	Single	Full	Single	Full	Single	Full
Mid CDS Premia														
l^{eur}	-0.74***	45.51***	-2.05***	36.59***	-2.37***	120.20***	3.60***	215.06***	-37.48***	1,162.26***	-21.49***	1,878.80***	-36.92***	853.96**
	(0.03)		(0.04)		(0.01)		(0.00)		(0.01)		(0.01)		(0.04)	
s^{eur}	-6.76***	-14.63***	-17.08***	-1.08***	-38.06***	-16.69***	-77.68***	-64.35***	-396.33***	-149.80***	-196.79***	122.99***	-280.76***	-340.90***
	(0.16)		(0.26)		(0.16)		(0.08)		(0.16)		(0.07)		(0.45)	
$MAGGIE$	-0.14***	-0.39***	0.87***	0.68***	1.92***	1.22***	4.37***	4.58***	24.77***	18.94***	8.09***	11.73***	-1.71	3.08
	(0.04)		(0.45)		(0.26)		(0.17)		(0.31)		(0.07)		(0.01)	
$SPWC$	-1.04***	2.40***	-14.29***	-6.96***	52.62***	-9.47***	45.91***	-17.47***	141.85***	53.69***	84.46***	133.24***	194.63***	-78.02*
	(0.03)		(0.04)		(0.11)		(0.12)		(0.40)		(0.24)		(0.34)	
FML	-3.14***	-3.02***	-16.99***	-10.80***	-35.49***	-12.55***	-84.05***	-11.20***	-479.53***	50.99**	-238.05***	-140.11***	277.16***	220.89**
	(0.05)	(0.26)	(0.44)	(0.52)	(0.25)	(0.31)	(0.16)	(0.29)	(0.31)	(0.49)	(0.15)	(0.44)	(0.16)	(0.63)
Bond Yield Spreads														
l^{eur}	-12.47***	31.67	23.33***	495.24***	3.34***	-112.65***	-2.35***	41.72	-12.49***	773.79***	-37.07***	1,043.83***	-69.60***	-1,157.07***
	(0.11)		(0.02)		(0.00)		(0.00)		(0.00)		(0.01)		(0.11)	
s^{eur}	-41.04***	1.97	62.07***	47.16***	-13.99***	-3.58	-33.90***	-39.29***	-295.23***	-108.36***	-187.35***	159.47**	17.05	-419.93***
	(0.08)		(0.02)		(0.00)		(0.01)		(0.10)		(0.03)		(0.00)	
$MAGGIE$	-1.62***	0.90**	-1.69***	-2.26***	1.13***	0.09	1.36***	3.40***	19.58***	5.28**	9.94***	24.40***	-7.40***	4.81*
	(0.08)		(0.01)		(0.01)		(0.01)		(0.22)		(0.04)		(0.11)	
$SPWC$	-9.25***	-5.94**	14.94***	-7.60	44.81***	13.39***	10.53***	15.35***	117.51***	22.95***	74.40***	206.16***	-18.55	-155.76***
	(0.03)		(0.00)		(0.01)		(0.00)		(0.31)		(0.08)		(0.00)	
FML	-22.03***	9.55**	15.17***	-47.61***	-25.53***	-11.89***	-14.15***	60.62***	-455.33***	-271.15***	-190.14***	403.56***	423.86***	87.56
	(0.04)	(0.16)	(0.00)	(0.05)	(0.02)	(0.03)	(0.00)	(0.04)	(0.32)	(0.39)	(0.04)	(0.17)	(0.27)	(0.70)
Basis														
l^{eur}	11.73***	13.84	-25.38***	-458.61***	-5.72***	232.91***	5.98***	173.32***	-24.98***	389.96***	15.20***	835.26***	35.48***	2,017.20***
	(0.09)		(0.03)		(0.01)		(0.00)		(0.01)		(0.00)		(0.19)	
s^{eur}	34.27***	-16.60***	-79.11***	-48.24***	-24.02***	-13.08***	-43.59***	-24.97***	-99.83***	-41.34*	-10.42	-36.23	-297.58***	78.59
	(0.06)		(0.03)		(0.01)		(0.01)		(0.03)		(0.00)		(0.29)	
$MAGGIE$	1.48***	-1.29***	2.56***	2.94***	0.79***	1.13***	3.01***	1.18***	5.12***	13.65***	-1.81**	-12.67***	5.62***	-1.67
	(0.07)		(0.02)		(0.01)		(0.03)		(0.03)		(0.00)		(0.05)	
$SPWC$	8.21***	8.35***	-29.50***	0.64	7.40***	-22.91***	35.45***	-32.79***	24.24***	30.81***	9.96**	-72.67***	213.06***	78.14
	(0.02)		(0.00)		(0.00)		(0.03)		(0.03)		(0.00)		(0.25)	
FML	18.88***	-12.57***	-32.17***	36.82***	-10.05***	-0.68	-70.21***	-71.80***	-22.25***	321.98***	-47.11***	-543.60***	-133.59	132.98
	(0.03)	(0.14)	(0.01)	(0.06)	(0.00)	(0.02)	(0.05)	(0.06)	(0.00)	(0.13)	(0.00)	(0.11)	(0.02)	(0.70)

For the non-financial corporate sector, the estimation yields higher coefficient estimates in the univariate setting. However, the explanatory power of all variables but SPWC is lower than for financial reference entities. Nevertheless, SPWC has a similar adjusted R^2 as the historical volatility in Panel A of Table 3.9. This suggests that firm-specific risk is more important for non-financial corporate reference entities than for financial ones.

The sovereign sector also reacts sensitively to market conditions, but the explanatory power of the interest rates and MAGGIE is poor. Only SPWC and the liquidity indicator have an adjusted R^2 of 7% and 5%, but compared to the impact of the rating, the effect remains limited. A similar result is documented by Aunon-Nerin et al. (2002) who find that up to 67% of the sovereign CDS variation can be explained through the rating alone.

In summary, we find that the CDS premia for the financial sector are closely connected to overall market conditions and that the non-financial corporate and sovereign sector seem to be predominantly affected by the reference entity's specific risk.

Rating Classes Regarding the different rating classes, Panel B of Table 3.10 shows that in contrast to the entire sample, CDS premia for the AAA class react negatively to changes in MAGGIE and SPWC in the univariate setting. For the AA rating class, the impact of SPWC is also negative. This finding agrees with the flight-to-quality effect. Interestingly, the joint explanatory power of the market-wide explanatory variables is more than twice as large as the firm-specific variables' in the multivariate model. Clearly, CDS on AAA rated reference entities are not only driven by the entity's idiosyncratic risk but rather depend on the financial markets' overall condition.

The remaining rating classes exhibit a similar sensitivity to the interest rate variables as the entire sample. In the investment grade segment below AAA, the coefficient estimates for l^{eur} and s^{eur} and the liquidity indicator become more pronouncedly negative in the univariate model. Simultaneously, their explanatory power as well as the adjusted R^2 of the multivariate model decrease as the rating deteriorates. The index spread coefficient estimates increase, and while the explanatory power of MAGGIE decreases to an adjusted R^2 of 17%, SPWC becomes more important with an increase to 12% for the BBB rating class.

The subinvestment grade segment is also highly sensitive to l^{eur} and s^{eur}. In particular for the CCC rating class, s^{eur} has an adjusted R^2 of 45% in the univariate setting. The rating-specific yield spread also has a larger explanatory power than for the investment grade segment, but the impact of the liquidity indicator decreases from an adjusted R^2 of 31% to 15% and 16%.

Bond Yield Spreads

Panel A of Table 3.10 shows that even though the coefficient estimates for the yield spreads are significant for all market-wide measures, they have almost no explanatory power. The effect (which pertains at the weekly frequency) contrasts with the result of Collin-Dufresne et al. (2001). For the entire sample, the slope of the interest rate curve has the expected negative impact, but the yield spreads exhibit a positive dependence on the level with a coefficient estimate of 4.88.

Industry Sectors The lack of the yield spreads' sensitivity to the market-wide measures is illustrated further if we compare the different industry sectors in Panel A of Table 3.10. The coefficient estimates for l^{eur} and s^{eur} become unexpectedly positive for financial reference entities in the univariate setting. In addition, l^{eur} also has a positive association with sovereign yield spreads.

Since financial reference entities are more likely to refinance themselves at an interest rate close to EURIBOR, we believe that the coefficient estimates indicate their sensitivity towards refinancing costs. In particular banks, who traditionally invest in longer-term risky assets and accept low-risk and short-term deposits, tend to hold fixed-interest rate assets and liabilities with diverging maturities. As Czaja et al. (2006) argue, this effect pertains to most financial institutions and makes them more sensitive to interest rate risk. Therefore, increasing interest rates decrease the value of the fixed-income assets to a larger extent than the short-term liabilities, leading to a higher credit risk and higher yield spreads.

Yield spreads in the financial sector are also positively associated with the liquidity indicator and negatively with MAGGIE, i.e. they increase when liquidity or credit risk decrease. This result illustrates that the flight-to-quality and the flight-to-liquidity effect are most pronounced in the financial sector. This agrees with the on average higher rating for financial reference entities. The small explanatory power prevails for all industry sectors, only the sovereign sector has an adjusted R^2 of 12% for the multivariate model.

Rating Classes Comparing the impact of the market-wide measures for the different rating classes in Panel B of Table 3.10, the explanatory power of the multivariate model is surprisingly large for the AAA and the subinvestment grade rating classes. The liquidity measure in particular has an adjusted R^2 of approximately 30% for the BB and the CCC rating class, and the AAA rating class is more adequately described than through the firm-specific variables in Table 3.9. The coefficient estimates for l^{eur} and s^{eur} become positive for the AA rating class which agrees with the large proportion of financial reference entities in this class.

Basis

As a consequence of the low explanatory power for yield spreads, the market-wide risk measures cannot explain the basis very well either even though almost all coefficients are significant at the 1% level. Panel A of Table 3.10 shows that the basis depends negatively on l^{eur} and s^{eur} and the liquidity measure for the full sample in the univariate model. Since the signs agree with those we obtained for CDS premia, CDS premia react more sensitively to the market-wide measures than yield spreads. As the basis is mostly negative, we find that higher interest rates, a higher slope, and higher market-wide liquidity widen the basis.

Industry Sectors Regarding the results for the different industry sectors, we find that the basis in the financial sector exhibits a negative dependence on MAGGIE while the coefficient for the non-financial corporate and the sovereign sector is positive.

Rating Classes For the different rating classes in Panel B of Table 3.10, we again observe that the coefficient signs agree with those for the CDS premia in the univariate model. Only the AAA rating class exhibits a consistently reverse behavior, all coefficients have the reverse sign which suggests that in this case the impact of the explanatory variables on the bond market is higher.

To summarize, the market-wide fixed-effects analysis yields the following results. First, premia for CDS written on financial and sovereign reference entities are closely associated with market-wide explanatory variable while those for non-financial corporate reference entities are more adequately described by firm-specific variables. Second, yield spreads are significantly affected by the market-wide variables but the explanatory power is low. Sovereign reference entities fare best with an adjusted R^2 of 12% for government rates. Third, yield spreads for financial corporate reference entities have a positive dependence on the level and slope of the interest rate curve which we attribute to the impact of refinancing costs. Fourth, CDS premia tend to be more closely connected to market-wide measures than yield spreads, only for AAA-rated and financial reference entities the yield spreads depend more strongly on the market-wide measures. Last, the explanatory power of the market-wide variables in the multivariate model specification exceed those of the issuer-specific ones for the AAA and the AA rating classes for CDS premia, yield spreads, and the basis.

In the next chapter, we develop a reduced-form model that allows us to disentangle the credit risk and liquidity components of the CDS premia and bond yield spreads. This will allow us to explore in more detail how credit risk and liquidity interact in the two markets, and how the liquidity of one market affects that of the other.

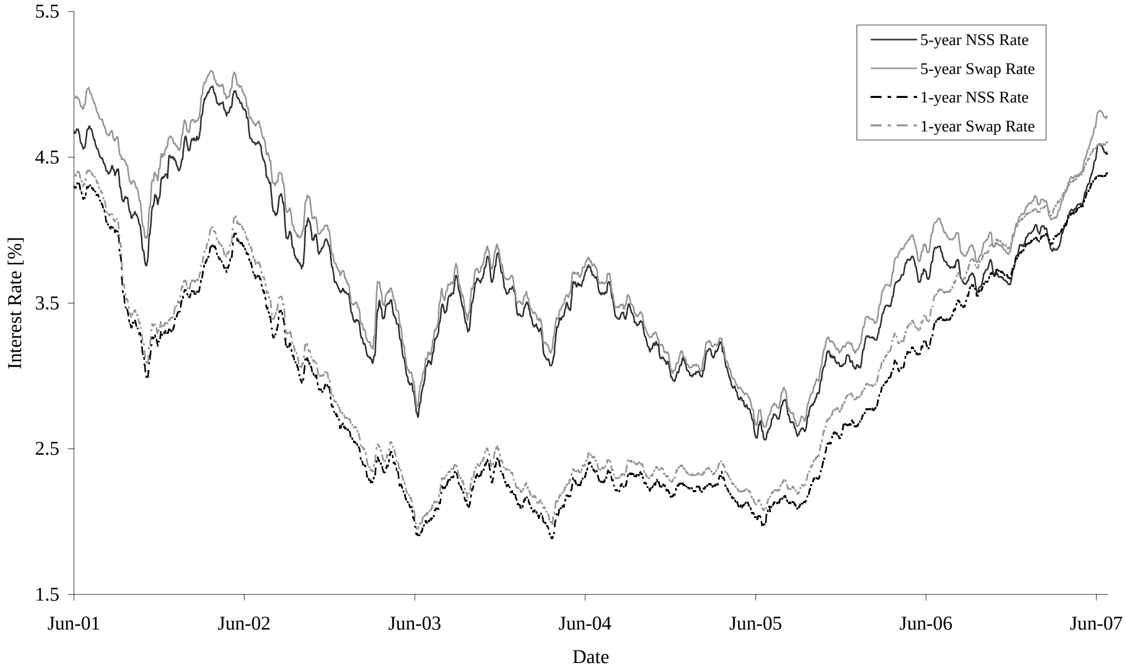
3.5 Appendix to Chapter 3 - Data Collection

Default-Free Interest Rates

In Chapter 3, we focus on bond yield spreads in excess of the Nelson-Siegel-Svensson curve computed from the Bundesbank parameter estimates for German government bonds. To demonstrate that the differences between the two proxies for the default-free interest rate were limited during our observation interval, we show the time series of the spot interest rates for the government rate and the Euro interest rate swap rate. The maturity is constant at 1 year and 5 years.

Figure 3.1: **German Government Bond Interest Rates and Euro Swap Rates**

The figure shows the time series of German government bond interest rates and the Euro swap rate in percentage points from June 2001 to June 2007. The German government bond interest rate is determined from the Bundesbank parameter estimates for the Nelson-Siegel-Svensson curve (NSS), the Euro swap rates are collected from Bloomberg. The maturity is constant at 1 year and at 5 years.



CDS Premia

We exclusively focus on data from the Euro area since the sample of Euro-denominated CDS contracts is much larger than that of US-Dollar denominated contracts in the early phase of our research interval: Between June 1, 2001 and September 30, 2001, we observe CDS ask and bid quotes on 119 Euro-denominated contracts in contrast to 16 US-Dollar denominated contracts. We exclude CDS contracts denominated in US-Dollar and Japanese Yen in order to obtain a sample that is homogenous with regard to the delivery option for restructured debt. Since the literature agrees that CDS with 5 years to maturity are the most liquid segment of the CDS market, see e.g. Meng and ap Gwilym (2006) and Gündüz et al. (2007), we exclude all CDS with 1, 3, 7, and 10 years until maturity. In total, we obtain a set of 458 reference entities on which CDS contracts fulfilling the above criteria exist.

To determine whether a given CDS contract has a constant time-to-maturity of 5 years or whether it follows the standard time conventions of fixed maturity days which have prevailed in the market since late 2002, we visually explore every CDS time series. If the observed time series exhibits a jump when the reference maturity date changes, we compute the size of the jump. If the jump is at least as large as 25% of the quarterly payment associated with the minimum annualized quoted CDS premium in a window of 5 days before and 5 days after the jump, we mark the CDS quotes as "standard maturity" starting from the first jump. Otherwise, the quotes are marked as "constant maturity".

Bond Yield Spreads

We perform the following interpolation scheme to compute the bond yield spreads over the default-free interest rates. In the first step, we compute the time-t yield spread $ys_t\left(c, F, t_1, \ldots, t_n\right)$ of each bond with coupon c, payment dates $t_1, \ldots, t_n$, and maturity t_n. In detail, $ys_t\left(c, F, t_1, \ldots, t_n\right)$ is defined as

$$
\begin{aligned}
ys_t\left(c, F, t_1, \ldots, t_n\right) \quad = \quad & \arg\min \left(c \cdot \sum_{t_i = t_1}^{t_n} \left[\frac{t_i - t_{i-1}}{\left(1 + y_{\text{rf}}\left(t_i\right) + ys\right)^{t_i - t_0}} - \frac{t_i - t_{i-1}}{\left(1 + ytm\right)^{t_i - t_0}} \right] + \right. \\
& \left. F \cdot \left[\frac{1}{\left(1 + y_{\text{rf}}\left(t_n\right) + ys\right)^{t_n - t_0}} - \frac{1}{\left(1 + ytm\right)^{t_n - t_0}} \right] \right)^2 ,
\end{aligned}
$$

where $t_0 := t$, $y_{\text{rf}}\left(t_i\right)$ denotes the yield-to-maturity of a default-free zero coupon bond with time-to-maturity $t_i - t_0$, and ytm denotes the observed yield-to-maturity of the given bond with time-to-maturity $t_n - t_0$.

In the second step, we perform a linear regression of the yield spreads for a given reference entity on the time-to-maturity of the bond for each of the observation dates. The resulting daily estimates of the intercept and the slope are used to compute the theoretical yield spread of a synthetical bond with the same maturity date as the CDS contract written on the reference entity of 5 to $5\frac{1}{4}$ years. This interpolation procedure yields a more stable time series of yield spreads than first interpolating the bond yields and then subtracting the yield-to-maturity of a default-free bond. The total number of 137,816 synthetical yield spreads equals that of the CDS quotes.

A potential problem which we incur through interpolating yield spreads concerns the dependence on explanatory variables. Basically, the linear interpolation suggests that we subtract the short-term from the long-term yield spread. If both depend positively on an explanatory variable but the sensitivity of the short-term yield spread is higher, the interpolated yield will have a negative dependence. Duffee (1998) shows that corporate bond yield changes for bonds with short maturities tend to have a more pronounced negative dependence on the 4-month T-bill yield than bonds with medium maturities, suggesting that while the impact on each yield spread is negative, the impact on an interpolated yield spread may be positive. This effect is an alternative, technical explanation for the positive dependence of the bond yield spreads on the interest rate level and slope for financial reference entities in Table 3.10

Rating

For each of the reference entities, we collect a complete rating history from Bloomberg between June 1, 2001 and June 30, 2007. We determine both the S&P rating and the Moody's rating for senior unsecured debt of each reference entity on June 1, 2001. If neither of these are available, we use the S&P and Moody's long-term issuer debt rating instead. If these are also unavailable, we choose the respective issuer rating. In the second step, we collect every published rating change, including changes of the quantifiers (+ and - for S&P, 1, 2, and 3 for Moody's) and the rating outlook (*+, *, and *-, both for S&P and Moody's) until June 30, 2007. In the third step, we map the ratings onto a numerical scale ranging from 1 to 67 where 1 corresponds to the AAA*+ S&P rating (Aaa*+ Moody's rating, both the highest rating grade with a positive outlook). The highest value, 66, corresponds to a D*- S&P rating (for Moody's, C*- is the lowest rating) which marks defaulted reference entities with a negative outlook. 67 is used to denote a withdrawn rating. If the resulting numerical rating differs by 2 or more on a given day, we assign the average numerical rating to the reference entity, rounding up to the next integer when the average is not in the rating scale. If the rating differs by 1, we choose the more conservative S&P rating and ignore the Moody's rating. This procedure gives us a numerical rating value for each of the reference entities on each of the dates where both a CDS quote and at least two bond yields were observed. The highest resulting numerical rating equals 2, corresponding to a AAA S&P rating, while the lowest rating in the sample is 50 and marks a CCC+ S&P rating.

Averages across the rating classes are determined in one out of two ways. The first approach is used when it is necessary to obtain a longer time series without gaps. Then, we first determine the time series average rating for each reference entity across all observation dates where there were at least two bond price quotes, a CDS ask quote, and a CDS bid quote available. The actual rating of the reference entity could therefore theoretically differ from the average rating on each observation date. We subsequently treat all reference entities with the same average rating as if they had exhibited this rating at each observation date. This is the approach used in the overview over the sample in Table 3.1 and in the time series analysis in Table 3.6, Table 3.7, and Table 3.8.

The second approach to determine averages is used when the time series relation is less important. We then allow reference entities to move between the rating classes and compute the average rating across the observations for all reference entities which had a specific rating on that observation date and across all observation dates. This is the approach used in the descriptive statistics in Table 3.2, Table 3.3, Table 3.4, and Table 3.5 as well as in the fixed-effects regression analysis in Panel B of Table 3.9 and Table 3.10.

Stock Returns and Volatility

We determine the equity tickers of the 171 reference entities for straight equity. For 16 sovereign reference entities, three fully state-owned, and 6 private firms, no equity data was available. For the remaining 146 firms, we obtain a time series of ex-dividend stock prices starting from June 1, 2000 from Bloomberg from which we compute a time series of daily stock returns. The earlier starting point allows us to determine the historical stock return volatility for an interval of up to 12 months. In addition, we obtain the time series of option-implied volatilities for the time interval from June 1, 2001 to June 30, 2007 for 98 firms. We use European vanilla at-the-money options with a time-to-maturity of 12 months since the data for these was most widely available; we only had access to option-implied volatilities for 32 firms for a maturity of 1 month and for 47 firms for a maturity of 3 and 6 months. Overall, we observe 233,785 daily stock return and 54,099 option-implied volatility data points.

Corporate Bond Indices

All index data is obtained from Bloomberg. We use the JPMorgan Aggregate Index Europe (MAGGIE) and the S&P Global Corporate Bond Indices (SPWC).

The MAGGIE is a weighted average of three subindices, the EMU Government Bond

Index, the Euro Credit Index, and a Jumbo Pfandbrief index. As of June 2007, the MAGGIE contained approximately 1,800 bonds from the Eurozone with a maturity of 5 to 7 years which JPMorgan claims are chosen on the basis of their traded liquidity. We obtain the daily MAGGIE mid quote yield-to-maturity from June 1, 2001 to June 30, 2007, thus yielding a total of 1,548 observations each.

The SPWC represents the S&P Creditweek Corporate Bond Yield Indices, containing bonds with a minimum outstanding volume of USD 100 million. Bloomberg contains 307 weekly yield observations with a constant 5-year maturity for all rating classes between AAA and B, computed from bond prices in USD. The SPWC indices have been discontinued from May 1, 2007.

Financial Market Liquidity Indicator

The description of the liquidity indicator was made available to us by the ECB. The first three constituents which proxy for the market tightness are the bid-ask spreads on (1) the EUR/USD, EUR/JPY and EUR/GBP exchange rates, (2) the 50 individual stocks which form the Dow Jones EURO STOXX 50 index, and (3) 1-month EONIA and 3-month swap rates. The three measures of market depth are the return-to-rollover ratios for (4) the 50 individual stocks which form the Dow Jones EURO STOXX 50 index, (5) the Euro Bond market total return index and the Deutsche Boerse total turnover on the bond market as well as (6) the EURO STOXX 50 index option-implied volatility absolute change divided by the open interest in options contracts on the EURO STOXX 50 index. The final components quantify the liquidity premium and are given by (7) spreads on Euro area high-yield corporate bonds adjusted by the expected default frequency and (8) the spreads between interbank deposit rates and repo interest rates for the Euro area. Taking the simple average of all the liquidity measures at each point-in-time gives the time series of the liquidity indicator which is then demeaned and normalized to a standard deviation of 1.

Chapter 4

The Credit Risk and Liquidity Model

In this chapter, we introduce our reduced-form model that accounts for credit risk and liquidity premia in bond and CDS markets. As the analysis in Chapter 3 shows, an explicit model is warranted since both bond and CDS market liquidity proxies seem to play an important role in explaining the differences between bond yield spreads and CDS premia after the coupon and maturity mismatch is accounted for. We contribute to the existing literature on the components of bond yield spreads and CDS premia theoretically and empirically by exploring the idea that the bid and ask quotes for CDS premia contain information on the liquidity of the CDS market.

In the theoretical part of our analysis, we extend the reduced-form credit-risk model of Longstaff et al. (2005) to incorporate illiquidity both in the bond and the CDS market. In the bond market, illiquidity results in price discounts and yield surcharges. This assumption is also made by Longstaff et al. (2005). Our extension consists of the modelling of a twofold liquidity effect on CDS premia. First, the bond-specific liquidity has a direct effect on CDS premia since the potentially illiquid bond is delivered under the CDS contract if default occurs. Therefore, the CDS premium in our model accounts for bond liquidity as a source of bond price variation.

In addition to this straightforward liquidity spill-over, we include a CDS-specific liquidity which has a more intricate effect. After all, it is not obvious from a theoretical perspective whether liquidity should be included in a model for CDS premia. CDS are derivatives, not assets, and thus not exposed to illiquidity effects caused by a fixed supply or the costs of short-selling such as bonds are. Both in empirical studies and in theoretical models, see e.g. Schueler and Galletto (2003) or Longstaff et al. (2005), it is generally assumed that the CDS mid premium reflects a price which is entirely free of liquidity risk. This assumption neglects the possibility of a liquidity-driven market imbalance that causes the pure credit risk CDS premium which is unaffected by the liquidity of the CDS market to be closer either to the ask or the bid quote. Undoubtedly, however, the bid and ask premia reflect liquidity aspects of a CDS. We therefore circumvent the question of systematic liquidity premia in CDS mid premia by modelling the ask and bid premia instead. This procedure is equivalent to assuming that the bid and ask quote are affected by illiquidity. As a consequence, we model two values of the fixed leg of the CDS, one for the ask and one for the bid side. From these, we extract the unobservable, pure credit risk premium. Typically, this premium will differ from the mid premium. Our measure of CDS liquidity then arises as the difference between this liquidity-free CDS premium and the mid premium.

Our model allows us to analyze in a consistent way the empirical relationship between time-varying bond- and CDS-specific liquidity premia. To the best of our knowledge, we are the first to explore this dynamic relationship in a model of bond and CDS liquidity.[32] Our results on the behavior of the liquidity premia can be consistently interpreted by demand relations for credit risk between the bond and the CDS market.

In the empirical part of our analysis, we estimate the credit risk and the liquidity components of yield spreads and CDS premia for the data set described in Chapter 3. We then analyze the relation between the time-varying credit risk and liquidity premia for the two markets.

Our most important findings are threefold. First, we find that adding a CDS-specific liquidity component to the model has the important consequence of consistently positive credit risk and liquidity premia in corporate bond markets. This result contrasts with those in Longstaff et al. (2005) who obtain strongly negative liquidity premia in corporate bond yields. In particular, we show that neglecting CDS-specific liquidity can result in negative bond liquidity premia. The average bond liquidity premia for corporate reference entities are of a similar magnitude as the liquidity risk premia which de Jong and Driessen (2005) identify for expected excess bond returns. The CDS liquidity premium is mostly positive which points to a demand pressure in the CDS market which supports the cross-sectional results of Chen et al. (2007), Bongaerts et al. (2007), and Meng and ap Gwilym (2006).

Second, our model allows us to analyze the relation between credit risk and liquidity premia in the bond and the CDS market. We find that the bond market's liquidity dries up as the reference entity's credit risk increases. This empirical result in our reduced-form model setting supports the theoretical prediction of the structural-form model by Ericsson and Renault (2006). They assume that liquidity shocks to the bond holder are correlated

[32] A similar approach is chosen by Dunbar (2007) who develops a reduced-form model that includes a liquidity risk factor in CDS premia. However, his model does not take into account the bond market, and he does not determine time-varying credit risk and liquidity premia.

with default risk. In the CDS market, the dynamics of the liquidity premia depend on the rating class. The investment grade sector becomes more dominated by protection sellers during times of high default risk. For the subinvestment grade sector, increasing credit risk coincides with a lower demand pressure for credit protection, thus decreasing CDS liquidity premia in the subinvestment grade sector. This analysis complements the cross-sectional evidence by Dunbar (2007).

Third, we extend the empirical evidence of Nashikkar et al. (2007) on the relation between the liquidity of the bond and the CDS market by disentangling the credit risk and liquidity premia. Instead of the absolute or relative CDS bid-ask spread which are affected by credit risk, our model allows us to determine comparable pure liquidity premia for the bond and the CDS market. For these, we obtain a significant relationship in excess of the liquidity spill-over which is immanent to our model.

The remainder of this chapter is organized as follows. Section 4.1 presents the setup of the base case model, the measures of credit risk and liquidity and a simulation analysis. Section 4.2 presents the empirical results of the model calibration and a detailed analysis of the estimated credit risk and liquidity premia. Section 4.3 contains several stability analyses, and a discussion of the shortcomings of the base case model is provided in Section 4.4.

4.1 Model Framework

In this section, we develop our approach to measure the size of the default and the liquidity component in CDS premia and corporate bond prices.

4.1.1 Base Case Model

We assume a standard Duffie and Singleton (1997) arbitrage-free capital market in which default-free zero coupon bonds, default-risky coupon-bearing bonds, and CDS written on the issuers of the coupon-bearing bonds are traded. The liquidity of these instruments can differ. We choose the default-free zero coupon bond as the liquidity numéraire. This choice implies that the liquidity of each instrument is measured relative to the default-free zero coupon bond. We therefore circumvent the problem of specifying a perfectly liquid instrument in comparison to which each illiquid instrument must trade at a discount.

In the setting of Duffie and Singleton (1997), we can write the stochastic discount factors in the well-known multiplicative exponential-affine form. We use r_t to denote the instantaneous default-free interest rate process that determines the price of the default-free zero coupon bond. λ_t refers to the credit risk hazard rate which governs the default probability and which is assumed to be reflected in CDS premia and bond prices. We use γ_t as the illiquidity process which determines the fraction of an asset's price due to liquidity deviations from the reference liquidity of 1. Then

$$\tilde{D}(t,\tau) = \exp\left(-\int_t^\tau r(s)\,ds\right)$$

is the stochastic risk-free discount factor from time t to τ,

$$\tilde{P}(t,\tau) = \exp\left(-\int_t^\tau \lambda(s)\,ds\right)$$

denotes the stochastic credit risk discount factor from time t to τ, and

$$\tilde{L}(t,\tau) = \exp\left(-\int_t^\tau \gamma(s)\,ds\right)$$

equals the stochastic liquidity discount factor that causes the price of an illiquid instrument to deviate from that of the liquidity numéraire. Consequently, the time-t value of a unit payment that occurs at time τ conditional upon survival until t and taking into account illiquidity equals

$$E_t\left[\tilde{P}(t,\tau)\,\tilde{L}(t,\tau)\,\tilde{D}(t,\tau)\right]$$

where E_t denotes the expectation with respect to the risk-neutral measure. Note that the choice of an identical instantaneous credit risk intensity λ_t for bonds and CDS implies that the default and survival probability are *issuer*-specific instead of *instrument*-specific.

In Appendix 4.5.1, we show that modelling the liquidity discount as a stochastic discount factor for each future payment in the same way as the survival probability is appropriate. Since we model mid bond prices and CDS ask and bid premia, we specify three illiquidity processes γ^b, γ^{ask}, and γ^{bid} which describe the liquidity of the two instruments. We denote the associated discount factors by $\tilde{L}^b$, $\tilde{L}^{\text{ask}}$, and $\tilde{L}^{\text{bid}}$.

If default occurs at time τ, the bondholder recovers a fixed fraction R of the face value F. This assumption causes the delivery option to be worthless. Default can occur at any time, and recovery takes place on the first trading day following the default event. Then, the time-t price of a coupon-bearing bond with fixed coupon c paid at times $t_1, \ldots, t_n$, notional

F, maturity in t_n, and possible recovery at time θ_j $(t \leq \theta_1 < \ldots < \theta_N \leq t_n)$ is given by

$$\begin{aligned} CB\left(\lambda, \gamma^b, t\right) &= c \cdot \sum_{i=1}^{n} E_t\left[\tilde{P}\left(t, t_i\right) \tilde{D}\left(t, t_i\right) \tilde{L}^b\left(t, t_i\right)\right] + F E_t\left[\tilde{P}\left(t, t_n\right) \tilde{D}\left(t, t_n\right) \tilde{L}^b\left(t, t_n\right)\right] \\ &+ R \cdot F \cdot \sum_{j=1}^{N} E_t\left[\Delta \tilde{P}\left(t, \theta_j\right) \tilde{D}\left(t, \theta_j\right) \tilde{L}^b\left(t, \theta_j\right)\right] \qquad (4.1) \end{aligned}$$

where $\theta_0 := t$ and $\Delta\tilde{P}\left(t, \theta_j\right) := \tilde{P}\left(t, \theta_{j-1}\right) - \tilde{P}\left(t, \theta_j\right)$ denotes the probability of surviving from t until θ_{j-1} and then defaulting between θ_{j-1} and θ_j given that the current date is t. Equation (4.1) can be interpreted as the expected present value of all future bond cash-flows: The first summand gives the expected present value of the coupon payments at each coupon date. The second summand equals the expected present value of the principal payment in the last period. The last term is the expected present value of the recovery rate payment. Each future payment is therefore discounted with regard to the default risk of the bond and to the illiquidity which affects the instrument.

The value of the fixed leg of a CDS contract at time t with fixed premium payments s^{ask} made in arrear at times $T_1, \ldots, T_m$, maturity in T_m, and recovery at θ_j $(t \leq \theta_1 < \ldots < \theta_M \leq T_m)$ equals

$$\begin{aligned} CDS_{\text{fix}}\left(t\right) &= s^{\text{ask}} \Bigg(\sum_{i=1}^{m} E_t\left[\tilde{P}\left(t, T_{i-1}\right) \tilde{D}\left(t, T_i\right) \tilde{L}^{\text{ask}}\left(t, T_i\right)\right] \\ &\quad + \sum_{j=1}^{M} \delta_j E_t\left[\Delta P\left(t, \theta_j\right) \tilde{D}\left(t, \theta_j\right) \tilde{L}^{\text{ask}}\left(t, \theta_j\right)\right] \Bigg), \qquad (4.2) \end{aligned}$$

where δ_j accounts for the premium fraction accrued in the interval between the last payment date and the recovery date θ_j. $\tilde{L}^{\text{ask}}$ is defined like $\tilde{L}^b$ with the bond liquidity intensity γ^b replaced by the CDS ask liquidity intensity γ^{ask}.

Equation (4.2) suggests that the payment of all ask premia s^{ask} from the protection buyer to the protection seller has to be discounted for the default probability since the payment at time T_{i-1} only occurs with a probability $P\left(t, T_{i-1}\right)$. The CDS-specific liquidity discount factor for the ask premium $\tilde{L}^{\text{ask}}\left(t, T_i\right)$ is added since we assume that a part of the CDS ask premium is not due to default risk but to the fact that the protection seller demands an additional premium because of illiquidity.

The value of the floating leg, that is the payment of the protection seller contingent upon default, equals

$$CDS_{\text{float}}(t) = F\sum_{j=1}^{M} E_t\left[\Delta\tilde{P}(t,\theta_j)\tilde{D}(t,\theta_j) - R\Delta\tilde{P}(t,\theta_j)\tilde{D}(t,\theta_j)\tilde{L}^b(t,\theta_j)\right]. \tag{4.3}$$

The first summand in (4.3) equals the discounted present value of the face value F which we assume the protection seller pays out in cash. Since physical delivery of the defaulted bond constitutes the CDS market standard, the second summand equals the discounted present value of the defaulted bond which the protection seller has to sell in the market upon the bond's delivery. Therefore, the second summand contains the discounting factor for the bond liquidity in addition to the credit risk discounting factor. Note that the floating leg is not discounted with regard to the CDS-specific liquidity.

Setting equal (4.2) and (4.3) and solving for s^{ask}, we obtain

$$s^{\text{ask}} = \frac{F\sum_j E_t\left[\left(1-R\tilde{L}^b(t,\theta_j)\right)\Delta\tilde{P}(t,\theta_j)\tilde{D}(t,\theta_j)\right]}{\sum_i E_t\left[\tilde{P}(t,T_{i-1})\tilde{D}(t,T_i)\tilde{L}^{\text{ask}}(t,T_i)\right] + \sum_j \delta_j E_t\left[\Delta\tilde{P}(t,\theta_j)\tilde{D}(t,\theta_j)\tilde{L}^{\text{ask}}(t,\theta_j)\right]}. \tag{4.4}$$

The solution for the CDS bid premium is identical to that for the ask premium only with $\tilde{L}^{\text{ask}}$ replaced by $\tilde{L}^{\text{bid}}$:

$$s^{\text{bid}} = \frac{F\sum_j E_t\left[\left(1-R\tilde{L}^b(t,\theta_j)\right)\Delta\tilde{P}(t,\theta_j)\tilde{D}(t,\theta_j)\right]}{\sum_i E_t\left[\tilde{P}(t,T_{i-1})\tilde{D}(t,T_i)\tilde{L}^{\text{bid}}(t,T_i)\right] + \sum_j \delta_j E_t\left[\Delta\tilde{P}(t,\theta_j)\tilde{D}(t,\theta_j)\tilde{L}^{\text{bid}}(t,\theta_j)\right]}. \tag{4.5}$$

Equations (4.4) and (4.5) differ only with regard to the liquidity discount factor. If, as the absence of arbitrage implies, the bid quote lies below the ask quote, $\tilde{L}^{\text{bid}}$ must exceed $\tilde{L}^{\text{ask}}$. Technically, the relation that the bid quote lies below the ask quote could be included into our model by demanding that the CDS ask liquidity intensity γ^{ask} always exceeds the CDS bid liquidity intensity γ^{bid}, i.e. by assuming that γ^{bid} equals γ^{ask} minus a non-negative stochastic process. This, however, would complicate the identification of the non-negative credit risk component λ, the ask liquidity intensity γ^{ask}, and the non-negative difference process. Therefore, our model does not formalize this relation, but our empirical study never yields values of γ^{ask} and γ^{bid} that imply arbitrage opportunities.

4.1.2 Specification of Intensity Processes

The second step in the specification of the model consists of choosing the dynamics of the default and the liquidity intensities. As Longstaff et al. (2005), we assume a square-root process for the credit risk intensity $\lambda(t)$ with

$$d\lambda = (\alpha - \beta\lambda)\, dt + \sigma\sqrt{\lambda} dW_{\lambda},$$

where α, β, and $\sigma > 0$ are real numbers, and W_{λ} is a standard Brownian motion.

The dynamics of the liquidity intensities γ_t^l, $l \in \{b, \text{ask}, \text{bid}\}$, for the liquidity discount factors of the bond (b), the CDS ask premium (ask), and the CDS bid premium (bid) are given by

$$d\gamma^l = \mu^l dt + \eta^l dW_{\eta^l},$$

with μ^l and $\eta^l > 0$ constants, and W_{η^l} a standard Brownian motion. This specification allows the liquidity process to take on both positive and negative values. The above specification of the liquidity intensity dynamics can be favored over the simple White-Noise process in Longstaff et al. (2005) since it additionally allows for liquidity trends which may be more appropriate for the maturing CDS markets.

It is convenient from an econometric point of view to assume that the instantaneous default-free interest rate r_t, the default intensity λ_t, and the liquidity intensities are independent in order to obtain a parsimonious model with closed-form solutions. However, we do not need to assume that the liquidity intensities themselves are independent. Economically, this potential correlation is especially important for the liquidity intensities in the CDS market since an increasing liquidity of the CDS market would move both the bid and the ask quote closer to each other independently of the default intensity.

Given the above independence assumption, we know that

$$\begin{aligned} E_t\left[\tilde{P}(t,\tau)\,\tilde{D}(t,\tau)\,\tilde{L}^l(t,\tau)\right] &= E_t\left[\tilde{P}(t,\tau)\right] E_t\left[\tilde{D}(t,\tau)\right] E_t\left[\tilde{L}^l(t,\tau)\right] \\ &=: P(t,\tau,\lambda)\, D(t,\tau)\, L\left(t,\tau,\gamma^l\right), \end{aligned}$$

where $l \in \{b, \text{ask}, \text{bid}\}$ and $D(t,\tau)$ is the time-t price of a default-free liquidity numéraire zero bond with maturity in τ.

For $P(t,\tau,\lambda)$ and $L\left(t,\tau,\gamma^l\right)$, the following well-known analytical solutions arise:

$$P(t,\tau,\lambda) := a_1(t,\tau) \cdot \exp\left[-\lambda_t \cdot a_2(t,\tau)\right], \tag{4.6}$$

$$L\left(t,\tau,\gamma^l\right) := a_3^l(t,\tau) \cdot \exp\left[-\gamma_t^l \cdot a_4^l(t,\tau)\right], \tag{4.7}$$

where the functions $a_1(t,t_i)$, $a_2(t,t_i)$, $a_3^l(t,t_i)$, and $a_4^l(t,t_i)$, $l \in \{b, \text{ask}, \text{bid}\}$, are given in Appendix 4.5.2.

Substituting these functions in Equations (4.1), (4.4), and (4.5) yields the analytical solutions $CB(t) = CB\left(t,\lambda,\gamma^b\right)$ for the bond price, $s^{\text{ask}} = s^{\text{ask}}\left(t,\lambda,\gamma^b,\gamma^{\text{ask}}\right)$ for the CDS ask premium, and $s^{\text{bid}} = s^{\text{bid}}\left(t,\lambda,\gamma^b,\gamma^{\text{bid}}\right)$ for the CDS bid premium. These closed-form solutions can be calibrated to our set of bond prices and CDS ask and bid quotes to obtain estimates of the default and liquidity intensities.

4.1.3 Measures for Credit Risk and Liquidity Premia

The model developed in Sections 4.1.1 and 4.1.2 allows us to disentangle the total bond spread cs into a pure credit risk component cs^{def} and a liquidity component cs^{liq}. By an analogous procedure based on CDS bid and ask quotes, we compute a pure credit risk component s^{def} and a liquidity component s^{liq} for the CDS. The rationale for this decomposition is most obvious for the bond. The credit risk premium cs^{def} equals the yield spread that would apply if credit risk were the only priced factor (excepting, of course, r). The liquidity premium cs^{liq} then measures the additional yield spread that is incurred because of illiquidity.

As mentioned in Chapter 3, even in a perfectly liquid bond and CDS market, the bond yield spread is directly comparable to the CDS premium only if the maturity of both instruments is identical and if, in addition, the bond price equals its face value. This second condition is important to avoid the difficulties discussed by Duffie (1999) and Duffie and Liu (2001) who show that the yield spreads on fixed-coupon corporate bonds cannot be directly compared to CDS premia. Therefore, we define a bond's pure credit risk premium cs^{def} for a given value of λ in two steps. First, we assume that γ^b equals 0 and determine the coupon c^{par} that makes the theoretical bond price in Equation (4.1) equal to par, i.e., $CB(t,\lambda,0)$ equals F for c^{par}. Second, we compute cs^{def} as the bond spread over the risk-free rate for this bond:

$$CB(t,\lambda,0) = \sum_{i=1}^{n} \frac{c^{\text{par}}}{\left(1+y(t,T_i)+cs^{\text{def}}\right)^{(T_i-t)}} + \frac{F}{\left(1+y(t,T_m)+cs^{\text{def}}\right)^{(T_m-t)}} \tag{4.8}$$

where $y(t,T_i) = D(t,T_i)^{-\frac{1}{T_i-t}} - 1$ equals the yield-to-maturity of a default-free zero bond with reference liquidity and maturity $T_i - t$.

The bond liquidity premium cs^{liq} follows as the premium increase in excess of cs^{def} if the impact of the bond liquidity intensity γ^b is included, i.e., the bond spread increase for $CB\left(t,\lambda,\gamma^b\right)$.

We define the credit risk and liquidity components of a CDS analogously to the procedure in the bond market. First, we compute the pure credit risk premium s^{def} by assuming that the liquidity discount factors $\tilde{L}^{\text{ask}}$ or $\tilde{L}^{\text{bid}}$ are equal to 1. Equations (4.4) and (4.5) illustrate that in this case, s^{def} is exclusively determined by the default-free interest rates, the default probability, and the bond liquidity. Note that the bond liquidity affects the CDS both in the case of physical delivery and cash settlement as described in Section 2.3. A less liquid bond has a lower post-default price compared to an otherwise identical bond with higher liquidity. The CDS premium therefore is higher to compensate the protection seller for the lower value of the bond should default occur. This effect pertains even if the CDS market is perfectly liquid.

In a CDS market whose liquidity differs from the liquidity numéraire, the ask and bid premia differ from the pure credit risk premium s^{def}. In line with the literature on market microstructure, it seems apparent to select the absolute or relative size of the bid-ask spread as a measure of illiquidity. This is not an appropriate approach in our context for two reasons. First, a comparison of (4.4) and (4.5) shows that the absolute bid-ask spread is also affected by credit risk. Assume that only the default intensity increases, then the ask premium increases more strongly than the bid premium does. Therefore, an increasing credit risk results in a larger absolute bid-ask spread which would be contributed inconsistently to a decreasing liquidity of the CDS. Second, the bid-ask spread, even if taken relatively to s^{def}, is not comparable to our liquidity measure cs^{liq} in the bond market.

We therefore proceed analogously to the bond market and define the liquidity premium in the CDS market s^{liq} by

$$s^{\text{liq}} = \frac{1}{2}\left(s^{\text{ask}} + s^{\text{bid}}\right) - s^{\text{def}}, \tag{4.9}$$

i.e., s^{liq} is the difference between the mid premium – which may include illiquidity – and the pure credit risk premium s^{def}. This definition of s^{liq} corresponds fully to the definition of the bond liquidity premium cs^{liq}. In addition to this formal analogy, s^{liq} allows for an inventory-related interpretation: If a trader has entered into a number of CDS contracts as protection seller, she moves the ask premium and the bid premium at which she is willing to trade upwards in order to balance her inventory. Since the pure credit risk premium s^{def} remains at its initial value while s^{ask} and s^{bid} increase, s^{liq} increases as well. If, on the other hand, demand for transactions on the bid side increases and the trader ends up with an increased short credit risk position, she sets lower bid and ask quotes in order to cancel out this inventory imbalance. This effect results in lower values of s^{liq}.

Our measure of CDS liquidity is thus consistent with the measure of the bond liquidity premia: if a large number of investors want to sell credit risk by selling bonds — which can be interpreted as buying credit protection — the liquidity premium in the bond market increases and vice versa.

In the next section, we turn to a simulation analysis of our model. In particular, we show how changes in the credit risk and liquidity processes affect our credit risk and liquidity measures in the bond and CDS market. In this way, we demonstrate that our model does not automatically yield credit risk and liquidity premia which are cointegrated. If we obtain cointegration relations between the premia in a calibration to observed data, we can therefore deduce that these relations are data-driven instead of model-driven.

4.1.4 Model-Implied Credit Risk and Liquidity Premia Relation

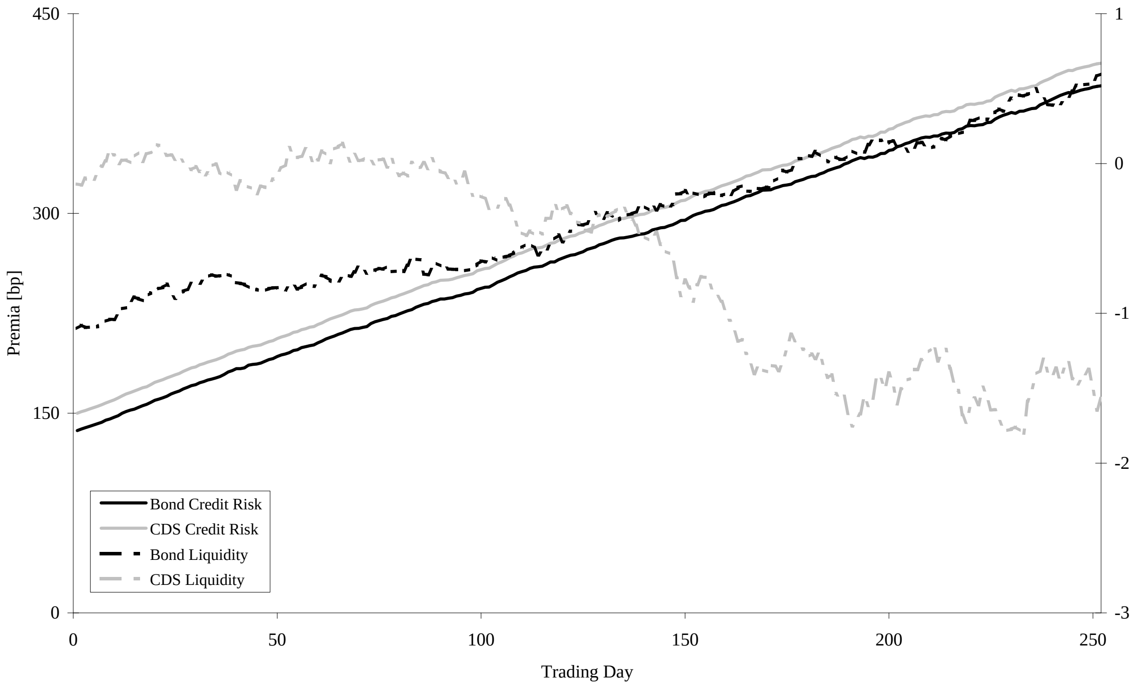
Due to the form of the model, a fully analytic derivation of the comparative-static premia behavior is not feasible. A numerical comparative-static analysis is mostly redundant because of the straightforward relation between the credit risk and liquidity intensities and the credit risk and liquidity premia: If the instantaneous credit risk intensity increases, cs^{def} and s^{def} increase to a similar extent as the intensity. The liquidity premia cs^{liq} and s^{liq} decrease when the credit risk intensity increases, but the effect is very small (cs^{liq} by about 2 bp, s^{liq} by about 0.5 bp for an intensity increase from 10 bp to 1,000 bp). A higher bond liquidity intensity does not affect cs^{def} or s^{liq}, but cs^{liq} increases to a similar extent as the intensity. s^{def} also increases slightly through the direct liquidity spillover (6 bp for an intensity increase from 10 bp to 1,000 bp). An increase in the CDS ask intensity and a decrease in the CDS bid intensity increase s^{liq} in a similar way, but the sensitivity is very small with a change of 4 bp for an intensity change from 10 bp to 1,000 bp.

Instead of a more extensive comparative-static analysis, we therefore conduct an exemplary simulation analysis. In this way, we simultaneously demonstrate the sensitivity of cs^{def}, cs^{def}, cs^{liq}, and s^{liq} to the intensities and explore how a given dependence between the intensities translates into a time series relation between the credit risk and liquidity premia.

The reference parameter values are chosen as follows: We assume that the default free interest rate is flat at 5%. The default intensity parameters equal $(\alpha, \beta, \sigma) = (0.05, 0.10, 0.15)$, and the bond and CDS liquidity parameters are $\left(\mu^{b}, \eta^{b}\right) = \left(\mu^{\text{ask}}, \eta^{\text{ask}}\right) = (0.05, 0.15)$, and $\left(\mu^{\text{bid}}, \eta^{\text{bid}}\right) = (-0.05, 0.15)$. This parameter choice leads to increasing credit risk and decreasing bond liquidity over time, resulting in increases of cs^{def}, s^{def}, and cs^{liq}. The effect on CDS liquidity is not ex ante clear. As the bid and the ask liquidity intensity move in opposite directions, s^{liq} can either increase or decrease, depending on which intensity is larger. We choose the starting values identically at 10 bp for λ, γ^b, and γ^{ask}, and at -10 bp for γ^{bid}. The recovery rate equals 40%. Using these values, we simulate a single time series of length 252 for λ, γ^b, γ^{ask}, and γ^{bid} each using a discretized version of the dynamics described in Section 4.1.2. The mean values of the simulated intensities equal $\bar{\lambda} = 247$ bp, $\bar{\gamma}^b = 90$ bp, $\bar{\gamma}^{\text{ask}} = 189$ bp, and $\bar{\gamma}^{\text{bid}} = -232$ bp. From the time series, we compute the resulting credit risk and liquidity premia. The results are displayed in Figure 4.1.

Figure 4.1: **Simulated Credit Risk and Liquidity Premia**

The figure shows the credit risk (solid line) and liquidity premia (dashed line) in bond yield spreads (black) and CDS mid premia (grey) for the base case intensity time series. The time-to-maturity remains constant at 1 year. The CDS liquidity premium is measured on the secondary (right-hand side) axis.



As Figure 4.1 shows, the direct impact of the bond liquidity which we derived in Equation (4.3) causes the CDS credit risk premium s^{def} to exceed the bond credit risk premium cs^{def}, but the overall effect is small. cs^{def} has a mean value of 270.99 bp which s^{def} exceeds with a mean of 285.70 bp.[33] The difference of 14.71 bp between these mean values equals 5% of the mean bond liquidity premium cs^{liq} which lies at 298.07 bp. Because of its comparably small value, the CDS liquidity premium s^{liq} is depicted on the secondary axis. The absolute mean value of γ^{bid} is larger than that of γ^{ask} for the simulated path, thus s^{liq} has a negative mean of -0.65 bp. Overall, s^{liq} fluctuates between -1.82 bp and 0.13 bp. The

[33] Doubling the default-free interest rate leads to an average value for s^{def} of 284.63 bp.

average value of s^{ask} equals 290.72 bp, and s^{bid} has a mean of 279.38 bp. Therefore, the mean of s^{def} is closer to the mean of s^{bid} by exactly the mean of the liquidity premium s^{liq}, -0.65 bp. Economically, this result would imply that transactions the the CDS market are mostly bid-initiated.

The process parameters translate to a premium increase of 189% for cs^{def}, 175% for s^{def}, and 90% for cs^{liq} over time. The standard deviation of the premium change equals 0.54 bp for cs^{def}, 0.51 bp for s^{def}, 2.75 bp for cs^{liq}, and 0.06 bp for s^{liq}. Neither the augmented Dickey-Fuller test nor the Phillips-Perron test can reject the hypothesis of a unit root in any of the premia time series at the 10% significance level. The Phillips-Ouliaris cointegration test yields a cointegration coefficient of 0.99 which is significant at the 1% level for cs^{def} and s^{def}. The coefficient estimates for the liquidity premia and the credit risk premia with one another and that for the liquidity premia with each other is not significant.

We now demonstrate the effect of a higher default intensity by doubling it. To do so, we multiply α, σ, and the time series of $\lambda(t)$, $t = 1, \ldots, 252$, by 2 while β remains the same as in the base case. In the second step, we double the bond liquidity intensity by multiplying μ^b, η^b, and the time series of $\gamma^b(t)$, $t = 1, \ldots, 252$, by 2 but the credit risk intensity and the CDS bid and ask liquidity intensities are the same as in the base case. The resulting premia time series are depicted in Figure 4.2.

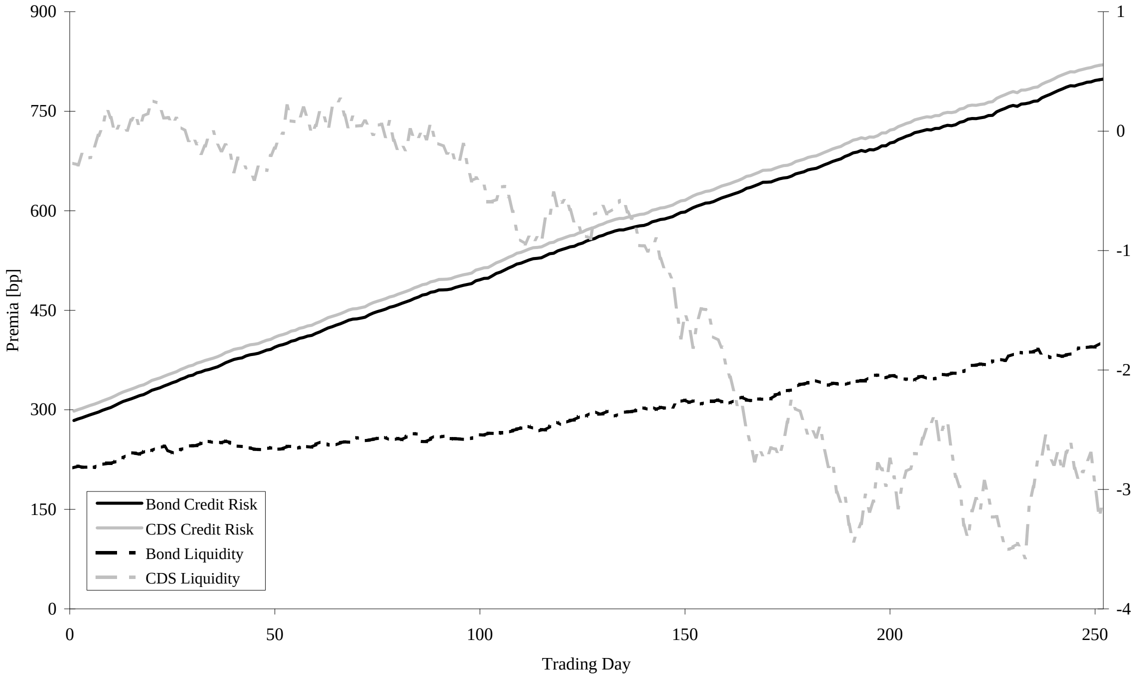
As Panel A of Figure 4.2 shows, doubling the default intensity approximately doubles cs^{def} and s^{def}. The average of cs^{def} increases to 550.54 bp and that of s^{def} to 567.74 bp. The increase in s^{def} is therefore somewhat smaller. Interestingly, cs^{liq} and s^{liq} also change even though γ^b, γ^{ask}, and γ^{bid} are the same as in the base case. This shows that the identical liquidity intensity translates into a larger asymmetry because of the higher credit risk. The mean of cs^{liq} changes from of 298.07 bp in the base case to 295.96 bp for the doubled default intensity. The decrease is clear from Equation (4.1), illiquidity has a higher impact on the coupon and the face value payment than on the recovery payment. Therefore, decreasing the probability that the coupon and the face value payments occur also decreases the liquidity premia. For s^{liq}, the mean decreases from -0.65 bp to -1.28 bp.

The effect of doubling γ^b can be seen in Panel B of Figure 4.2. cs^{def} is completely unaffected. s^{def} also reflects the change in the bond liquidity, but its mean only increases from 285.70 bp to 288.40 bp. This demonstrates that the effect of γ^b on s^{def} is highly non-linear which is both due to the definition of L as an exponential-affine function and to the way in which L enters Equation (4.4). The bond liquidity affects the floating leg of the CDS contract weighted with the default probability, and this limits the impact of γ^b.

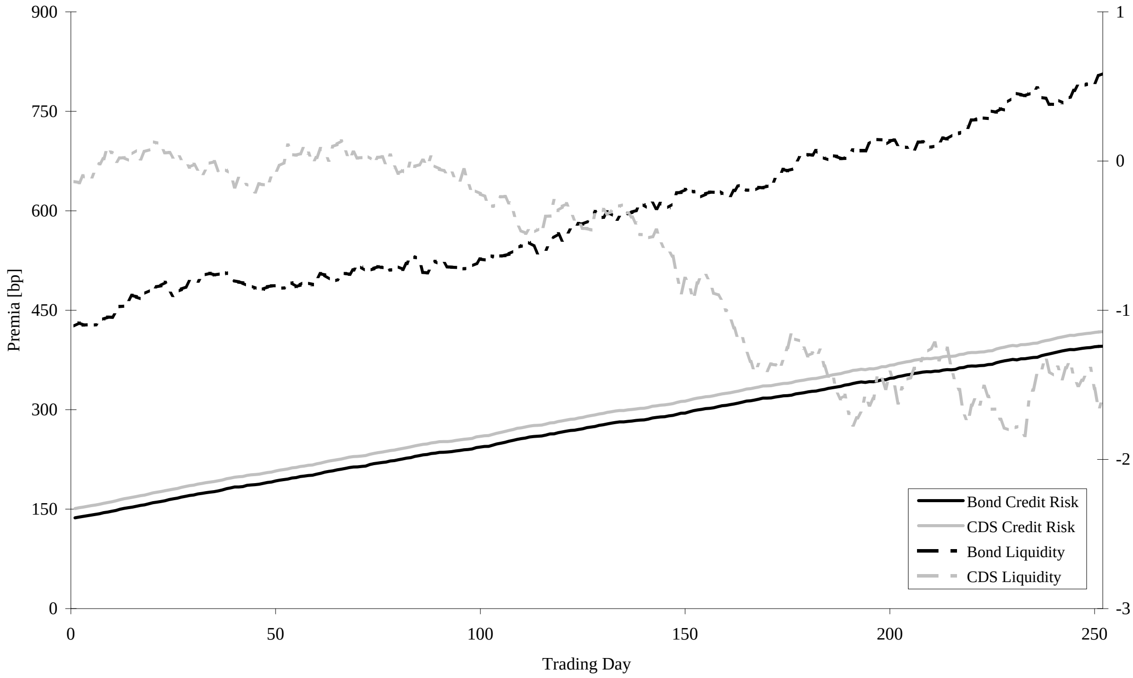
Figure 4.2: **Doubled Default and Bond Liquidity Intensities**

The figure shows the credit risk (solid line) and liquidity premia (dashed line) in bond yield spreads (black) and CDS mid premia (grey) for the doubled default intensity in Panel A and the doubled bond liquidity intensity in Panel B. The CDS liquidity premium is measured on the secondary (right-hand side) axis.

Panel A: Doubled Default Intensity



Panel B: Doubled Bond Liquidity Intensity



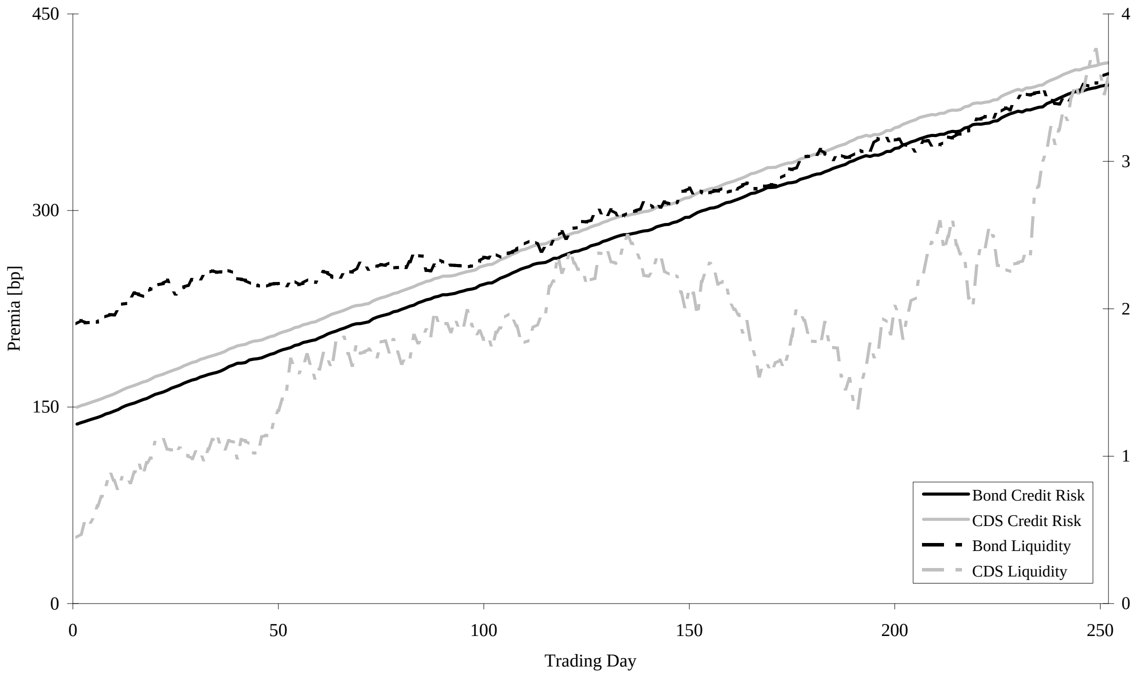
cs^{liq} approximately doubles from a mean of 298.07 bp to 594.23 bp, and s^{liq} remains mostly unchanged. In each panel, the cointegration relationship is the same as in the base case.

We now explore the effect of changing the CDS bid and ask liquidity. We use the same default and bond liquidity intensities as in the base case. In Panel A of Figure 4.3, we double the CDS ask intensity by multiplying the process parameter values μ^{ask} and η^{ask} and the time series of $\gamma^{\text{ask}}(t)$, $t = 1, \ldots, 252$, by 2 and use the base case CDS bid intensity. In Panel B, we use the base case CDS ask intensity and double the CDS bid intensity.

Figure 4.3: **Doubled CDS Liquidity Intensities**

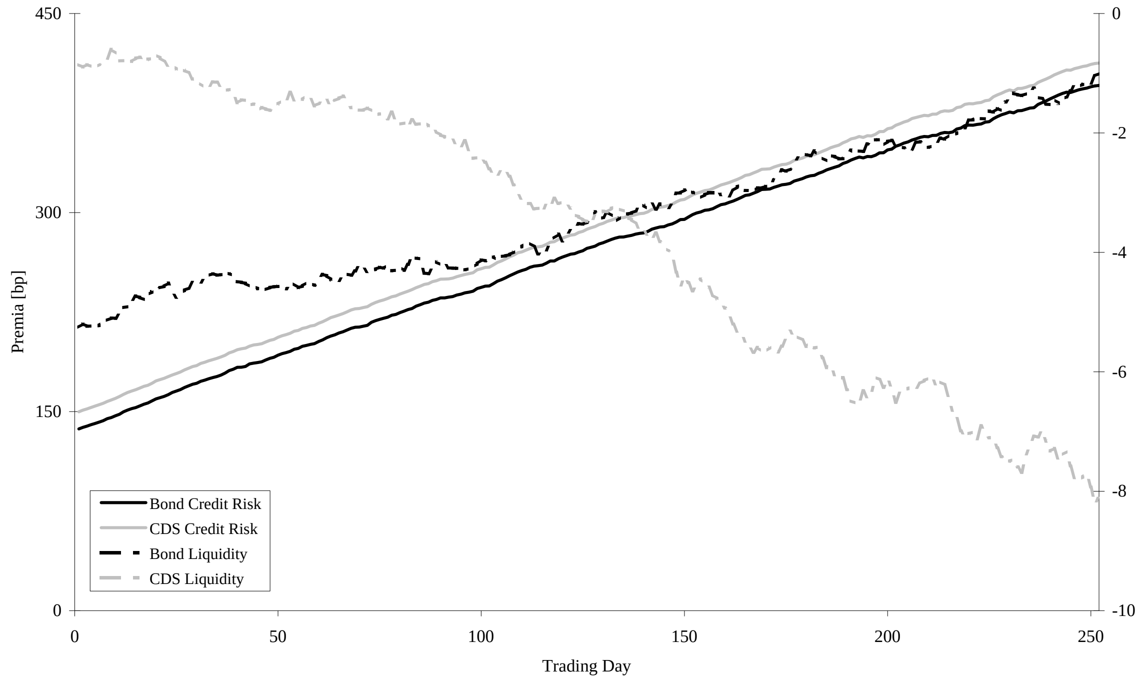
The figure shows the credit risk (solid line) and liquidity premia (dashed line) in bond yield spreads (black) and CDS mid premia (grey) for the doubled CDS ask intensity in Panel A and the CDS bid intensity in Panel B. The CDS liquidity premium is measured on the secondary (right-hand side) axis.

Panel A: Doubled CDS Ask Intensity



As Figure 4.3 shows, the impact of doubling the CDS ask and bid intensity yields different CDS liquidity premia but the credit risk and the bond liquidity premia remain unaffected. Panel A presents s^{liq} for the doubled ask intensity γ^{ask} and the original bid intensity γ^{bid}. The resulting average CDS liquidity premium of 1.88 bp is caused by the asymmetric position of s^{def} with its original mean of 285.70 bp between s^{ask} with a mean 295.78 bp and s^{bid} which remains at its original mean of 279.38 bp. In Panel B of Figure 4.3 where γ^{bid} is doubled and γ^{ask} is at its original value, s^{liq} decreases to a mean of -3.78 bp with a mean value of 273.13

Panel B: Doubled CDS Bid Intensity



bp for s^{bid}. These values illustrate that even high asymmetries between γ^{ask} and γ^{bid} only translate to small absolute values of s^{liq}. As before, the cointegration relation is unaffected by the doubling of the intensities.

In the next section, we turn to the empirical application of our model.

4.2 Empirical Analysis

In this section, we calibrate our model to the bond and CDS data. The purpose of this empirical analysis is not to validate or test our model, but to disentangle the credit risk and liquidity components of bond yield spreads and CDS premia and to explore the relation between these components. Due to its flexible stochastic structure, a formal test for the model is only of limited interest in any event, and we focus on the economic plausibility of our results instead.

4.2.1 Data and Calibration Procedure

We use the same data set we described in Section 3.2. For the current term structure of the default-free interest rates, we use the estimates which are provided by the Deutsche Bundesbank on a daily basis by means of the Nelson-Siegel-Svensson method from prices of

German government bonds.[34] From this term structure of interest rates, we compute prices of default-free zero-coupon bonds which we assume to have the reference liquidity discount factor of 1. Therefore, for the empirical study we do not explicitly consider the stochastic nature of r_t. The recovery rate is assumed to equal 40%.

We estimate the parameters and the current factor values of the 4 intensity processes individually for each of the 171 reference entities from the observed senior unsecured bond prices and CDS bid and ask premia. In total, we estimate for each firm the 9 parameters $\left(\alpha, \beta, \sigma, \mu^b, \eta^b, \mu^{\text{ask}}, \eta^{\text{ask}}, \mu^{\text{bid}}, \eta^{\text{bid}}\right)$, and for each date t the current value of the intensities $\left(\lambda, \gamma^b, \gamma^{\text{ask}}, \gamma^{\text{bid}}\right)(t)$, $t = 1, \ldots, 1548$. In order to keep the model tractable, we assume that the instantaneous default and liquidity intensity are equal for bonds of the same issuer with identical seniority but different time-to-maturity and coupon rate.[35] This identification assumption makes our parameters issuer-specific.

The calibration procedure consists of two basic steps. In the first step, we initiate a base grid for the process parameters $\left(\alpha, \beta, \sigma, \mu^b, \eta^b, \mu^{\text{ask}}, \eta^{\text{ask}}, \mu^{\text{bid}}, \eta^{\text{bid}}\right)$. In the second step, we then determine the values $\left(\lambda, \gamma^b, \gamma^{\text{ask}}, \gamma^{\text{bid}}\right)(t)$, $t = 1, \ldots, 1548$, which simultaneously minimize the sum of squared errors between the time series of the observed and the theoretical CDS premia and bond yield spreads. This second step matches all values at the basis point level, and estimation is conditional on the presumed process parameters. We follow this procedure in each grid point and determine the point associated with the smallest sum of squared errors. Around this point, we initiate a finer local grid as in the first step and repeat the second step in each point of the new grid. We stop this two-step calibration procedure when the minimal sum of squared errors twice decreases by less than 1% on two subsequent grid specifications. In order to control for local optima, we repeat the analysis for the points in the base grid associated with the second and third smallest sum of squared errors.

Given the estimates of the process parameters and the intensity time series, we compute the credit risk and liquidity premia for CDS and for bonds in the third step as explained in Section 4.1.3.

---

[34] As an alternative, we also used the interest rate swap curve. On average, we obtained slightly lower credit risk premia of about 1.40 bp, lower bond liquidity premia of about 6.28 bp, and an almost identical CDS liquidity premium which is on average 0.01 bp lower. Since the dynamics are almost identical, we only present the results for the German government bonds.

[35] It is natural that bonds of the same issuer with identical seniority have the same default probability during the next infinitesimally small time interval. The liquidity, on the other hand, may well depend on the maturity and the coupon of a bond. We expect the homogeneity of the bonds of the same issuer to limit the differences. In addition, the functional form of the stochastic liquidity process results in larger liquidity premia for bonds with a longer maturity.

4.2.2 Credit Risk and Liquidity Premia: Cross-Sectional Results

We display the estimated premium components by industry sector and rating class in Table 4.1. The premia are attributed to the rating class to which the reference entity belonged on each reference date.

As Table 4.1 shows, cs^{def} on average amounts to 52.21 bp and cs^{liq} to 26.26 bp. Therefore, the total bond yield spread consists to 67% of credit risk and to 33% of liquidity. s^{def} exceeds cs^{def} by on average 0.48 bp with a mean value of 52.69 bp, and the mean of s^{liq} lies at 2.04 bp. As explained in Section 4.1.3, we measure the liquidity of the CDS market by the asymmetry between bid and the ask quotes relative to the credit risk premium. The positive average of s^{liq} shows that CDS ask premia are further away from the pure credit risk premia s^{def} than CDS bid premia. This suggests that most transactions in the CDS market are ask-initiated.

Compared to the sample mean of 54.82 bp presented in Table 3.2, we underestimate the mid CDS premium by 0.09 bp. This small error implies that the model fits the CDS data very well, suggesting that the stochastic structure is reasonably specified. The error with regard to the yield spread is larger, the sum of cs^{def} and cs^{liq} equals 78.47 bp and thus falls below the interpolated yield spread by 21.43 bp. However, as discussed in Section 4.1.3, the theoretical par yield spread which we compute from the parameter estimates is not directly comparable to the interpolated yield spreads.

Industry Sectors Regarding the results for the different industry sectors, Table 4.1 shows that cs^{def} only slightly exceeds cs^{liq} for financial reference entities. On average, cs^{def} equals 17.73 bp and cs^{liq} equals 12.34 bp. This translates into a premium decomposition of 59% due to credit risk and 41% due to liquidity. s^{def} on average exceeds cs^{def} by 0.17 bp, and s^{liq} fluctuates between -22.79 bp and 44.94 bp with a mean of 0.71 bp. The positive mean suggests that there is on average a demand pressure for credit risk protection in the CDS market. However, the small value of the mean and the negative minimum values imply that the asymmetry is not very pronounced and that in some periods, a supply pressure prevails.

In the non-financial corporate sector, credit risk has a higher relative impact than bond liquidity. On average, cs^{def} amounts to 67% and cs^{liq} to 33% of the yield spread, and the total levels are higher than for financial reference entities. This higher level of cs^{liq} also translates into a higher difference between cs^{def} and s^{def} of 0.62 bp. The largest difference occurs for s^{liq} which is on average about 4 times higher than for financial reference entities with a mean of 2.56 bp. In conjunction with the higher absolute values of s^{liq}, this suggests

Table 4.1: **Estimated Credit Risk and Liquidity Premia**

The table shows the mean, standard deviation, minimum, and maximum for the credit risk and the liquidity premia components for each industry sector and each rating class. cs^{def} is the credit risk and cs^{liq} the liquidity component in the yield spread of a synthetical 5-year par bond. s^{def} is the credit risk and s^{liq} the liquidity component in the mid premium for a 5-year CDS contract. The mean, standard deviation, minimum, and maximum are determined both over time and across observations within the industry sector, respectively rating class, on each date. All values are in basis points.

	Sectors			Rating Classes							
	Fin.	Non-Fin.	Sov.	AAA	AA	A	BBB	BB	B	CCC	All
cs^{def}	17.73	68.12	38.43	6.04	13.90	32.21	64.71	267.49	394.64	275.14	52.21
Std. Dev.(cs^{def})	15.09	95.14	87.19	4.39	10.46	27.99	64.46	236.23	163.97	34.34	83.04
min(cs^{def})	4.61	4.63	4.59	4.59	4.63	4.61	4.63	33.94	33.43	113.84	4.59
max(cs^{def})	306.54	1,824.39	814.95	51.71	257.94	351.53	1,232.23	1,824.39	1,141.96	387.06	1,824.39
cs^{liq}	12.34	33.67	2.17	0.64	12.53	23.94	42.44	38.29	23.32	11.26	26.26
Std. Dev.(cs^{liq})	27.95	53.00	6.42	3.04	30.07	43.19	58.05	53.85	46.47	2.87	47.27
min(cs^{liq})	0.58	0.66	-0.55	-0.47	-0.55	0.58	0.66	0.58	0.34	0.27	-0.55
max(cs^{liq})	499.77	504.90	103.63	30.70	499.77	488.98	341.76	504.90	293.11	13.38	504.90
s^{def}	17.90	68.74	38.46	6.07	14.08	32.87	65.74	270.71	398.35	278.84	52.69
Std. Dev.(s^{def})	15.33	96.00	87.79	4.40	10.68	28.38	64.91	240.69	164.59	33.83	83.79
min(s^{def})	5.09	5.09	5.11	5.11	5.09	5.09	5.11	35.03	33.87	114.24	5.09
max(s^{def})	309.98	1,849.62	817.45	51.78	279.04	353.00	1,245.38	1,849.62	1,147.46	390.62	1,849.62
s^{liq}	0.71	2.56	2.55	0.08	0.50	1.41	2.86	6.10	20.13	10.84	2.04
Std. Dev.(s^{liq})	1.33	11.17	16.34	0.28	0.72	2.15	7.78	39.13	38.53	11.19	9.91
min(s^{liq})	-22.79	-401.20	-84.77	-0.57	-22.79	-17.36	-155.79	-401.20	-119.05	-3.73	-401.20
max(s^{liq})	44.94	361.00	262.92	2.86	10.22	68.00	213.72	361.00	262.92	91.09	361.00

that demand-supply asymmetries are more prevalent for non-financial reference entities. The fraction of the averages, however, is identical as for financial reference entities with a credit risk premium of 96% and a liquidity premium of 4%.

For sovereign reference entities, bond liquidity has almost no impact which agrees with the economic intuition. The average liquidity premium of 2.17 bp only amounts to 5% of the total yield spread, and the negative values for cs^{liq} with a minimum of -0.55 bp are only attained for this sector. This suggests, as explained in Section 3.2, that the liquidity of the observed government bonds is partly higher than the liquidity which is measured by the default-free term structure of interest rates. Since the difference between the bond and the CDS credit risk premium is only due to the bond liquidity, s^{def} only exceeds cs^{def} by 0.03 bp on average for the sovereign sector. The relatively high value of s^{liq} with a mean of 2.55 bp, on the other hand, points at an asymmetry between protection buyers and sellers similar to that in the non-financial corporate sector.

Rating Classes With regard to the different rating classes, we see that the credit risk and liquidity premia increase as the rating deteriorates. For the AAA rating class, cs^{def} has an average of 6.04 bp which approximately doubles for each rating downgrade in the investment grade segment. The subinvestment grade segment exhibits values of cs^{def} which are at least 4 times as large as for the investment grade segment. For cs^{liq}, the difference between the investment grade and the subinvestment grade average is less pronounced than for the credit risk premia. The maximum average bond liquidity premia are observed in the BBB and BB rating class. The A and B rating class exhibit similar average liquidity premia. Overall, we obtain strictly positive estimates for the liquidity premia except for the sovereign reference entities in the AAA and AA rating class. It is also interesting to note that the minimum of cs^{liq} is not monotonously increasing as credit risk increases. These findings indicate that even though the liquidity premia tend to be higher for more risky bonds (at least in the investment grade sector), the relation is not a simple one-to-one mapping.

Comparing the CDS credit risk premia s^{def}, we find that they consistently exceed cs^{def} but that the difference, caused by the bond liquidity premia, is very limited. The average difference is smallest for the AAA rating class with 0.03 bp and maximal for the B rating class with 3.71 bp. This agrees with our results in the simulation analysis in Figure 4.2. Even though cs^{liq} is on average higher for the BBB than for the B rating class, the fact that the delivery of the defaulted, illiquid bond is more likely for the B-rated reference entities leads to a stronger effect on the CDS premium than for the BBB-rated reference entities.

The most noteworthy results of Table 4.1 concern the CDS-specific liquidity premia. As explained in Section 4.1.3, we measure the liquidity of the CDS market by the asymmetry between the ask and the bid quotes relative to the pure credit risk premium: If our estimate of s^{def} is closer to the bid than to the ask quote, s^{liq} has a positive value and vice versa. On average, the liquidity premium s^{liq} is positive for each rating class which suggests that most transactions in the CDS market are ask-initiated. On an absolute level, the asymmetry increases as the rating deteriorates with the average of s^{liq} actually close to the average of cs^{liq} for the B and CCC rating class. If we take them relative to the pure credit risk premia, however, s^{liq} is on average smaller for the subinvestment grade segment, and the difference is particularly pronounced for the gap between the investment and the subinvestment grade segment where the ratio descends from 4% to 2%. In addition, 19% of the liquidity premia in the subinvestment grade segment are negative, suggesting that the asymmetry between buyers and sellers may effectively be smaller. In the next section, we attribute the negative liquidity premia to unusual market events.

As for the bond market, the relative liquidity premia decrease in a particularly pronounced way for the transition from the investment grade to the subinvestment grade sector. In contrast to the bond market, on the other hand, we find that the CDS liquidity premia are much smaller for all rating classes. Their average size across all rating classes is only 2.04 bp compared to 26.26 bp in the bond market.

In the next section, we further explore how credit risk and liquidity premia behave over time.

4.2.3 Credit Risk and Liquidity Premia: Time Series Results

In this section, we first present the time series of the premia estimates for the the different industry sectors and rating segments. We next explore the relation between the premia across the bond and the CDS market. The section concludes with an empirical analysis of the impact of market-wide credit risk and liquidity measures on the dynamics of the estimated premia time series and the comparison of periods with increasing and decreasing credit risk.

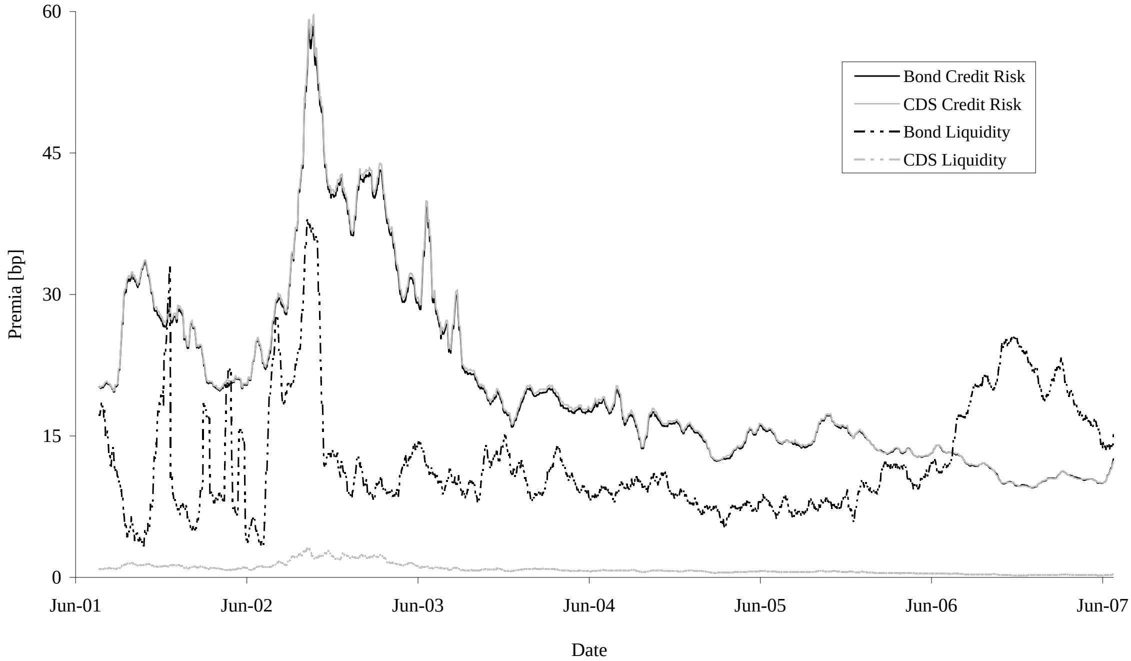
Time Series Graphs

The estimated credit risk and liquidity premia are depicted in Figure 4.4. For ease of presentation, the three industry sectors and the investment and subinvestment grade rating classes are summarized into a single time series each.

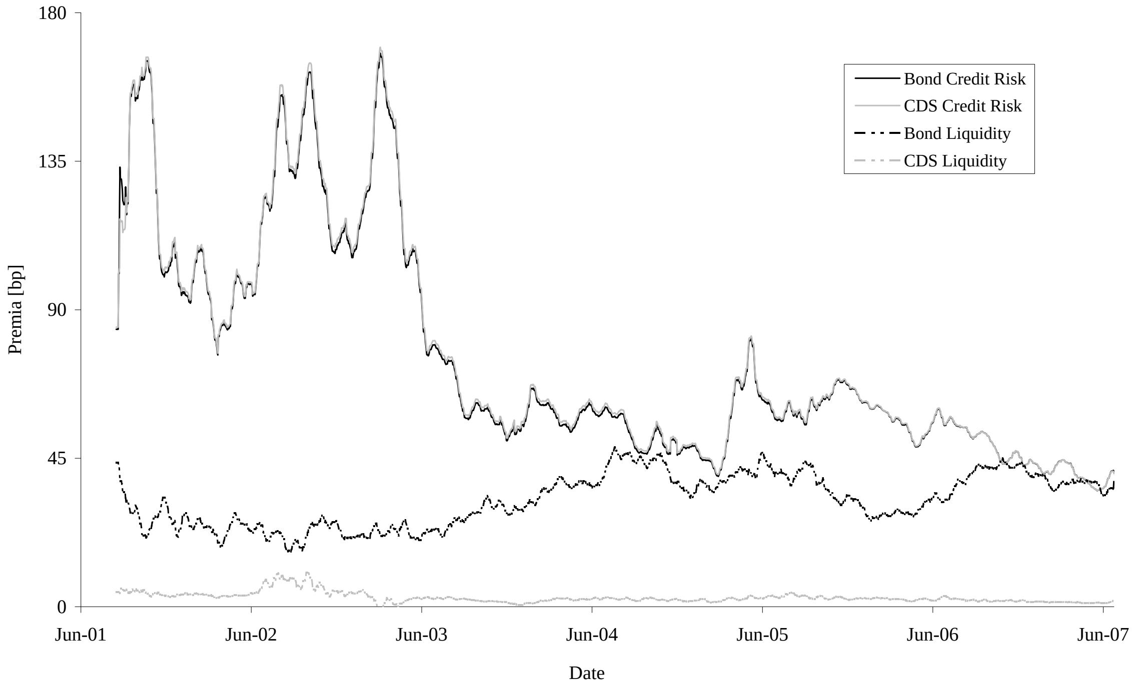
Figure 4.4: **Credit Risk and Liquidity Premia Time Series**

The figure shows the estimated credit risk and liquidity components in yield spreads and CDS premia for all rating classes. The estimates are computed with regard to a constant time-to-maturity of 5 years and a synthetical par bond.

Panel A: Financial



Panel B: Non-Financial



Panel C: Sovereign

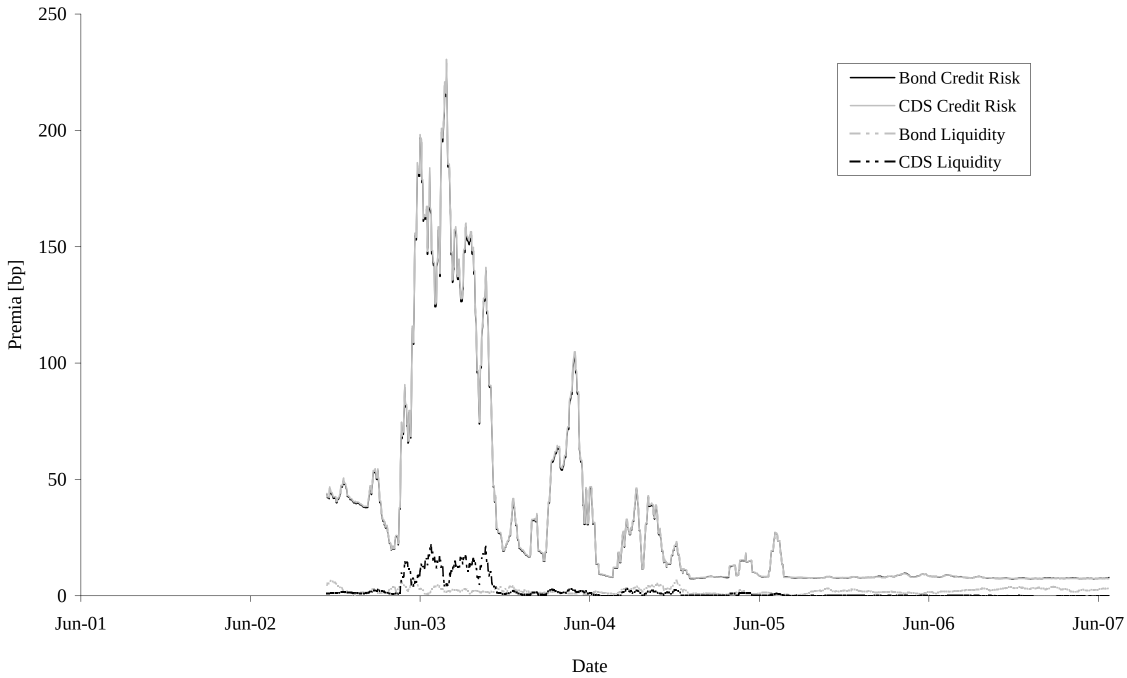
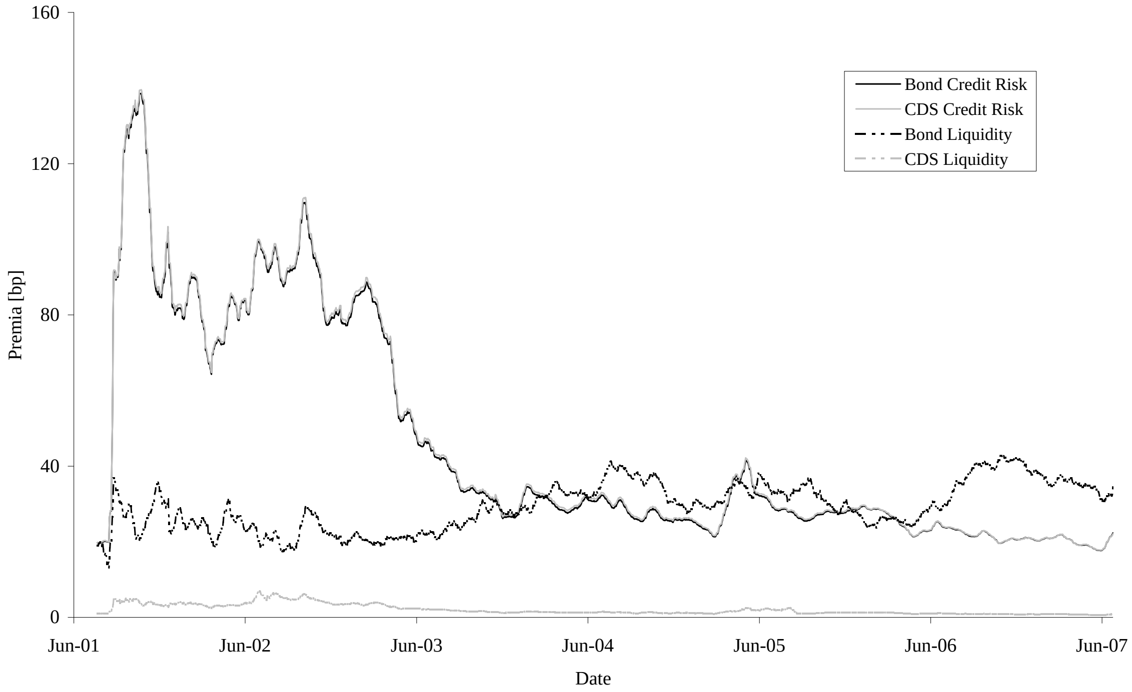


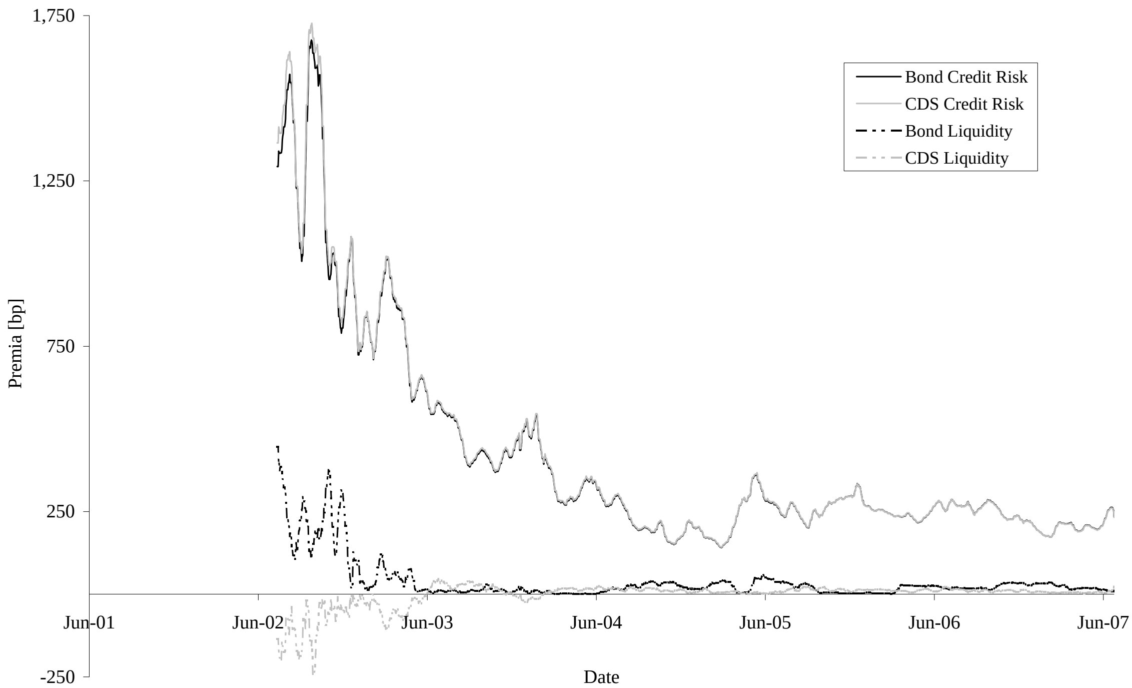
Figure 4.4 shows that the pure credit risk premia cs^{def} and s^{def}, depicted in the solid lines, cannot be visually distinguished either for any of the industry sectors in Panel A to C nor for the investment grade and the subinvestment grade segment in Panel D and E. Overall, we observe a flattening of the pure credit risk premia curves of cs^{def} and s^{def} over time with much lower average levels at the end of the observation interval. In the financial sector, the rating-class average of cs^{def} and s^{def} fluctuates between 15 bp and 60 bp in the early part of the observation interval and decreases to approximately 15 bp towards the end of the observation interval. The decrease and flattening of the credit risk premia is even more prevalent for the sovereign sector in Panel C, and for the investment and the subinvestment grade subsamples in Panel D and E. In the non-financial corporate sector, the effect is less pronounced. We also observe distinct spikes in the time series of cs^{def} and s^{def}, in particular for the non-financial corporate sector, in late 2001 and late 2002 which can be associated with the defaults by Enron and WorldCom. The reaction of the financial sector's credit risk premia to the Enron default in late 2001 is almost negligible while the investment grade segment as a whole reacts less sensitively to the WorldCom default.

The bond liquidity premia cs^{liq} exhibit a different behavior across the industry sectors and rating classes. During the high credit risk periods, cs^{liq} is high and rather volatile for the financial and sovereign sector and the subinvestment grade segment while they are mostly

Panel D: Investment Grade



Panel E: Subinvestment Grade



stable in the non-financial corporate sector and the investment grade segment. Towards the end of the observation interval, we obtain an increase of cs^{liq} for the financial and the non-financial corporate sector while liquidity premia in the sovereign sector were highest during the period of high credit risk premia in mid 2003. A similar result holds for the subinvestment grade segment where cs^{liq} had the highest level and volatility in late 2002 around the WorldCom default.

Visual inspection of the CDS-specific liquidity premia s^{liq} is more difficult since the absolute values are small. For all industry sectors and rating classes, we observe a trend towards 0 as the CDS market matures. Overall, the level of s^{liq} is closer to 0 near the end of the observation interval for all industry sectors and rating sectors and higher when credit risk is high. But while the behavior of s^{liq} is also similar over time for all industry sectors, it differs strongly between the investment grade and the subinvestment grade segment during times of high credit risk. For the investment grade segment, s^{liq} is higher during times of high credit risk. In the subinvestment grade segment, s^{liq} becomes large and more negative when credit risk is high. This finding suggests that the ask-initiated transactions are partly replaced by bid-initiated transactions for the subinvestment grade sector, pointing at a high number of investors who attempt to take on credit risk synthetically in the CDS market.

Johansen VAR Analysis

In order to study the dynamic interaction between the bond and the CDS market, we perform a Johansen VAR analysis.[36] To do so, we first test for each reference entity whether cs^{def}, s^{def}, cs^{liq}, and s^{liq} are stationary. If the augmented Dickey-Fuller test cannot reject a unit root at the 10% level for each time series, we test whether the first differences of cs^{def}, s^{def}, cs^{liq}, and s^{liq} are stationary. If the augmented Dickey-Fuller test can reject a unit root in the first differences at the 10% level for each time series, we perform the Johansen test for cointegration between cs^{def}, s^{def}, cs^{liq}, and s^{liq}. Since cs^{def} and s^{def} mostly contain the same information, we only include either cs^{def} in the estimation equation s^{def}.

This procedure identifies 164 reference entities for which we cannot reject cointegration of cs^{def}, cs^{liq}, and s^{liq} and of s^{def}, cs^{liq}, and s^{liq} at the 10% significance level. Since cointegration suggests that a linear combination of the level variables is stationary, we estimate the following system of equations:

[36] See Johansen and Juselius (1990) and Johansen (1991). For a textbook illustration, see chapters 6.7 and 6.8 in Enders (1995).

$$
\begin{aligned}
\Delta cs_t^{\text{def}} &= \sum_{j=1}^{5} u_{1_j} \Delta cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} u_{2_j} cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} u_{3_j} \Delta cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} u_{4_j} cs_{t-j}^{\text{liq}} \\
&+ \sum_{j=1}^{5} u_{5_j} \Delta s_{t-j}^{\text{liq}} + \sum_{j=1}^{5} u_{6_j} s_{t-j}^{\text{liq}} + \varepsilon_{1,t}, \\
\Delta s_t^{\text{def}} &= \sum_{j=1}^{5} v_{1_j} \Delta s_{t-j}^{\text{def}} + \sum_{j=1}^{5} v_{2_j} s_{t-j}^{\text{def}} + \sum_{j=1}^{5} v_{3_j} \Delta cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} v_{4_j} cs_{t-j}^{\text{liq}} \\
&+ \sum_{j=1}^{5} v_{5_j} \Delta s_{t-j}^{\text{liq}} + \sum_{j=1}^{5} v_{6_j} s_{t-j}^{\text{liq}} + \varepsilon_{2,t}, \\
\Delta cs_t^{\text{liq}} &= \sum_{j=1}^{5} x_{1_j} \Delta cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} x_{2_j} cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} x_{3_j} \Delta cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} x_{4_j} cs_{t-j}^{\text{liq}} \\
&+ \sum_{j=1}^{5} x_{5_j} \Delta s_{t-j}^{\text{liq}} + \sum_{j=1}^{5} x_{6_j} s_{t-j}^{\text{liq}} + \varepsilon_{3,t}, \\
\Delta s_t^{\text{liq}} &= \sum_{j=1}^{5} y_{1_j} \Delta cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} y_{2_j} cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} y_{3_j} \Delta cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} y_{4_j} cs_{t-j}^{\text{liq}} \\
&+ \sum_{j=1}^{5} y_{5_j} \Delta s_{t-j}^{\text{liq}} + \sum_{j=1}^{5} y_{6_j} s_{t-j}^{\text{liq}} + \varepsilon_{4,t}. \qquad (4.10)
\end{aligned}
$$

We demand that the parameters are identical for all, respectively all financial, non-financial, sovereign, investment grade, or subinvestment grade reference entities.[37] Time lags up to 5 days are considered to capture a weekly time interval, and the resulting parameter estimates are transformed into a single estimate for ease of presentation. We subsequently test whether the regression residuals are stationary.

The results of the estimation are displayed in Table 4.2. We first discuss the results for the entire sample, then the results for the investment and subinvestment grade segment, and last the results for the different industry sectors.

As the coefficient estimates for the entire sample in Panel A of Table 4.2 show, Δcs^{def} and Δs^{def} are negatively autocorrelated and negatively correlated with their lagged level. The negative correlation with the previous level implies that credit risk premia have decreased over time. The level of cs_{-1}^{liq} and its changes positively affect Δs^{def}, but the coefficients are only statistically significant at the 10% level, and the economic impact is small with a coefficient estimate of 0.02 for $\Delta cs_{-1}^{\text{liq}}$ and 0.01 for cs_{-1}^{liq}. The adjusted R^2 of 12.93% for

[37] This estimation restriction could result in non-stationary residuals for reference entities for which the residuals of the cointegrated variables were stationary in the first test. We therefore additionally test whether the residuals of the restricted estimation were stationary for each of the 164 reference entities.

Table 4.2: **Dynamic Relationship of Credit Risk and Liquidity Premia**

The table shows the estimated coefficients for the Johansen VAR model in Equation (4.10). cs^{def} is the credit risk and cs^{liq} the liquidity component in the yield spread of a synthetical 5-year par bond. s^{def} is the credit risk and s^{liq} the liquidity component in the mid premium for a 5-year CDS contract. The dependent variables are the premium changes, the explanatory variables are the lagged premium changes and the lagged premium levels. The top row of each panel displays the number of reference entities for which 1) the augmented Dickey-Fuller test cannot reject a unit root in the premia time series at the 10% significance level, 2) the augmented Dickey-Fuller test can reject a unit root in the first differences at the 10% level, 3) the Johansen test cannot reject cointegration of the time series at the 10% level, 4) the augmented Dickey-Fuller can reject a unit root in the residuals at the 10% level. ***, **, and * denote significance at the 1%, 5%, and 10% level. Coefficients are for premia in basis points, the adjusted R^2 are in percentage points.

Panel A: Rating Classes

	Investment Grade				Subinvestment Grade				All			
	Δcs^{def}	Δs^{def}	Δcs^{liq}	Δs^{liq}	Δcs^{def}	Δs^{def}	Δcs^{liq}	Δs^{liq}	Δcs^{def}	Δs^{def}	Δcs^{liq}	Δs^{liq}
# Firms	152				12				164			
$\Delta cs^{\text{def}}_{-1}$	-0.10***		0.02***	0.02***	-0.13***		0.08***	0.04***	-0.12***		0.02***	0.02***
$\Delta s^{\text{def}}_{-1}$		-0.10***				-0.13***				-0.12***		
$\Delta cs^{\text{liq}}_{-1}$	0.01	0.01	-0.37***	0.01***	0.10	0.01**	-0.30***	-0.01**	0.03	0.02*	-0.35***	0.01***
$\Delta s^{\text{liq}}_{-1}$	0.11	0.11	-0.02	-0.63***	0.20	0.20	-0.05	-0.53***	0.21	0.21	-0.02	-0.55***
cs^{def}_{-1}	-0.02***		0.01***	0.01***	-0.01***		-0.00	-0.01***	-0.01***		0.00	0.01***
s^{def}_{-1}		-0.02***				-0.01***				-0.01***		
cs^{liq}_{-1}	0.00	0.00	-0.02***	0.05***	0.04	0.04	-0.07***	-0.04***	0.01	0.01*	-0.03***	0.00
s^{liq}_{-1}	0.12	0.12	0.04	-0.26***	0.16	0.17	-0.01**	-0.25***	0.16	0.16	0.05	-0.24***
Adj. R^2	8.20	7.88	28.97	43.69	17.97	17.62	24.51	36.49	12.93	12.46	27.83	36.33

Panel B: Industry Sectors

	Financial				Non-Financial				Sovereign			
	Δcs^{def}	Δs^{def}	Δcs^{liq}	Δs^{liq}	Δcs^{def}	Δs^{def}	Δcs^{liq}	Δs^{liq}	Δcs^{def}	Δs^{def}	Δcs^{liq}	Δs^{liq}
# Firms	50				99				15			
$\Delta cs^{\text{def}}_{-1}$	-0.20***		-0.01	0.01***	-0.13***		0.02***	0.03***	-0.03		0.00	0.05***
$\Delta s^{\text{def}}_{-1}$		-0.20***				-0.12***				-0.03		
$\Delta cs^{\text{liq}}_{-1}$	0.01	0.01	-0.30***	0.02***	0.02	0.02*	-0.36***	0.01**	0.10	0.09	-0.33***	0.01
$\Delta s^{\text{liq}}_{-1}$	0.93	0.96	0.13*	-0.64***	0.23	0.23	-0.03	-0.54***	0.02	0.02	-0.02	-0.62***
cs^{def}_{-1}	-0.07***		0.00	0.02***	-0.01***		0.01***	0.01***	-0.01***		0.00	0.02***
s^{def}_{-1}		-0.08***				-0.01***				-0.01***		
cs^{liq}_{-1}	0.01	0.01	-0.03***	0.01***	0.01	0.01*	-0.03***	0.01**	0.02	0.02	-0.11***	-0.02
s^{liq}_{-1}	0.82	0.84	0.17**	-0.34***	0.18	0.19	-0.02*	-0.25***	0.02	0.02	0.00	-0.26***
Adj. R^2	16.72	16.87	21.86	40.75	16.25	15.84	28.41	36.22	2.42	2.31	26.69	42.27

Δcs^{def} and 12.46% for Δs^{def} is rather low, suggesting that the negative autocorrelation and the correlation with the lagged level in addition to the cross-market impact only explain a low amount of variation.

The changes of the bond and CDS liquidity premia Δcs^{liq} and Δs^{liq} are also negatively autocorrelated and negatively correlated with their lagged level. This level correlation is stronger for the CDS premia with a coefficient estimate of -0.24 which suggests that CDS liquidity premia decrease more strongly on an absolute level. We interpret this as a sign that the CDS market matures over time. Both Δcs^{liq} and Δs^{liq} are positively associated with $\Delta cs^{\text{def}}_{-1}$, suggesting that increases in credit risk premia also increase liquidity premia in both markets. Δs^{liq} also exhibits a positive dependence on the level of cs^{def}. This relation implies that the intensities governing credit risk and liquidity implicitly capture a data-driven correlation, even though they are assumed to be independent. We explore the impact of including a formal covariance structure for the intensities in our model in Section 5.1.

With regard to the liquidity spillover between the bond and the CDS market, we find that Δs^{liq} reacts to $\Delta cs^{\text{liq}}_{-1}$, and the positive sign of the coefficient estimate suggests that liquidity premia move in the same direction. Even though the estimate is small at 0.01, it is economically significant since bond liquidity premia are on average higher than CDS liquidity premia. Reversely, the CDS market's liquidity does not seem to affect the bond market's liquidity. This relation suggests that a lower bond market liquidity causes a higher number of ask-initiated transactions in the CDS market and that the ask premium moves further away from the liquidity-free CDS premium. The adjusted R^2 of Δcs^{liq} and Δs^{liq} is about double and triple the size we obtain for the credit risk premia at 27.83% and 36.33%. Liquidity premia seem to be more adequately described in the VAR model than credit risk premia, and the dependence on credit risk and, for CDS, on the bond market's liquidity, is an important source of premia variation.

Rating Classes As Figure 4.4 already indicated, the time series behavior of the premia differs between the investment and the subinvestment grade segment. The results of the VAR analysis for the investment grade segment in Panel A of Table 4.2 show that the dynamics of the premia are similar to those for the entire sample, but that the size of the coefficients and the explanatory power changes. Δcs^{def} and Δs^{def} remain negatively autocorrelated and negatively correlated with their lagged level, but the coefficients of the previous change and the adjusted R^2 decrease (on the absolute level). The impact of $\Delta cs^{\text{liq}}_{-1}$ on Δs^{def} becomes insignificant even at the 10% level which supports our earlier result that the impact of bond liquidity on CDS premia is higher for a higher default probability. Δcs^{liq} exhibits the same dependence on cs^{def}_{-1} as Δs^{liq} with a coefficient estimate of 0.01.

With regard to the cross-market liquidity spillover, Δcs^{liq} remains unaffected by s^{liq}_{-1} and $\Delta s^{\text{liq}}_{-1}$, but the reverse is not true. Both cs^{liq}_{-1} and $\Delta cs^{\text{liq}}_{-1}$ significantly affect Δs^{liq}, and the positive coefficient estimate implies that a lower bond market liquidity also causes liquidity premia in the CDS market to increase. Accordingly, the adjusted R^2 of Δcs^{liq} remains virtually unaffected while that for Δs^{liq} increases by 7 percentage points.

Overall, the investment grade segment exhibits a lower connection between the premia in the bond and the CDS market than the entire sample. These findings suggest that the premia for investment grade reference entities may be affected by market-specific conditions in excess of the firm-specific ones. We further explore this possibility below.

The time series behavior of the subinvestment grade credit risk premia also resembles that of the entire sample, but the adjusted R^2 increases to 17.97% for Δcs^{def} and 17.62% for Δs^{def}. Besides, Δs^{def} now exhibits a positive dependence on cs^{liq}_{-1}.

The central difference to the investment grade segment lies in the relation of the liquidity premia. The coefficient estimate for the cross-market liquidity impact becomes negative and significant for both bonds and CDS at the 5% significance level. A lower liquidity level of one market therefore causes the other market to become more liquid, suggesting that taking on and selling off credit risk occurs interchangeably on the bond and the CDS market. Economically, this relation seems more plausible. If liquidity in the bond market decreases, taking on credit risk directly through the bond becomes cheaper, and short-selling credit risk directly through the bond becomes more expensive. Therefore, the price for taking on credit risk in the CDS market should decrease while and selling off credit risk should become more expensive. This relation translates into lower CDS ask premia and higher CDS bid premia, reducing the asymmetry between s^{ask} and s^{bid} with regard to s^{def} and, consequently, s^{liq}.

Moreover, Δs^{liq} also reacts negatively to the level of credit risk, suggesting that high credit risk in the subinvestment grade segment effectually reduces the demand for credit risk protection in the CDS market and thus the amount of ask-initiated transactions.

In comparison to the investment grade segment, the adjusted R^2 implies that the credit risk premia are more closely interconnected while liquidity premia are less adequately explained in the VAR setting.

Industry Sectors With regard to the different industry sectors in Panel B of Table 4.2, we observe that Δcs^{def} and Δs^{def} exhibit a larger negative autocorrelation and correlation with their lagged level for financial reference entities with coefficient estimates of -0.20 for the previous change and -0.07, respectively -0.08, for the level.

The liquidity premia become more closely interdependent. Both Δcs^{liq} and Δs^{liq} react positively to the level and the change of the other market's liquidity premia. Interestingly, Δcs^{liq} only exhibits a weak dependence on $\Delta cs^{\text{def}}_{-1}$, suggesting that liquidity in the bond market evolves partly independent from credit risk.

The time series of the credit risk premia in the non-financial corporate sector only differs from the behavior of the entire sample in the impact of cs^{liq}_{-1} on Δs^{def} which is positive but only significant at the 10% level. The liquidity premia exhibit a higher sensitivity to credit risk than for the financial sector with a coefficient estimate of 0.02 and 0.03 for $\Delta cs^{\text{def}}_{-1}$. cs^{def}_{-1} also affects Δcs^{liq} more strongly than for the entire sample, but its impact on Δs^{liq} decreases from 0.02 to 0.01. Concerning the liquidity spillover, the evidence is not wholly conclusive because the investment and subinvestment grade classes are treated jointly. Δs^{liq} reacts positively to cs^{liq}_{-1} and $\Delta cs^{\text{liq}}_{-1}$ while the coefficient of s^{liq}_{-1} with regard to the impact on Δcs^{liq} is negative at -0.02 and significant at the 10% level. This result implies that we need to distinguish between investment and non-investment grade rating classes if we want to explore the liquidity spillover between bond and CDS markets. The adjusted R^2 for the credit risk premia are similar to those in the financial sector, but the explanatory power for cs^{liq} increases and that for s^{liq} decreases.

The time series behavior of the sovereign sector differs strongly from those of the corporate sectors. We do not find evidence of negative autocorrelation in cs^{def} and s^{def}, only the negative correlation with the lagged level persists. For cs^{liq}, we find no further impact of credit risk, and neither of the liquidity premia reflects a spillover from the other market. Hence, we infer that both markets evolve independently. The explanatory power for the credit risk premia is very low, but the liquidity premia exhibit an adjusted R^2 in line with that for investment grade segment.

In summary, our time series analysis reveals that the credit risk premia in the bond and the CDS market behave almost identically, further confirming that the model-immanent impact of the bond liquidity on s^{def} is limited. The largest dependence applies for the subinvestment grade segment and the non-financial corporate sector which suggests that the level of the bond liquidity is less important for the direct spillover than the probability of default. Over time, the credit risk premia decrease for all rating classes and industry sectors. The credit risk premia show strong reactions to the Enron and the WorldCom default, financial reference entities in particular to the WorldCom default.

One result of the time series analysis is that the liquidity premia exhibit a strong dependency on the credit risk premia. This result is delicate since the intensities are assumed to be independent. The link is more pronounced for non-financial reference entities and the investment grade segment. In addition, the liquidity premia also show a cross-market impact on one another. In the investment grade segment and for the non-financial and sovereign sector, only CDS liquidity reacts to changes in bond liquidity while the subinvestment grade segment and financial sector also feature a dependency of the bond liquidity on the CDS liquidity. The dependency may partly be due to the joint sensitivity to credit risk, in particular since the coefficient sign for the relation between the two liquidities always agrees with the dependency on credit risk: In the investment grade segment, both Δcs^{liq} and Δs^{liq} depend positively on the credit risk premia, and the relation between the liquidity premia is also positive. In the subinvestment grade segment where Δs^{liq} becomes negatively related to credit risk, the relation between the liquidity premia is also negative.

4.3 Stability Analysis

In this section, we perform a stability analysis of the estimated credit risk and liquidity premia for bonds and CDS. To this purpose, we first explore how bond premia react if we ignore liquidity in the CDS market. We then compare the pure credit risk premia which are obtained if the default and liquidity intensities are estimated either from CDS ask or from bid quotes only to the estimate which uses both the bid and the ask quote simultaneously. Eventually, we analyze the effect of market-wide credit risk and liquidity measures on the time series dynamics of the credit risk and liquidity premia and compare the behavior in periods with increasing and decreasing credit risk.

4.3.1 Effect of Excluding CDS Illiquidity

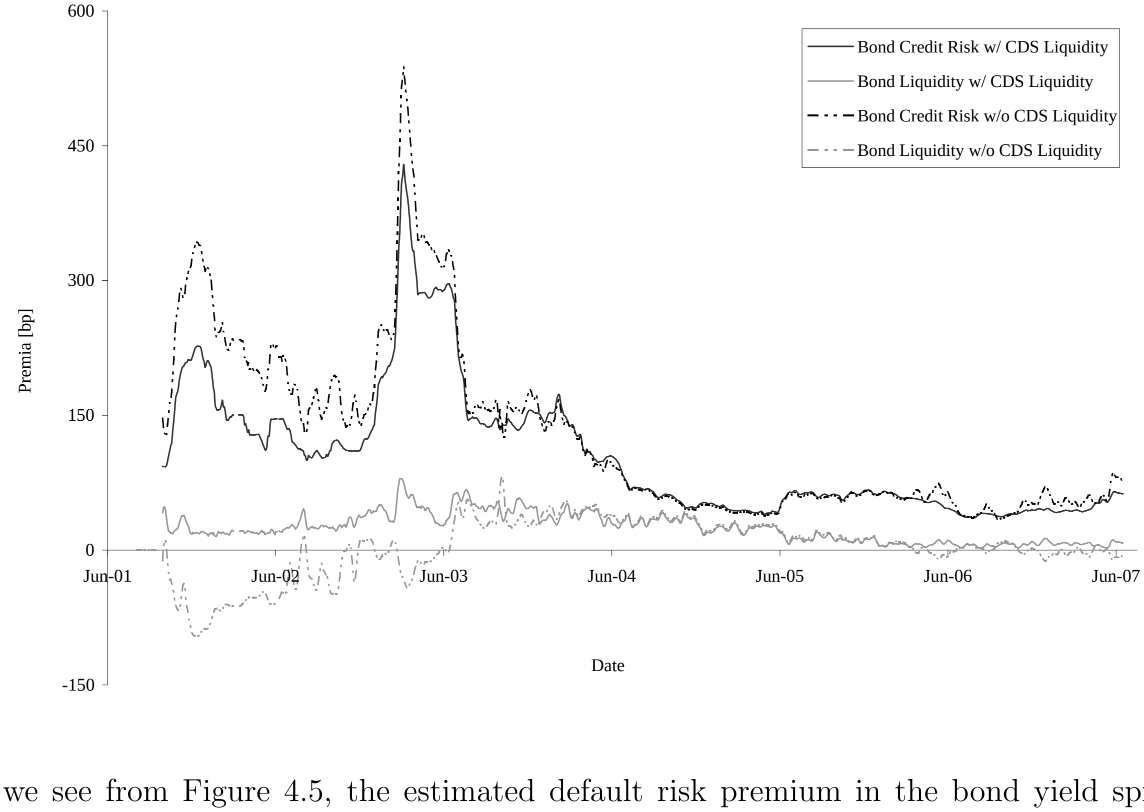
As Table 4.1 shows, our model yields almost exclusively positive estimates of the bond liquidity premia cs^{liq}. In contrast, Longstaff et al. (2005) who do not account for CDS liquidity in their model obtain large negative estimates of the bond liquidity intensity which would be associated with large negative estimates of cs^{liq}.

We therefore explore whether the positive bond liquidity premia we obtain in our estimation are a result of including stochastic liquidity in CDS ask and bid premia or simply a property of our data set. To do so, we propose the following modification of our model: First, we shift our focus to the CDS mid premia in our calibration procedure since there is no theoretically compelling reason why s^{def} must differ systematically from the mid premium. Second, we re-estimate the default and bond liquidity intensity time series under the restriction $\gamma^l = \mu^l = \eta^l = 0$, $l = \text{ask}, \text{bid}$. This is basically the approach by Longstaff et al. (2005) and suggests that the CDS market is the liquidity numéraire. Last, we compute the bond credit risk and liquidity premia cs^{def} and cs^{liq} and compare them to the results from the initial estimation which includes illiquidity in CDS premia.

Since the effect only pertains when bonds are liquid relative to the CDS, we first present the estimated time series for a single firm, the Dutch communications company The Nielsen Company (formerly VNU Group B.V.).[38]

Figure 4.5: **Effect of Excluding Stochastic CDS Illiquidity**

The figure shows the bond credit risk (black) and liquidity premia (grey) estimated for the communications firm Nielsen when stochastic CDS illiquidity is included (solid line) and ignored (dashed line).



As we see from Figure 4.5, the estimated default risk premium in the bond yield spread cs^{def} has similar dynamics whether CDS liquidity is included or not, but there are clear level differences. Overall, when stochastic CDS liquidity is excluded, cs^{def} is higher, fluctuating between 34.98 bp and 537.71 bp with a mean of 127.02 bp and a standard deviation of 97.56

[38]The Nielsen Company is active in marketing and media information, business publications, and trade shows in over 100 countries and has a total of 42,000 employees.

bp. When stochastic CDS liquidity is included, cs^{def} lies between 35.74 bp and 429.29 bp, the mean equals 105.94 bp, and the standard deviation 73.36 bp. The differences are most pronounced during the beginning of our observation interval when the CDS market was still relatively illiquid.

Conversely, the bond liquidity premium cs^{liq} that results from excluding stochastic CDS liquidity is consistently and considerably lower than when CDS liquidity is modelled with a mean of 3.74 bp versus 24.69 bp, a minimum of -95.95 bp (5.26 bp), a maximum of 81.82 bp (79.78 bp) and a standard deviation of 32.55 bp (16.11 bp).

We repeat the above analysis for the entire sample, i.e. we re-estimate the default and bond liquidity intensity time series under the assumption that the CDS market is the liquidity numéraire for each firm. Overall, this re-estimation gives 12,285 negative bond liquidity estimates out of 137,816 estimates for 136 out of 171 reference entities. Out of these 136, 123 have an average investment grade rating, and all 13 subinvestment grade rated reference entities have negative bond liquidity estimates. With regard to the industry sectors, all sovereign reference entities, 27 financial reference entities, and 93 non-financial corporate reference entities exhibit negative bond liquidity estimates. We determine the resulting bond credit risk and liquidity premia cs^{def} and cs^{liq} as described in Section 4.1.3. The resulting mean, standard deviation, minimum, and maximum are displayed in Table 4.3.

A comparison of the estimates in Table 4.3 to the original estimates that allow for CDS liquidity in Table 4.1 shows that the average bond credit risk premium cs^{def} tends to be slightly higher if CDS liquidity is ignored. Across all rating classes, the mean value of cs^{def} is higher at 54.13 bp by 1.92 bp than in Table 4.1 which is approximately equal to the mean CDS pure liquidity premium s^{liq} of 2.04 bp. The main difference, however, lies in the higher averages and the negative minimal values for the bond liquidity premia cs^{liq}. For each industry sector and each rating class, the minimal value of cs^{liq} is negative with a minimum of -206.72 bp for a BB-rated sovereign reference entity.

These results suggest that neglecting stochastic CDS liquidity can yield underestimates of liquidity premia in the bond market and, for above time series, bond price surcharges instead of discounts. Besides, the default intensity is overestimated when the bond liquidity premium becomes negative, and this results in overestimates of a firm's default probability. As neglecting CDS liquidity attributes yield differences between the bond and the CDS market directly to bond liquidity in our model, the effect is especially pronounced when the bond liquidity is high relative to the CDS liquidity. As the CDS market matures, the

Table 4.3: **Bond Credit Risk and Liquidity Premia Without CDS Liquidity**

The table presents the mean, standard deviation, minimum, and maximum of the model-implied bond premia components when stochastic liquidity in the CDS market is ignored. cs^{def} is the credit risk and cs^{liq} the liquidity component in the yield spread of a synthetical 5-year par bond. The standard deviation, minimum, and maximum are determined both over time and across observations within the sample on each date. All values are in basis points.

	Sectors			Rating Classes							
	Fin.	Non-Fin.	Sov.	AAA	AA	A	BBB	BB	B	CCC	All
cs^{def}	18.50	70.77	39.88	7.93	13.67	32.24	66.47	274.46	404.47	282.87	54.13
Std. Dev.(cs^{def})	16.53	112.00	102.59	5.13	12.40	29.44	68.64	251.74	166.90	43.96	100.86
min(cs^{def})	3.38	4.00	2.05	2.05	3.38	3.95	4.05	33.60	33.94	110.83	2.05
max(cs^{def})	510.96	1,832.76	1,021.80	65.97	380.39	372.65	1,447.75	1,832.76	1,298.52	409.612	1,832.76
cs^{liq}	11.57	31.01	0.71	-1.25	13.75	23.90	40.68	31.32	13.78	3.52	24.35
Std. Dev.(cs^{liq})	41.31	57.29	12.09	5.60	56.32	54.34	76.87	71.53	50.84	5.05	97.36
min(cs^{liq})	-204.39	-191.66	-206.72	-13.63	-121.75	-19.61	-200.91	-206.72	-150.92	-18.81	-206.72
max(cs^{liq})	650.37	778.26	218.69	30.58	335.12	479.03	650.37	778.26	394.58	114.45	778.26

erroneous results of neglecting CDS liquidity becomes less striking as long as the net liquidity premium in the bond market remains positive.

4.3.2 Estimation from CDS Ask or Bid Premia

In Section 4.2, we use the CDS ask and bid premia simultaneously in order to extract the pure credit risk and liquidity components from CDS premia and bond yield spreads. However, only the sum of these two components can be observed, and our estimates could therefore differ significantly from the true values.

As a robustness test, we repeat the firm-specific calibration procedure described in Section 4.2.1 once using only CDS ask premia and once using only CDS bid premia instead of both. We then compare the resulting estimates of cs^{def}, cs^{liq}, s^{def}, and s^{liq} with those we obtained for the entire sample. In particular, we compute the mean, standard deviation, and mean absolute difference between the estimates which are obtained using only one CDS premium and the estimates which use both simultaneously. If the estimates do not differ too strongly, we take this as an indication that our model allows us to adequately separate the credit risk and liquidity components.

The results are displayed in Table 4.4.

Table 4.4 shows that the estimates of the credit risk and liquidity components are almost identical regardless of which CDS premia are used in the estimation. On average, the mean estimate of cs^{def} from the CDS ask premium of 51.75 bp falls below the one using both premia by 0.46 bp, but the similar standard deviation and the mean absolute difference of 1.48 bp imply that the sign is not indicative of a systematic error. The same is true for the estimate which uses only the bid premia with a mean difference between the credit risk premia of 0.77 bp and a mean absolute difference of 1.45 bp. For the bond liquidity premia cs^{liq}, we observe the reverse result, the mean estimates which only use ask premia are slightly higher and the ones using only bid premia are slightly lower. The difference, however, does not appear to be systematic in this case either which is supported by the low mean absolute difference of 1.13 bp and 1.14 bp, respectively. The results for the CDS credit risk premia s^{def} and liquidity premia s^{liq} are similar to those for the bond. Again, the use of ask premia leads to a very slight underestimation of the credit risk premia and overestimation of the liquidity premia while bid premia yield slightly higher values for s^{def} and lower ones for s^{liq}. Therefore, CDS ask premia suggest a higher demand pressure and bid premia a lower demand pressure in the CDS market.

Table 4.4: **Estimated Credit Risk and Liquidity Premia using CDS Ask or Bid Premia**

The table presents the sample mean, standard deviation, and mean absolute difference between the credit risk and liquidity premia estimated from CDS bid and ask premia simultaneously (column 2), using only CDS ask premia (column 3), and using only CDS bid premia (column 4). cs^{def} is the credit risk and cs^{liq} the liquidity component in the yield spread of a synthetical 5-year par bond. s^{def} is the credit risk and s^{liq} the liquidity component in the mid premium for a 5-year CDS contract. All values are in basis points.

	Bid and Ask	Ask Only	Bid Only
Mean(cs^{def})	52.21	51.75	52.98
Std. Dev.(cs^{def})	83.04	85.76	85.99
Mean Abs. Difference	–	1.48	1.45
Mean(cs^{liq})	26.26	26.71	25.49
Std. Dev.(cs^{liq})	47.27	48.90	50.02
Mean Abs. Difference	–	1.13	1.14
Mean(s^{def})	52.69	51.40	53.93
Std. Dev.(s^{def})	83.79	84.01	84.16
Mean Abs. Difference	–	1.58	1.55
Mean(s^{liq})	2.04	2.54	1.70
Std. Dev.(s^{liq})	9.91	10.25	10.29
Mean Abs. Difference	–	0.57	0.55

Overall, we find that the choice of ask or bid premia in the CDS market does not significantly affect the size and the dynamics of the estimated credit risk and liquidity premia. Since these premia are not directly observable in the market, we take the robust behavior of the estimates as a sign that our estimation does not result in a systematic deviation from the true premia.

4.3.3 Impact of Market-Wide Credit Risk and Liquidity Factors

We explore whether the time series of the credit risk and liquidity premia are exclusively driven by firm- and instrument-specific changes or whether aggregate market conditions have an additional impact. We therefore analyze the effect of market-wide credit risk and liquidity measures on the VAR dynamics. Our previous findings in Table 4.2 suggest that the impact of these measures is higher for the investment grade segment and the financial sector.

As a proxy for credit risk, we choose the S&P Creditweek Corporate Bond Index yield spreads described in Appendix 3.5. Liquidity is proxied by the ECB Financial Market Liquidity Indicator. Since the level of the premia are not stationary, we estimate a Johansen VAR similar to the one in Equation (4.10) with the changes of the credit risk and liquidity premia as endogenous variables and the index yield spreads and the liquidity indicator as exogenous variables. The procedure yields three additional investment-grade reference entities with stationary residuals, two of them from the financial and one from the non-financial corporate sector. The results are displayed in Table 4.5.

As Table 4.5 shows, the inclusion of the aggregate credit risk and liquidity measures does not affect the dynamics of the firm-specific credit risk premia. Both Δcs^{def} and Δs^{def} depend positively on market-wide credit risk and negatively on liquidity, but the increase of the adjusted R^2 from 12.93% to 13.32% shows that the explanatory power of the market-wide measures is small. The impact is stronger for the investment grade segment: the adjusted R^2 almost doubles from 8.20% to 14.20% for Δcs^{def} and from 7.88% to 16.90% for Δs^{def}. For the subinvestment grade segment, the coefficient estimates are either insignificant or only significant at the 10% level. Clearly, changes in the credit risk premia in the subinvestment grade segment almost completely depend on the reference entity's idiosyncratic default risk.

A similar result as for the investment grade segment holds with regard to the financial, non-financial, and sovereign sector. For the financial sector, Δcs^{def} and Δs^{def} depend positively on credit risk and liquidity at the 1% significance level, and the adjusted R^2 increases by approximately 10 percentage points compared to the entire sample. Credit risk

Table 4.5: **Impact of Market-Wide Credit Risk and Liquidity Factors**

The table shows the estimated coefficients for the Johansen VAR with exogenous variables. The rating class-specific S&P Creditweek Corporate Bond Index yield spread is used to proxy for credit risk, the ECB financial market liquidity indicator for liquidity. cs^{def} is the credit risk and cs^{liq} the liquidity component in the yield spread of a synthetical 5-year par bond. s^{def} is the credit risk and s^{liq} the liquidity component in the mid premium for a 5-year CDS contract. The dependent variables are the premium changes, the explanatory variables are the lagged premium changes, the lagged premium levels, and the credit risk and liquidity measures. The top row of each panel displays the number of reference entities for which 1) the augmented Dickey-Fuller test cannot reject a unit root in the premia time series at the 10% significance level, 2) the augmented Dickey-Fuller test can reject a unit root in the first differences at the 10% level, 3) the Johansen test cannot reject cointegration of the time series at the 10% level, 4) the augmented Dickey-Fuller can reject a unit root in the residuals at the 10% level. ***, **, and * denote significance at the 1%, 5%, and 10% level. Coefficients are for premia in basis points, the adjusted R^2 are in percentage points.

	Panel A: Rating Classes											
	Investment Grade				Subinvestment Grade				All			
	Δcs^{def}	Δs^{def}	Δcs^{liq}	Δs^{liq}	Δcs^{def}	Δs^{def}	Δcs^{liq}	Δs^{liq}	Δcs^{def}	Δs^{def}	Δcs^{liq}	Δs^{liq}
# Firms	155				12				167			
$\Delta cs^{\text{def}}_{-1}$	-0.10***		0.02***	0.02***	-0.13***		0.01	0.04***	-0.12***		0.02***	0.02***
$\Delta s^{\text{def}}_{-1}$		-0.10***				-0.13***				-0.12***		
$\Delta cs^{\text{liq}}_{-1}$	0.01	0.01	-0.37***	0.01***	0.10	0.01*	-0.30***	-0.02	0.03	0.02*	-0.35***	0.01*
$\Delta s^{\text{liq}}_{-1}$	0.11	0.11	-0.02	-0.63***	0.20	0.20	-0.04	-0.53***	0.21	0.21	-0.03	-0.55***
cs^{def}_{-1}	-0.02***		0.01***	0.01***	-0.02***		0.00	-0.01***	-0.01***		0.00	0.01***
s^{def}_{-1}		-0.02***				-0.02***				-0.01***		
cs^{liq}_{-1}	0.00	0.00	-0.02***	0.00	0.05	0.04	-0.07***	-0.03***	0.01	0.01***	-0.03***	0.00
s^{liq}_{-1}	0.12	0.12	0.04*	-0.26***	0.16	0.16	-0.01**	-0.25***	0.16	0.16***	0.05	-0.24***
Credit Risk	0.07***	0.07***	0.05***	0.02**	0.08	0.07*	1.14***	0.03**	0.02***	0.02***	0.01***	0.01**
Liquidity	-0.07***	-0.08***	-0.80***	-0.29***	1.14	0.11	-0.06*	-0.01*	-0.08**	-0.07***	-0.41***	-0.05***
Adj. R^2	14.22	16.90	35.85	48.70	18.09	17.73	24.53	36.48	13.32	14.92	35.72	43.53

	Panel B: Industry Sectors											
	Financial				Non-Financial				Sovereign			
# Firms	52				100				15			
$\Delta cs^{\text{def}}_{-1}$	-0.20***		0.00	0.01***	-0.13***		0.01***	0.03***	-0.03		0.00	0.05***
$\Delta s^{\text{def}}_{-1}$		-0.20***				-0.12***				-0.03		
$\Delta cs^{\text{liq}}_{-1}$	0.01	0.01*	-0.29***	0.01**	0.02	0.02*	-0.36***	0.02*	0.08	0.07	-0.33***	0.01
$\Delta s^{\text{liq}}_{-1}$	0.93	0.96	0.14*	-0.64***	0.23	0.23	-0.04	-0.54***	0.02	0.02	-0.02	-0.62***
cs^{def}_{-1}	-0.08***		0.00	0.02***	-0.01***		0.00	0.01***	-0.01***		0.00	0.02***
s^{def}_{-1}		-0.08***				-0.01***				-0.01***		
cs^{liq}_{-1}	0.01	0.01*	-0.03***	0.01*	0.01	0.01*	-0.03***	0.01*	0.01	0.01	-0.11***	-0.02
s^{liq}_{-1}	0.83	0.86	0.18**	-0.34***	0.18	0.19	-0.03**	-0.25***	0.01	0.01	-0.01	-0.26***
Credit Risk	0.13***	0.10***	0.03***	0.01***	0.04*	0.09**	0.02***	0.01***	0.24*	0.24**	0.06	0.17
Liquidity	-0.82***	-0.83***	-0.15***	-0.05***	-0.48***	-0.48***	0.07	0.00	-1.60***	-1.62***	-0.05**	-0.86*
Adj. R^2	24.92	25.06	25.74	43.82	16.95	16.38	29.53	37.24	2.50	2.39	26.73	42.27

premia in the non-financial and the sovereign sector are more sensitive to the liquidity than to the credit risk measure, and the adjusted R^2 is mostly unaffected.

The impact of the market-wide measures on the liquidity premia is stronger than on the credit risk premia as measured by the adjusted R^2. We obtain a positive dependence on the credit risk and a negative one on the liquidity measure for the entire sample, and the adjusted R^2 for Δcs^{liq} increases by approximately 7 percentage points for the entire sample.

For the investment grade segment, Δcs^{liq} and Δs^{liq} both react positively to increases of credit risk and negatively to increases of liquidity, but the effect on the bond liquidity premium is more pronounced. We partly attribute this to the fact that the CDS market is, on average, rather liquid, and partly to the increasing overall liquidity in the CDS market throughout the observation interval.

In the subinvestment grade segment, on the other hand, Δcs^{liq} reacts with more pronounced increases to increases in aggregate credit risk and with only slight decreases to increases in overall market liquidity. However, the additional explanatory power of the market-wide measures is low. For CDS liquidity premia, we obtain a low dependence on market-wide credit risk and liquidity, and the adjusted R^2 decreases from the Johansen VAR analysis without exogenous variables in Table 4.2.

As for the credit risk premia, the liquidity premia in the financial sector exhibit a higher dependence on the market-wide variables with the expected coefficient signs. The explanatory power, however, is lower with an increase of 4 percentage points in comparison to the increase of 7 percentage points for the entire sample. This difference suggests that liquidity premia in the financial sector do not necessarily move in unison with the entire market. The non-financial corporate sector's liquidity premia are unaffected by the liquidity measure, but interestingly, credit risk has a positive impact. The reverse result applies for the sovereign sector, only the liquidity indicator has an impact on Δcs^{liq} and Δs^{liq}.

4.3.4 Impact of Increasing and Decreasing Market-Wide Risk

To conclude the stability analysis, we explore how the relation between the credit risk and liquidity premia and the relation between the liquidity premia across the two markets are affected by increasing and decreasing credit risk conditions. We measure the integration of the premia by the cointegration coefficient and the speed of adjustment by the coefficient of the error correction term in a VECM. We rewrite Equation (4.10) in the following form:

$$\Delta cs_t^{\text{def}} = u_1\left(cs_{t-1}^{\text{def}} + \rho_1 cs_{t-1}^{\text{liq}}\right) + \sum_{j=1}^{5} u_{2_j}\Delta cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} u_{3_j}\Delta cs_{t-j}^{\text{liq}} + \varepsilon_{1,t},$$

$$\Delta cs_t^{\text{liq}} = v_1\left(cs_{t-1}^{\text{def}} + \rho_1 cs_{t-1}^{\text{liq}}\right) + \sum_{j=1}^{5} v_{2_j}\Delta cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} v_{3_j}\Delta cs_{t-j}^{\text{liq}} + \varepsilon_{2,t}, \tag{4.11}$$

$$\Delta s_t^{\text{def}} = w_1\left(s_{t-1}^{\text{def}} + \rho_2 s_{t-1}^{\text{liq}}\right) + \sum_{j=1}^{5} w_{2_j}\Delta s_{t-j}^{\text{def}} + \sum_{j=1}^{5} w_{3_j}\Delta s_{t-j}^{\text{liq}} + \varepsilon_{3,t},$$

$$\Delta s_t^{\text{liq}} = x_1\left(s_{t-1}^{\text{def}} + \rho_2 s_{t-1}^{\text{liq}}\right) + \sum_{j=1}^{5} x_{2_j}\Delta s_{t-j}^{\text{def}} + \sum_{j=1}^{5} x_{3_j}\Delta s_{t-j}^{\text{liq}} + \varepsilon_{4,t}, \tag{4.12}$$

$$\Delta cs_t^{\text{liq}} = y_1\left(cs_{t-1}^{\text{liq}} + \rho_3 s_{t-1}^{\text{liq}}\right) + \sum_{j=1}^{5} y_{2_j}\Delta cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} y_{3_j}\Delta s_{t-j}^{\text{liq}} + \varepsilon_{5,t},$$

$$\Delta s_t^{\text{liq}} = z_1\left(cs_{t-1}^{\text{liq}} + \rho_3 s_{t-1}^{\text{liq}}\right) + \sum_{j=1}^{5} z_{2_j}\Delta cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} z_{3_j}\Delta s_{t-j}^{\text{liq}} + \varepsilon_{6,t}, \tag{4.13}$$

where ρ_i, $i \in \{1, \ldots, 3\}$ are the cointegration coefficients and u_1, v_1, w_1, x_1, y_1, and z_1 are the coefficients of the error correction term. Lags of up to 5 days are considered in order to capture a weekly time interval.

We estimate the above equations for increasing and decreasing risk phases. Increasing risk phases are defined as time intervals with 4 consecutive weekly increases in the S&P Creditweek Corporate Bond Index yield spread for the rating class to which a firm belonged during that interval. Decreasing risk phases are analogously defined as intervals with 4 consecutive weekly decreases. Overall, we obtain 21 4-week intervals with increasing and 17 with decreasing risk for which we perform a VECM analysis of the premia at the daily level.[39] As above, we demand that the coefficient estimates are identical for all reference entities, all investment grade, all subinvestment, all financial, and all non-financial reference entities during the increasing, respectively decreasing, risk phases. We do not treat the sovereign sector separately because we do not have sufficient data during the increasing risk phase. The results of the estimation are given in Table 4.6. For ease of presentation, we denote u_1, w_1, and y_1 as $ECT1$ and v_1, x_1, and z_1 as $ECT2$.

For the entire sample, we find that the relation between cs^{def} and cs^{liq}, s^{def} and s^{liq}, and cs^{liq} and s^{liq} is quantitatively similar both during increasing and decreasing credit risk phases. In each case, we obtain a negative cointegration coefficient which implies that the premia

[39] Alternatively, we have used the JPMorgan Aggregate Index Europe yield spreads and the ICMA European Corporate Bond All Maturities Index yield spreads to define the increasing and the decreasing risk phases. The results were virtually identical.

Table 4.6: **Impact of Increasing and Decreasing Market-Wide Risk**

The table shows the estimated coefficients for the VECM in the error correction form in Equations (4.11) to (4.13). cs^{def} is the credit risk and cs^{liq} the liquidity component in the yield spread of a synthetical 5-year par bond. s^{def} is the credit risk and s^{liq} the liquidity component in the mid premium for a 5-year CDS contract. The dependent variables are the premium changes, the explanatory variables are the error correction terms and the lagged premium changes. ECT 1 refers to the error correction coefficient for the first dependent variable in Equations (4.11) to (4.13) (u_1 for Δcs^{def}, w_1 for Δs^{def}, and y_1 for Δcs^{liq}). ECT 2 refers to the error correction coefficient for the second dependent variable in Equations (4.11) to (4.13) (v_1 for Δcs^{liq}, x_1 for Δs^{liq}, and z_1 for Δs^{liq}). ***, **, and * denote significance at the 1%, 5%, and 10% level. Coefficients are for premia in basis points, the adjusted R^2 are in percentage points.

	Panel A: Increasing Risk Phase								
	Investment Grade			Subinvestment Grade			All		
	$\Delta cs^{\text{def}}/\Delta cs^{\text{liq}}$	$\Delta s^{\text{def}}/\Delta s^{\text{liq}}$	$\Delta cs^{\text{liq}}/\Delta s^{\text{liq}}$	$\Delta cs^{\text{def}}/\Delta cs^{\text{liq}}$	$\Delta s^{\text{def}}/\Delta s^{\text{liq}}$	$\Delta cs^{\text{liq}}/\Delta s^{\text{liq}}$	$\Delta cs^{\text{def}}/\Delta cs^{\text{liq}}$	$\Delta s^{\text{def}}/\Delta s^{\text{liq}}$	$\Delta cs^{\text{liq}}/\Delta s^{\text{liq}}$
Coint. Coef.	-5.56***	-27.16***	-78.45***	-6.80***	12.18***	5.72***	-7.00***	-15.96***	-66.69***
ECT 1	0.00	0.00	0.00	-0.02	-0.03	-0.01**	0.00	-0.02	0.00
Adj. R^2	8.08	7.21	24.42	23.30	17.19	26.50	13.24	12.25	24.56
ECT 2	0.01***	0.01***	0.01***	0.03***	0.05***	-0.08***	0.01***	0.04***	0.01***
Adj. R^2	24.74	47.24	45.88	27.74	43.56	39.24	25.26	41.54	37.56
	Financial			Non-Financial			Sovereign		
Coint. Coef.	-0.08***	-12.93***	85.75**	-7.40***	-15.84***	-36.04***	-	-	-
ECT 1	0.03	0.08	0.00	-0.01	0.02	0.00	-	-	-
Adj. R^2	9.84	23.51	9.80	14.60	12.31	24.87	-	-	-
ECT 2	0.06***	0.02***	0.00	0.01***	0.04***	0.01***	-	-	-
Adj. R^2	18.56	43.56	34.16	25.76	41.63	37.81	-	-	-
	Panel B: Decreasing Risk Phase								
	Investment Grade			Subinvestment Grade			All		
Coint. Coef.	-0.32***	-21.80***	-188.55***	-19.32***	-24.83***	-0.48***	-74.36***	-188.14***	-36.11***
ECT 1	-0.02***	-0.02***	0.00	-0.01*	0.00	0.02**	0.00	0.00	0.00
Adj. R^2	6.57	6.77	16.28	15.79	12.85	21.86	7.06	6.19	17.32
ECT 2	0.01***	0.01***	0.01***	0.02***	0.01***	0.15***	0.01***	0.01***	0.01***
Adj. R^2	17.18	35.91	33.66	26.79	36.00	35.10	19.28	35.29	35.57
	Financial			Non-Financial			Sovereign		
Coint. Coef.	-1.11***	-17.01***	-62.16**	-12.13***	-150.69***	-40.39***	-	-	-
ECT 1	0.02	0.05	0.01*	0.03	0.06	0.01	-	-	-
Adj. R^2	8.80	11.32	23.42	8.51	9.24	23.27	-	-	-
ECT 2	0.03***	0.02***	0.01***	0.02***	0.01***	0.02***	-	-	-
Adj. R^2	24.04	38.79	42.35	23.98	34.44	34.24	-	-	-

themselves move in the same direction. The error correction term which is positive and significant at 0.01 for cs^{liq} in relation to cs^{def}, 0.04 for s^{liq} in relation to s^{def}, and 0.01 for s^{liq} in relation to cs^{liq}, shows that liquidity premia react to the credit risk premia and CDS liquidity to bond liquidity. The reverse impact is not significant both in increasing and decreasing risk phases. Only the adjusted R^2 shows that the link between credit risk and liquidity premia and between the liquidity of the two markets is stronger when credit risk increases.

A similar result holds for the investment grade segment, the largest difference between increasing and decreasing risk phases lies in the weaker explanatory power during the latter. The subinvestment grade segment, on the other hand, exhibits a different behavior during times of increasing and decreasing phases. In the former, the positive cointegration coefficient and the negative error correction terms show that s^{def} and s^{liq} as well as cs^{liq} and s^{liq} move in opposite directions, and this changes in decreasing risk phases.

For financial reference entities, the relation between credit risk and liquidity premia is invariant across the increasing and the decreasing risk phases, they move in the identical direction and liquidity premia adjust to credit risk premia. The relation between the liquidity premia, however, is sensitive to the increasing and the decreasing risk phase. During increasing risk phases, the cointegration coefficient of 85.75 is significant at the 5% significance level, but neither error correction term is significant. This implies that liquidity premia move in opposite directions but that deviations from the equilibrium relation are not smoothed out over time. When overall credit risk decreases, the relation reverts to movements in the same direction, and s^{liq} reacts to cs^{liq}. In the non-financial sector, increasing and decreasing risk phases do not differ systematically either except for the higher adjusted R^2 in the increasing risk phase.

To summarize, the results imply that the relation between the credit risk and liquidity premia and between the liquidity premia across the two markets is mostly unaffected by the increasing and decreasing risk phases. Only for the subinvestment grade segment and for the financial sector, s^{def} and s^{liq} as well as cs^{liq} and s^{liq} exhibit a comovement in decreasing and a countermovement in increasing risk phases.

4.4 Shortcomings of the Base Case Approach

Due to its simple structure, the base case model exhibits some shortcomings in the empirical analysis. First, the time series analysis reveals a dependence of the liquidity premia on the credit risk premia. The analytical pricing equations, however, are determined under the assumption of independence of the intensities from which we determine the premia. This difference points to a misspecification of the model's risk factor structure. A potential secondary effect of the impact of the credit risk on the liquidity premia is the autocorrelation of the latter. Since the liquidity intensity does not allow for this behavior, it is possible that the data-driven correlation of the credit risk and liquidity premia causes the liquidity premia to be autocorrelated. In Section 5.1, we explore the effect of explicitly modelling the correlation between the credit risk and liquidity intensities.

A second shortcoming pertains to the assumption of an identical post-default price for all bonds of a given issuer. This assumption renders the protection buyer's delivery option which is included in a standard CDS contract worthless. As a consequence, CDS premia should on average be higher when the delivery option is included. It is possible that the CDS liquidity premium is mostly positive simply because we do not model the delivery option and that, given an appropriate adjustment, the liquidity premium would decrease. This possibility is explored in Section 5.2.

4.5 Appendix to Chapter 4

4.5.1 Derivation of the Bond Pricing Equation

The crucial assumption in our model is that the value CB^{def} of the default-risky bond is a fraction P of the default-free bond value, CB^{nodef}, and that the illiquid bond's value CB_{illiq} is a fraction L of the perfectly liquid bond's value CB_{liq}:

$$
\begin{aligned}
CB^{\text{def}} &= P \cdot CB^{\text{nodef}}, \\
CB_{\text{illiq}} &= L \cdot CB_{\text{liq}}
\end{aligned}
$$

Naturally, the size of the factors P and L will depend on the period during which the bond is subject to default risk or illiquidity and to the extent of the default risk and illiquidity. A simple interpretation for P is developed by Duffie and Singleton (1997) who view $P(t, t+\Delta_t) = \mathbf{E}_t\left[\exp\left(-\int_t^{t+\Delta_t} \lambda(s)\, ds\right)\right]$ as the conditional survival probability between t and $t+\Delta_t$.

Attaching an interpretation to L is somewhat more difficult. For our purposes, it will suffice to assume that selling an illiquid bond involves random searching costs $(1-L)$ proportional to the bond value. This yields the relation $CB_{\text{illiq}} = L \cdot CB_{\text{liq}}$. We assume that L has a similar exponential-affine representation as P, i.e. $L(t, t+\Delta_t) = \mathbf{E}_t\left[\exp\left(-\int_t^{t+\Delta_t} \gamma(s)\, ds\right)\right]$. The liquidity intensity γ can then be interpreted as the continuous-time rate formulation of the searching costs which arise for each infinitesimally small time interval until the maturity of the bond.

We now show our argument in a three-period model with independent interest rate, default risk, and liquidity factors for notational simplicity. However, this model can easily be extended to dependent risk factors by replacing the expectations operator for D, P, and L with the joint expectations operator. Our goal is then to price a coupon-bearing, default-risky, illiquid bond at time 0 with a fixed coupon c paid at times $\mathbf{t} = (1, 2, 3)$, notional F, and maturity in 3. For ease of exposition, we also assume a recovery rate of 0. This bond will pay the coupon c and the face value F at time 3 if no default has occurred prior to 3. Therefore, the dirty price of the bond at time 3, $CB\,(t=3)$ is equal to the payment $F+c$ since there is no default or liquidity risk as well as no time delay until the payment is made.

If we go back one time step to 2, the value of the bond is equal to the coupon c plus the value of the claim on the payment $F+c$ at 3. The (dirty) price of a perfectly liquid, default-free bond with identical payment structure at 2 is given by

$$\begin{aligned} CB^{\text{nodef}}_{\text{liq}}(t=2,\text{dirty}) &= c + CB^{\text{nodef}}_{\text{liq}}(t=2,\text{clean}) \\ &= c + \mathbf{E}_2\left[CB^{\text{nodef}}_{\text{liq}}(t=3,\text{dirty})\right] \\ &= c + D_{2,3}\cdot CB^{\text{nodef}}_{\text{liq}}(t=3,\text{dirty}) \\ &= c + D_{2,3}\cdot(F+c), \end{aligned}$$

where $D_{2,3}$ is the default-free interest rate discount factor that applies between 2 and 3.

If the claim is subject to default risk between 2 and 3, then the price is equal to

$$\begin{aligned} CB^{\text{def}}_{\text{liq}}(t=2,\text{dirty}) &= c + CB^{\text{def}}_{\text{liq}}(t=2,\text{clean}) \\ &= c + P_{2,3}\cdot CB^{\text{nodef}}_{\text{liq}}(t=2,\text{clean}) \\ &= c + P_{2,3}\cdot\mathbf{E}_2\left[CB^{\text{nodef}}_{\text{liq}}(t=3,\text{dirty})\right] \\ &= c + P_{2,3}\cdot D_{2,3}\cdot CB^{\text{nodef}}_{\text{liq}}(t=3,\text{dirty}) \\ &= c + P_{2,3}\cdot D_{2,3}\cdot(F+c) \\ &= c \;+\; P_{2,3}\cdot D_{2,3}\cdot c \\ &\quad\; + P_{2,3}\cdot D_{2,3}\cdot F. \end{aligned}$$

If, in addition, the claim is also subject to liquidity risk, that is searching, trading, or transaction costs are incurred if the claim on the payment at time 3 is sold prior to time 3, the price is given by

$$\begin{aligned} CB^{\text{def}}_{\text{illiq}}(t=2,\text{dirty}) &= c + CB^{\text{def}}_{\text{illiq}}(t=2,\text{clean}) \\ &= c + L_{2,3}\cdot CB^{\text{def}}_{\text{liq}}(t=2,\text{clean}) \\ &= c + L_{2,3}\cdot P_{2,3}\cdot CB^{\text{nodef}}_{\text{liq}}(t=2,\text{clean}) \\ &= c + L_{2,3}\cdot P_{2,3}\cdot D_{2,3}\cdot CB^{\text{nodef}}_{\text{liq}}(t=3,\text{dirty}) \\ &= c + L_{2,3}\cdot P_{2,3}\cdot D_{2,3}\cdot(F+c) \\ &= c \;+\; L_{2,3}\cdot P_{2,3}\cdot D_{2,3}\cdot c \\ &\quad\; + L_{2,3}\cdot P_{2,3}\cdot D_{2,3}\cdot F. \end{aligned}$$

One time-step earlier at time 1, the price of a claim on the bond's cash flows that is subject to default risk and illiquidity both between 2 and 3 but *not* between 1 and 2 equals

$$\begin{aligned}
CB^{\text{def},t=2}_{\text{illiq},t=2}(t=1,\text{dirty}) &= c + CB^{\text{def},t=2}_{\text{illiq},t=2}(t=1,\text{clean}) \\
&= c + \mathbf{E}_1\left[CB^{\text{def},t=2}_{\text{illiq},t=2}(t=2,\text{dirty})\right] \\
&= c + D_{1,2}\cdot CB^{\text{def}}_{\text{illiq}}(t=2,\text{dirty}) \\
&= c + D_{1,2}\cdot [c + L_{2,3}\cdot P_{2,3}\cdot D_{2,3}\cdot (F+c)] \\
&= c \;+\; D_{1,2}\cdot c \\
&\quad + L_{2,3}\cdot P_{2,3}\cdot D_{1,2}\cdot D_{2,3}\cdot c \\
&\quad + L_{2,3}\cdot P_{2,3}\cdot D_{1,2}\cdot D_{2,3}\cdot F.
\end{aligned}$$

If above claim is also subject to default risk between 1 and 2, the value equals

$$\begin{aligned}
CB^{\text{def},t=1}_{\text{illiq},t=2}(t=1,\text{dirty}) &= c + CB^{\text{def},t=1}_{\text{illiq},t=2}(t=1,\text{clean}) \\
&= c + P_{1,2}\cdot CB^{\text{def},t=2}_{\text{illiq},t=2}(t=1,\text{clean}) \\
&= c + P_{1,2}\cdot D_{1,2}\cdot CB^{\text{def}}_{\text{illiq}}(t=2,\text{dirty}) \\
&= c + P_{1,2}\cdot D_{1,2}\cdot [c + L_{2,3}\cdot P_{2,3}\cdot D_{2,3}\cdot (F+c)] \\
&= c \;+\; P_{1,2}\cdot D_{1,2}\cdot c \\
&\quad + L_{2,3}\cdot P_{1,2}\cdot P_{2,3}\cdot D_{1,2}\cdot D_{2,3}\cdot c \\
&\quad + L_{2,3}\cdot P_{1,2}\cdot P_{2,3}\cdot D_{1,2}\cdot D_{2,3}\cdot F.
\end{aligned}$$

Adding liquidity risk between 1 and 2 gives the value of the default-risky, illiquid bond as

$$\begin{aligned}
CB^{\text{def},t=1}_{\text{illiq},t=1}(t=1) &= c + L_{1,2}\cdot CB^{\text{def},t=1}_{\text{illiq},t=2}(t=1,\text{clean}) \\
&= c + L_{1,2}\cdot P_{1,2}\cdot CB^{\text{def},t=2}_{\text{illiq},t=2}(t=1,\text{clean}) \\
&= c + L_{1,2}\cdot P_{1,2}\cdot D_{1,2}\cdot CB^{\text{def},t=2}_{\text{illiq},t=2}(t=2,\text{dirty}) \\
&= c \;+\; L_{1,2}\cdot P_{1,2}\cdot D_{1,2}\cdot c \\
&\quad + L_{1,2}\cdot L_{2,3}\cdot P_{1,2}\cdot P_{2,3}\cdot D_{1,2}\cdot D_{2,3}\cdot c \\
&\quad + L_{1,2}\cdot L_{2,3}\cdot P_{1,2}\cdot P_{2,3}\cdot D_{1,2}\cdot D_{2,3}\cdot F.
\end{aligned}$$

The choice of the form of the default-free discount factor, the survival probability and the liquidity discount factor yields that $D_{1,2}\cdot D_{2,3} = D_{1,3}$, $P_{1,2}\cdot P_{2,3} = P_{1,3}$, and $L_{1,2}\cdot L_{2,3} = L_{1,3}$.

Therefore, we can write above equation as

$$CB_{\text{illiq},t=1}^{\text{def},t=1}(t=1) = c \cdot \sum_{i=1}^{3} L_{1,i} \cdot P_{1,i} \cdot D_{1,i} + F \cdot L_{1,3} \cdot P_{1,3} \cdot D_{1,3},$$

where $L_{1,1} = P_{1,1} = D_{1,1} = 1$.

Adding a non-zero recovery rate and allowing for pricing at any point-in-time t yields the bond pricing equation.

4.5.2 Analytical Solutions for the Discount Factors in the Base Case

Our model specification results in the following well-known analytical solutions for the credit risk discount factor and the liquidity discount factor $P(t, t_i, \lambda)$ and the liquidity discount factor $L\left(t, t_i, \gamma^l\right)$, $l \in \{b, \text{ask}, \text{bid}\}$:

$$P(t, t_i, \lambda) := a_1(t, t_i) \cdot \exp\left[-\lambda_t \cdot a_2(t, t_i)\right],$$

$$L\left(t, t_i, \gamma^l\right) := a_3^l(t, t_i) \cdot \exp\left[-\gamma_t^l \cdot a_4^l(t, t_i)\right],$$

$$a_1(t, t_i) = \left(\frac{1-\kappa}{1-\kappa \exp\left[\phi\left(t_i - t\right)\right]}\right)^{\frac{2\alpha}{\sigma^2}} \exp\left[\frac{\alpha(\beta+\phi)}{\sigma^2}\left(t_i - t\right)\right],$$

$$a_2(t, t_i) = \frac{\phi-\beta}{\sigma^2} + \frac{2\phi}{\sigma^2\left(\kappa \exp\left[\phi\left(t_i - t\right)\right] - 1\right)},$$

$$a_3^l(t, t_i) = \exp\left[\frac{\eta^{l2}\left(t_i - t\right)^3}{6} + \frac{\mu^l\left(t_i - t\right)^2}{6}\right],$$

$$a_4^l(t, t_i) = t_i - t,$$

$$\phi = \sqrt{2\sigma^2 + \beta^2},$$

$$\kappa = \frac{\beta+\phi}{\beta-\phi}.$$

Chapter 5

Model Extensions

In this chapter, we describe two extensions to the basic reduced-form model developed in Section 4. The first extension concerns an explicit modelling of the correlation structure of the credit risk and the liquidity intensity. The second extension includes the cheapest-to-deliver option into our valuation framework.

5.1 Explicit Modelling of the Correlation Structure

The VAR and the VECM analysis of the estimated credit risk and liquidity premia in Section 4.2 show that these two premia are cointegrated. This relation is unlikely to be inherent to our model since the simulation study in Section 4.1.4 did not result in credit risk and liquidity premia which were cointegrated with one another. In this section, we introduce a specific structure for the cross-dependence of the credit risk and liquidity premia. In detail, we assume that the credit risk and the liquidity intensity are affected by the same latent factors but to a degree that can differ. We then estimate the strength of the impact of these latent factors and compute a specific correlation-induced premium in bond yield spreads and mid CDS premia. Our results imply that the correlation premia were mostly subsumed in the liquidity premia in the previous section. Regarding the premium size, the credit-risk independent liquidity component is about 6 times larger than the correlation component for bonds and 5 times larger for CDS.

5.1.1 Extended Model with Correlated Intensities

Specification of Intensity Processes

Instead of directly modelling the default and liquidity intensities, we now assume that they are determined by 4 independent latent risk factors x, y^b, y^{ask}, and y^{bid}. The default-free instantaneous interest rate r constitutes the last risk factor, and we assume that it evolves independently of the other factors and that the time-t price of the default-free liquidity numéraire is given by $D(t,\tau) = E_t\left[\tilde{D}(t,\tau)\right]$.

We model x as a square root process, and y^b, y^{ask}, and y^{bid} as arithmetic Brownian motions. The default intensity λ and the liquidity intensities for the bond (γ^b), the CDS ask premium (γ^{ask}), and the CDS bid premium (γ^{bid}) are determined by the following model:

$$\begin{aligned}
\begin{pmatrix} d\lambda(t) \\ d\gamma^b(t) \\ d\gamma^{\text{ask}}(t) \\ d\gamma^{\text{bid}}(t) \end{pmatrix} &= \begin{pmatrix} 1 & g_b & g_{\text{ask}} & g_{\text{bid}} \\ f_b & 1 & \omega_{b,\text{ask}} & \omega_{b,\text{bid}} \\ f_{\text{ask}} & \omega_{b,\text{ask}} & 1 & \omega_{\text{ask,bid}} \\ f_{\text{bid}} & \omega_{b,\text{bid}} & \omega_{\text{ask,bid}} & 1 \end{pmatrix} \begin{pmatrix} dx(t) \\ dy^b(t) \\ dy^{\text{ask}}(t) \\ dy^{\text{bid}}(t) \end{pmatrix} \\
&= \begin{pmatrix} 1 & g_b & g_{\text{ask}} & g_{\text{bid}} \\ f_b & 1 & \omega_{b,\text{ask}} & \omega_{b,\text{bid}} \\ f_{\text{ask}} & \omega_{b,\text{ask}} & 1 & \omega_{\text{ask,bid}} \\ f_{\text{bid}} & \omega_{b,\text{bid}} & \omega_{\text{ask,bid}} & 1 \end{pmatrix} \left(\begin{pmatrix} \alpha - \beta x(t) \\ \mu^b \\ \mu^{\text{ask}} \\ \mu^{\text{bid}} \end{pmatrix} dt + \begin{pmatrix} \sigma\sqrt{x(t)}dW_x(t) \\ \eta^b dW_{y^b}(t) \\ \eta^{\text{ask}} dW_{y^{\text{ask}}}(t) \\ \eta^{\text{bid}} dW_{y^{\text{bid}}}(t) \end{pmatrix} \right),
\end{aligned} \tag{5.1}$$

with parameters α, β, μ^l, f_l, g_l, $\sigma > 0$, and $\eta^l > 0$. W_x and W_{y^l} are independent Brownian motions, $l \in \{b, \text{ask}, \text{bid}\}$. The matrix of the factor sensitivities is assumed to be of full rank in order to ensure parameter identification.

f_l and g_l determine the correlation between λ and γ^l. If both coefficients equal 0, credit risk and liquidity are uncorrelated. If $f_l \neq 0$, credit risk directly affects liquidity, and the reverse applies if $g_l \neq 0$. There are two links that determine the correlation between the liquidity intensities. First, there can be an indirect link through the impact of x via the factor sensitivity f_l. Second, the coefficients $\omega_{l,k}$ imply a direct link between the liquidity intensities through the latent risk factors y_l and y_k. Economically speaking, a correlation between the liquidity intensities which is not directly due to x allows us to determine the channel through which pure liquidity effects are transmitted from one market into the other.

A potential relation between the CDS ask and bid liquidity intensities as measured by $\omega_{\text{ask,bid}}$ can be attributed to a similar inventory argument as the one given in Section 4.1.3. If a trader enters into transactions on the ask side, thus taking on credit risk, she is likely to adjust the ask and bid premia accordingly in order to retain a balanced inventory, and vice versa. The bond liquidity intensity and the CDS ask and bid liquidity intensities, on the other hand, can be interdependent due to non-zero values of $\omega_{b,\text{ask}}$ and $\omega_{b,\text{bid}}$ because long (short) credit risk positions can be incurred either by buying (short-selling) the bond or by selling (buying) credit protection in the CDS contract on the ask (bid) side. A liquidity-driven price or premium change in one market presumably leads to corresponding changes in the other market: If the bond price falls due to a lower liquidity, buying credit risk becomes cheaper which is likely to drive down the CDS ask premium, and vice versa. The reverse effect applies for the CDS bid premium. Due to the symmetric nature of these direct liquidity spillover effects, we choose a symmetric structure of the factor sensitivity matrix with regard to the $\omega_{l,k}$-coefficients.

Due to the independence of x and y^l, the expected values of $\tilde{P}(t,\tau_i)\cdot\tilde{L}^l(t,\tau_i)$ and $\tilde{P}(t,\tau_i)\cdot\tilde{L}^l(t,\tau_{i+1})$ in Equations (4.1), (4.4), and (4.5) can be represented by analytical functions which are linear-exponential in x and y^l, $l \in \{b, \text{ask}, \text{bid}\}$. We denote these functions by $P^l(t,\tau_i,x;f)$ and $L^l(t,\tau,y;g)$, respectively $P^l(t,\tau_i,\tau_{i+1},x;f)$ and $L^l(t,\tau_i,\tau_{i+1},y;g)$, and derive their form in Appendix 5.3.1.

Substituting these functions in Equations (4.1), (4.4), and (4.5) yields the analytical solutions $CB(t) = CB(t,x,y;f,g)$ for the bond price, $s^{\text{ask}} = s^{\text{ask}}(t,x,y;f,g)$ for the CDS ask premium, and $s^{\text{bid}} = s^{\text{bid}}(t,x,y;f,g)$ for the CDS bid premium, where $y = \left(y^b, y^{\text{ask}}, y^{\text{bid}}\right)$, $f = (f_b, f_{\text{ask}}, f_{\text{bid}})$, and $g = (g_b, g_{\text{ask}}, g_{\text{bid}})$.

Measures for Credit Risk, Liquidity, and Correlation Premia

In addition to the credit risk and liquidity premia, we now additionally determine a correlation-induced component of the observed premia. The rationale for this decomposition is again most easily seen with regard to the bond. As in Section 4.1.3, the pure credit risk premium equals the yield spread that would apply if credit risk were the only priced factor (again excepting r). In this case, the latent factor y^b is identical to 0, all factor sensitivities g become irrelevant, and the default intensity λ and the latent factor x coincide.

The pure liquidity premium equals the yield spread that would apply if liquidity were the only priced factor, i.e. x is identical to 0, and the latent factor y^b and the liquidity intensity γ^b coincide.

The correlation premium then measures the part of the yield spread that is incurred because the default intensity λ and the liquidity intensity γ^b do not evolve independently. If, as our empirical analysis shows, x affects γ^b but λ is mostly independent of y, the liquidity discount may increase not because y changes but because liquidity declines due to the impact of x.

Consequently, we determine the pure credit risk premia cs^{def} and s^{def} by setting y and the factor sensitivities equal to 0, i.e. from $CB(t,x,0;0,0)$ and $s^{\text{ask}}(t,x,0;0,0) = s^{\text{bid}}(t,x,0;0,0)$. The pure liquidity premia cs^{liq} and s^{liq} follow as the premium increase above cs^{def} and s^{def} if the latent factor y is included but the factor sensitivities remain at 0. The correlation premia cs^{cor} and s^{cor} then arise naturally as the difference between the total yield spread, respectively the mid CDS premium, including the non-zero factor sensitivities f and g, and the sum of the credit risk and the correlation premia.

5.1.2 Empirical Analysis including Correlation Premia

Calibration Procedure

We calibrate the model developed in Section 5.1.1 to the identical data as before, i.e. we estimate for each firm the 9 parameters $\left(\alpha, \beta, \sigma, \mu^b, \eta^b, \mu^{\text{ask}}, \eta^{\text{ask}}, \mu^{\text{bid}}, \eta^{\text{bid}}\right)$, the 9 factor sensitivities $f = (f_b, f_{\text{ask}}, f_{\text{bid}})$, $g = (g_b, g_{\text{ask}}, g_{\text{bid}})$, and $\omega = (\omega_{b,\text{ask}}, \omega_{b,\text{bid}}, \omega_{\text{ask,bid}})$, and for each date t the current value of the intensities $\left(\lambda, \gamma^b, \gamma^{\text{ask}}, \gamma^{\text{bid}}\right)(t)$, $t = 1, \ldots, 1548$.

Compared to the calibration described in Section 4.2.1, the procedure now contains an additional step. In the first step, we initiate a base grid for the process parameters $\left(\alpha, \beta, \sigma, \mu^b, \eta^b, \mu^{\text{ask}}, \eta^{\text{ask}}, \mu^{\text{bid}}, \eta^{\text{bid}}\right)$, and set all factor sensitivities f, g, and ω to 0. This corresponds to the case of uncorrelated intensities. In the second step, we then determine the values $\left(\lambda, \gamma^b, \gamma^{\text{ask}}, \gamma^{\text{bid}}\right)(t)$, $t = 1, \ldots, 1548$, which simultaneously minimize the sum of squared errors between the time series of the observed and the theoretical CDS premia and bond yield spreads. As before, we match all values at the basis point level. Estimation is conditional on the presumed process parameters and, additionally, the factor sensitivities. In the third step, we determine the factor sensitivities f, g, and ω which are implied by the estimated time series of the intensities using a discrete version of equation (5.1). We iterate between the second and the third step using the updated factor sensitivities and intensity values until we obtain no further absolute change larger than 0.01 in the factor sensitivities in each of two subsequent steps.[40] We follow this procedure in each grid point and determine the point associated with the smallest sum of squared errors. Around this point, we initiate a finer local grid as in the first step and repeat the second and the third step in each point of the new grid. We stop this three-step procedure when the minimal sum of squared errors twice decreases by less than 1% on two subsequent grid specifications. In order to control for local optima, we repeat the analysis for the points in the base grid associated with the second and third smallest sum of squared errors.

Factor Sensitivities

We first discuss the coefficient estimates for the factor matrix in equation (5.1). This allows us to demonstrate how credit risk affects liquidity, how liquidity affects credit risk, and how the liquidity of the bond and the CDS market affect one another.

[40] Convergence is usually achieved in less than 10 iteration steps.

Table 5.1: **Factor Sensitivities**

The table presents the estimates for the factor sensitivities. f_b, f_{ask}, and f_{bid} measure the impact of the latent credit risk factor x on the bond, CDS ask, and CDS bid liquidity intensities γ^b, γ^{ask}, and γ^{bid}. g_b, g_{ask}, and g_{bid} measure the impact of the latent bond, CDS ask, and CDS bid liquidity factors y^b, y^{ask}, and y^{bid} on the default intensity λ. $\omega_{\text{b,ask}}$, $\omega_{\text{b,bid}}$, and $\omega_{\text{ask,bid}}$ measure the cross-impact of the latent bond, CDS ask, and CDS bid liquidity factors y^b, y^{ask}, and y^{bid} on the bond, CDS ask, and CDS bid liquidity intensities γ^b, γ^{ask}, and γ^{bid}. The first row of each panel gives the number of reference entities for which the sensitivity estimate was significantly different from 0, the second row the number of estimates significantly larger than 0, the third row the number of estimates significantly smaller than 0. The fourth and fifth row present the mean estimate and the standard deviation. ***, **, and * denote significance at the 1%, 5%, and 10% level for a standard t-test across firms.

	f_b	f_{ask}	f_{bid}	g_b	g_{ask}	g_{bid}	$\omega_{\text{b,ask}}$	$\omega_{\text{b,bid}}$	$\omega_{\text{ask,bid}}$
Panel A: All									
# Firms	156	148	76	1	3	2	134	95	139
# > 0	147	147	33	1	2	1	6	89	16
# < 0	9	1	43	-	1	1	128	6	123
Mean	0.17***	0.38***	-0.07***	0.01	0.01	0.00	-0.01***	0.01***	-0.39***
Std. Dev.	0.02	0.03	0.02	-	0.01	0.00	0.02	0.02	0.04
Panel B: Financial Sector									
# Firms	48	44	26	-	-	-	45	36	47
# > 0	46	44	10	-	-	-	1	34	5
# < 0	2	-	16	-	-	-	44	2	42
Mean	0.08***	0.31***	-0.13***	-	-	-	-0.02***	0.02***	-0.47***
Std. Dev.	0.02	0.03	0.03	-	-	-	0.02	0.02	0.03
Panel C: Non-Financial Corporate Sector									
# Firms	92	94	40	1	3	1	78	49	84
# > 0	92	94	19	1	2	-	4	46	10
# < 0	-	-	21	-	1	1	74	3	74
Mean	0.20***	0.43***	-0.06***	0.00	0.01	-0.00	-0.02***	0.01***	-0.30***
Std. Dev.	0.02	0.03	0.03	-	0.01	-	0.01	0.01	0.04
Panel D: Sovereign Sector									
# Firms	16	10	10	-	-	-	11	10	8
# > 0	9	9	4	-	-	-	1	9	1
# < 0	7	1	6	-	-	-	10	1	7
Mean	-0.10***	0.09***	0.01***	-	-	-	-0.06***	0.09***	-0.49***
Std. Dev.	0.04	0.04	0.03	-	-	-	0.03	0.02	0.05
Panel E: Investment Grade									
# Firms	146	140	71	1	3	1	123	91	127
# > 0	137	140	33	1	2	-	2	86	14
# < 0	9	-	38	-	1	1	121	5	113
Mean	0.10***	0.36***	-0.07***	0.01	0.01	-0.00	-0.02***	0.01***	-0.38***
Std. Dev.	0.02	0.03	0.03	-	0.01	-	0.02	0.02	0.04
Panel F: Subinvestment Grade									
# Firms	10	8	5	-	-	1	11	4	12
# > 0	10	7	-	-	-	1	4	3	2
# < 0	-	1	5	-	-	-	7	1	10
Mean	0.20***	0.46***	-0.06***	-	-	0.00	-0.06***	0.03***	-0.22***
Std. Dev.	0.03	0.03	0.02	-	-	-	0.02	0.01	0.03

As the estimates for the factor sensitivities for the entire sample in Panel A of Table 5.1 show, credit risk has an impact on both the bond liquidity intensity and the CDS liquidity intensities, but not vice versa. The latent factor x affects the bond liquidity intensity γ^b through f_b significantly for 156 out of 171 firms. 147 of these estimates for f_b are positive, and the positive mean factor sensitivity estimate of 0.17 suggests that the liquidity of the bond market dries up as credit risk increases. We quantify the impact on the premia components in more detail below. The impact of x on the CDS ask intensity γ^{ask}, measured by f_{ask}, is significant for 148 and positive for 147 firms with a mean estimate of 0.38. The CDS bid intensity γ^{bid}, in turn, is significantly affected by x for only 76 firms with a negative estimate for f_{bid} for 43 firms. The mean estimate of -0.07 is, however, significantly different from 0 at the 1% level and implies that the CDS bid quotes decrease disproportionately when credit risk increases.

The impact of the latent factors y^b, y^{ask}, and y^{bid} on the default intensity λ, on the other hand, is almost negligible. In Panel A of Table 5.1, we obtain only one significant coefficient estimate for g_b, three for g_{ask} – out of which two are positive – and two for g_{bid} with a positive and a negative one. These results illustrate that credit risk increases illiquidity in the bond market but not vice versa. We can also conclude that higher credit risk leads to a higher distance between the pure credit risk CDS premium and the ask premium. CDS bid premia, on the other hand, are not as unilaterally affected.

The liquidity spillover between the bond and the CDS market can be inferred from the estimates of $\omega_{\text{b,ask}}$ and $\omega_{\text{b,bid}}$ in Panel A of Table 5.1. The coefficient estimate for $\omega_{\text{b,ask}}$ is significant for 134 firms and negative for 128. The mean value of -0.01 implies that increasing illiquidity in the bond market results in lower CDS ask premia. This is consistent with a substitution effect in the bond and the CDS market. A decreasing liquidity in the bond market implies that buying credit risk through the bond becomes cheaper due to decreasing bond prices and increasing bond spreads, and thus more attractive. If a trader intends to take on credit risk synthetically by selling protection in a CDS contract, she accordingly decreases her ask quote compared to the case with high bond market liquidity.

The estimate for the CDS bid liquidity coefficient $\omega_{\text{b,bid}}$ which is significant for 95 firms and positive for 89 with a mean value of 0.01 for the full sample is also consistent with the substitution of bonds and CDS. Lower bond prices due to decreasing liquidity which correspond to higher bond spreads make shorting credit risk via the bond more costly and thus lead to higher bid quotes in the CDS market.

The estimate for $\omega_{\text{ask,bid}}$ is significant for 139 firms and negative for 123 firms. The negative mean of -0.39 implies that the bid and ask quote tend to move in opposite directions. This finding agrees with an overall increasing liquidity in the CDS market with decreasing bid-ask spreads as the market matures.

With regard to the different industry sectors in Panel B to D and the investment grade and subinvestment grade rating classes in Panel E and F of Table 5.1, we mostly observe a similar results as for the entire sample. Only the absolute values of the coefficient estimates for f_b, f_{ask}, and f_{bid} tend to be smaller for the financial and the investment grade sector. This points to a weaker relation between credit risk and liquidity.

Interestingly, we obtain 7 negative estimates for f_b and a mean of -0.10 for the sovereign sector, and two negative estimates for the financial sector. The negative estimates are obtained for AAA, respectively AA, rated reference entities which suggests that the liquidity of the very highly rated debt issues increases for higher credit risk. This finding points at a flight-to-quality effect.

The link between the liquidity of the bond and the CDS market, as shown by the coefficient estimates for $\omega_{b,\text{ask}}$, $\omega_{b,\text{bid}}$, and $\omega_{\text{ask,bid}}$ seems to be stronger for the sovereign sector as shown by the higher absolute value of the coefficient estimates.

Overall, the estimates of the factor sensitivities suggest that credit risk mostly affects liquidity and not vice versa. A higher latent credit risk factor x directly translates into a higher illiquidity in the bond market and a higher demand pressure in the CDS market which leads to higher ask premia. CDS bid premia, on the other hand, are not as symmetrically affected. The coefficient estimates for the cross-market impact of the latent liquidity factors are consistent with a substitution between bonds and CDS, and the relation between the CDS ask and bid liquidity imply that ask and bid premia move towards each other.

Credit Risk, Liquidity, and Correlation Premia: Cross-Sectional Results

In Table 5.2, we present the premia decomposition we obtain using the model that explicitly accounts for the factor sensitivities.

A comparison of Table 5.2 with Table 4.1 shows that the average estimates of cs^{def} and s^{def} are almost identical. The largest difference occurs for the A rating class where we obtain an average pure credit risk premium that falls below the original estimate by 3.75 bp for cs^{def} and by 3.89 bp for s^{def}. With regard to the different industry sectors, the change is largest for the sovereign sector where we obtain a decrease of 0.98 bp for cs^{def} and of 0.55 bp for

Table 5.2: **Estimated Credit Risk, Liquidity, and Correlation Premia**

The table shows the mean, standard deviation, minimum, and maximum for the credit risk, liquidity, and correlation premia components for each industry sector and each rating class. cs^{def} is the pure credit risk, cs^{liq} the pure liquidity component, and cs^{cor} the correlation component in the yield spread of a synthetical 5-year par bond. s^{def} is the pure credit risk, s^{liq} the pure liquidity, and s^{cor} the correlation component in the mid premium for a 5-year CDS contract. The mean, standard deviation, minimum, and maximum are determined both over time and across observations within the industry sector, respectively rating class, on each date. All values are in basis points.

	Sectors			Rating Classes							
	Fin.	Non-Fin.	Sov.	AAA	AA	A	BBB	BB	B	CCC	All
cs^{def}	17.75	68.11	37.45	6.11	13.05	28.46	65.18	266.54	393.04	276.62	52.08
Std. Dev.(cs^{def})	14.83	95.00	86.95	4.46	10.60	28.35	64.67	237.99	163.16	33.71	83.46
min(cs^{def})	1.59	2.63	0.96	0.96	1.38	2.96	2.96	33.86	32.60	113.59	0.96
max(cs^{def})	306.54	1,806.87	814.95	52.91	260.85	352.11	1,214.39	1,806.87	1,126.95	386.33	1,806.87
cs^{liq}	10.62	28.85	1.10	0.59	13.16	24.76	33.81	23.65	7.41	7.82	22.49
Std. Dev.(cs^{liq})	3.12	30.12	43.95	3.12	30.12	43.95	55.77	54.77	58.19	3.48	46.20
min(cs^{liq})	0.55	3.09	-0.48	-0.48	-0.33	1.02	3.09	1.51	1.48	1.50	-0.48
max(cs^{liq})	31.78	567.08	495.96	30.79	567.08	495.96	349.34	351.59	196.79	10.44	567.08
cs^{cor}	1.67	4.82	2.05	-0.02	0.25	2.93	8.25	16.89	17.51	1.96	3.94
Std. Dev.(cs^{cor})	2.43	13.76	13.27	0.03	4.92	6.44	16.01	44.38	14.17	1.98	12.04
min(cs^{cor})	0.06	0.71	-2.70	-2.70	-0.61	1.01	1.08	1.16	0.72	0.38	-2.70
max(cs^{cor})	60.68	275.96	102.30	0.54	97.21	120.79	251.51	275.96	133.98	5.09	275.96
s^{def}	17.98	68.89	37.91	6.18	13.45	28.98	66.33	267.52	394.97	277.83	52.36
Std. Dev.(s^{def})	13.86	95.38	87.18	4.42	12.88	28.35	65.59	242.82	167.45	34.96	82.96
min(s^{def})	1.62	4.03	0.96	0.96	4.24	4.65	4.58	34.92	33.97	115.92	0.96
max(s^{def})	308.22	1,948.43	819.74	52.21	279.05	356.83	1,281.93	1,948.43	1,175.58	397.29	1,948.43
s^{liq}	1.01	1.53	1.72	0.12	0.67	4.79	1.82	3.88	15.03	6.28	1.55
Std. Dev.(s^{liq})	6.98	13.73	17.69	0.30	6.47	2.32	8.23	40.46	43.38	12.05	10.74
min(s^{liq})	-14.23	-153.82	-54.01	-0.61	0.48	0.92	2.82	-153.82	-152.59	-6.86	-153.82
max(s^{liq})	47.02	352.84	140.95	1.69	3.43	8.97	27.66	123.06	194.25	96.38	194.25
s^{cor}	-0.41	0.87	1.38	-0.14	0.46	0.19	0.45	5.41	8.48	5.57	0.41
Std. Dev.(s^{cor})	9.27	3.66	3.62	0.34	8.83	0.49	1.49	10.53	7.96	1.30	4.91
min(s^{cor})	-12.50	-8.17	-1.84	-1.26	-0.89	-12.50	-1.24	-3.19	-1.42	-1.38	-12.50
max(s^{cor})	5.78	117.52	43.77	0.49	4.86	5.35	51.83	98.85	43.77	18.17	98.85

s^{def}. Across all observations, the estimate of cs^{def} decreases by 0.13 bp to 52.08 bp and that of s^{def} by 0.35 bp to 52.36 bp.

The small change in the credit risk premia implies that the correlation premia were subsumed in the liquidity premia in Table 4.1. On average, cs^{liq} decreases by 3.77 bp. The maximal change for the bond pure liquidity premium occurs for the BBB, BB, and B rating class. In particular, cs^{liq} is now largest for the BBB rating class at 33.81 bp. Regarding the different industry sectors, the highest absolute change is given in the non-financial corporate sector, but on an absolute level, cs^{liq} decreases to 51% of its original value for the sovereign sector which signifies a stronger decrease than the 14% decrease for both the financial and the non-financial corporate sector.

The average bond correlation premium cs^{cor} of 3.94 bp approximately agrees with the joint decrease of cs^{def} and cs^{liq} of 3.90 bp. The average of cs^{cor} increases monotonously across the different rating classes up to the B rating class which agrees with the increasing pure credit risk premia. For the AAA rating class, we obtain a negative mean which is due to the negative factor sensitivities we discussed above. Relative to cs^{def}, the mean of cs^{cor} is highest for the BBB rating class at 13% with values between between -0.03% and 10% for the remaining investment grade and 1% to 6% for the subinvestment grade rating classes. The financial sector has the highest percentage part of correlation premia with regard to the pure credit risk premia at 9%. This, however, is not necessarily a sign of a higher correlation between credit risk and liquidity since the overall pure liquidity premia are also highest for this sector. With regard to these, cs^{cor} amounts to 16% for the financial sector, 17% for the non-financial corporate sector, and 186% for the sovereign sector. This high percentage is especially noteworthy since for 7 sovereign reference entities credit risk and liquidity are, in fact, negatively correlated.

For the total yield spread, we find that cs^{def} attributes 66%, cs^{liq} 29%, and cs^{cor} 5%. Recall that in Table 4.1, cs^{def} amounted to 67%, suggesting that almost the entire correlation premium was subsumed in the liquidity premium.

For CDS premia, the pure liquidity premium s^{liq} remains positive with an average of 1.55 bp which suggests that transactions in the CDS market are, as before, mostly ask-initiated. In addition, the minimal pure liquidity premia for the AA to BBB rating class become positive, suggesting that the protection sellers dominate in each phase. In contrast to our earlier result, however, s^{liq} in Table 5.2 is now on average maximal for the A rating class in the investment grade segment with a mean of 4.79 bp, suggesting that the asymmetry is largest in this case. The subinvestment grade segment becomes more balanced if we exclude the effect of credit risk. In particular, the minimal and maximal values of s^{liq} decrease on an absolute level. Relative to the pure credit risk premia, s^{liq} lies at 17% for the A rating class and between 1% and 5% for the remaining classes.

Across the different industry sectors, we find that for financial reference entities s^{liq} actually increases from an average of 0.71 bp in Table 4.1 to 1.01 bp in Table 5.2 with a negative average of s^{cor} at -0.41 bp. The economic interpretation of this finding is as follows. On average, protection sellers in the CDS market set disproportionately higher ask quotes for financial reference entities as well as for non-financial reference entities. If credit risk increases, however, selling protection becomes less profitable, decreasing the supply relative to the demand and leading to a negative average of s^{cor}. The negative value is due to the fact that the correlation of both the bid and the ask liquidity with the default intensity are positive. Therefore, the CDS bid premium can at times increase more strongly than the ask premium. A similar result is obtained for the AAA rating class.

On average, the correlation premium s^{cor} is rather small with a mean value of 0.41 bp. For the investment grade segment, the mean values lie consistently below 0.50 bp and grow in excess of a factor of 10 for the subinvestment grade segment. Relative to the pure credit risk premia, they amount to 2%, but relative to the pure liquidity premia, they exceed 50%. We conclude that the pure liquidity premia in the subinvestment grade segment are relatively low and that changes in credit risk have a strong impact on the correlation premium because the changes are reflected differently in the bid and the ask premium. Concerning the decomposition of the total CDS premia, we observe that on average 96% of the total premium is due to s^{def}, 3% to s^{liq}, and 1% to s^{cor}.

Credit Risk, Liquidity, and Correlation Premia: Time Series Results

In order to explore the dynamic link between the premia, we again perform a Johansen VAR analysis. In contrast to our earlier analysis, the independence of the latent risk factors makes an analysis of the relation of the pure credit risk premia cs^{def} and s^{def} with the pure liquidity premia cs^{liq} and s^{liq} redundant.[41] Therefore, we analyze the pairwise relation between the pure credit risk premia, the pure liquidity premia, and the correlation premia of the two markets. This changes our earlier focus from the relation between credit risk and liquidity premia to the relation between the bond and the CDS market.

As in Section 4.2.3, we first test for each reference entity whether the levels and first differences of the pure credit risk, the pure liquidity, and the correlation premia are stationary

[41] The Johansen cointegration analysis which we perform as in Section 4.2.3 reveals that the pure credit risk and pure liquidity premia remain cointegrated for only 7 out of 171 reference entities.

and whether they are cointegrated. The VAR specification is as follows:

$$\begin{aligned}
\Delta cs_t^{\text{def}} &= \sum_{j=1}^{5} u_{1_j} \Delta cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} u_{2_j} cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} u_{3_j} \Delta s_{t-j}^{\text{def}} + \sum_{j=1}^{5} u_{4_j} s_{t-j}^{\text{def}} + \varepsilon_{1,t}, \\
\Delta s_t^{\text{def}} &= \sum_{j=1}^{5} v_{1_j} \Delta cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} v_{2_j} cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} v_{3_j} \Delta s_{t-j}^{\text{def}} + \sum_{j=1}^{5} v_{4_j} s_{t-j}^{\text{def}} + \varepsilon_{2,t},
\end{aligned} \tag{5.2}$$

$$\begin{aligned}
\Delta cs_t^{\text{liq}} &= \sum_{j=1}^{5} w_{1_j} \Delta cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} w_{2_j} cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} w_{3_j} \Delta s_{t-j}^{\text{liq}} + \sum_{j=1}^{5} w_{4_j} s_{t-j}^{\text{liq}} + \varepsilon_{3,t}, \\
\Delta s_t^{\text{liq}} &= \sum_{j=1}^{5} x_{1_j} \Delta cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} x_{2_j} cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} x_{3_j} \Delta s_{t-j}^{\text{liq}} + \sum_{j=1}^{5} x_{4_j} s_{t-j}^{\text{liq}} + \varepsilon_{4,t},
\end{aligned} \tag{5.3}$$

$$\begin{aligned}
\Delta cs_t^{\text{cor}} &= \sum_{j=1}^{5} y_{1_j} \Delta cs_{t-j}^{\text{cor}} + \sum_{j=1}^{5} y_{2_j} cs_{t-j}^{\text{cor}} + \sum_{j=1}^{5} y_{3_j} \Delta s_{t-j}^{\text{cor}} + \sum_{j=1}^{5} y_{4_j} s_{t-j}^{\text{cor}} + \varepsilon_{5,t}, \\
\Delta s_t^{\text{cor}} &= \sum_{j=1}^{5} z_{1_j} \Delta cs_{t-j}^{\text{cor}} + \sum_{j=1}^{5} z_{2_j} cs_{t-j}^{\text{cor}} + \sum_{j=1}^{5} z_{3_j} \Delta s_{t-j}^{\text{cor}} + \sum_{j=1}^{5} z_{4_j} s_{t-j}^{\text{cor}} + \varepsilon_{6,t}.
\end{aligned} \tag{5.4}$$

We demand that the parameters are identical for all, respectively all investment grade or subinvestment grade reference entities. As before, time lags up to degree 5 are considered to capture a weekly interval, and the resulting parameter estimates are transformed into a single estimate. We subsequently test whether the residuals are stationary.

The results of the estimation are displayed in Table 5.3. We first discuss the results for the entire sample, then the results for the investment and subinvestment grade segment. The industry sectors are not discussed separately for brevity.

As the coefficient estimates in Panel A of Table 5.3 show, Δcs^{def} and Δs^{def} are negatively autocorrelated and negatively correlated with their lagged level, and the coefficients estimates are absolutely larger for Δcs^{def}. The sensitivity of Δcs^{def} to $\Delta s_{-1}^{\text{def}}$ is also higher, and we attribute both these effects to the impact of the bond liquidity on s^{def}. The adjusted R^2 of 9.95% for Δcs^{def} and 9.02% for Δs^{def} is low, suggesting that the autoregressive time series relation in addition to the cross-market impact only explain a low amount of variation.

The changes of the bond and CDS pure liquidity premia Δcs^{liq} and Δs^{liq} are also negatively autocorrelated and negatively correlated with their lagged level, and the relation

Table 5.3: **The Dynamic Relationship of Credit Risk, Liquidity, and Correlation Premia**

The table shows the estimated coefficients for the Johansen VAR model in Equations (5.2) to (5.4). cs^{def} is the pure credit risk, cs^{liq} the pure liquidity, and cs^{cor} the correlation component in the yield spread of a synthetical 5-year par bond. s^{def} is the pure credit risk, s^{liq} the pure liquidity, and s^{cor} the correlation component in the mid premium for a 5-year CDS contract. The dependent variables are the premium changes, the explanatory variables are the lagged premium changes and the lagged premium levels. The top row of each panel displays the number of reference entities for which 1) the augmented Dickey-Fuller test cannot reject a unit root in the premia time series at the 10% significance level, 2) the augmented Dickey-Fuller test can reject a unit root in the first differences at the 10% level, 3) the Johansen test cannot reject cointegration of the time series at the 10% level, 4) the augmented Dickey-Fuller can reject a unit root in the residuals at the 10% level. ***, **, and * denote significance at the 1%, 5%, and 10% level. Coefficients are for premia in basis points, the adjusted R^2 are in percentage points.

	Δcs^{def}	Δs^{def}	Δcs^{liq}	Δs^{liq}	Δcs^{cor}	Δs^{cor}
Panel A: All						
#Firms	156		158		148	
Δcs_{-1}	-0.96***	0.34***	-0.44***	-0.02***	-0.30***	0.01**
Δs_{-1}	0.71***	-0.60***	-0.01	-0.58***	0.13***	-0.03***
cs_{-1}	-0.06***	0.03***	-0.04***	0.00	-0.01***	0.00**
s_{-1}	0.05***	-0.03***	0.01	-0.31***	0.00	-0.02***
Adj. R^2	9.95	9.02	19.18	27.00	8.81	0.97
Panel B: Investment Grade						
#Firms	148		159		142	
Δcs_{-1}	-0.41***	0.18***	-0.45***	-0.01*	-0.32***	0.01*
Δs_{-1}	0.14***	-0.07***	-0.02	-0.53***	0.15***	-0.02***
cs_{-1}	-0.02***	0.00	-0.03***	0.00	-0.01***	0.00
s_{-1}	0.00	-0.01***	-0.01	-0.14***	0.00*	-0.02***
Adj. R^2	7.67	6.80	19.17	25.35	9.28	1.00
Panel C: Subinvestment Grade						
#Firms	8		9		6	
Δcs_{-1}	-2.54***	1.79***	-0.46***	-0.08***	-0.30***	0.03***
Δs_{-1}	2.28***	-1.51***	-0.01*	-0.63***	0.51***	-0.17***
cs_{-1}	-2.29***	1.86***	-0.08***	-0.02***	-0.01***	0.01***
s_{-1}	2.32***	-1.88***	0.03	-0.45***	0.00	-0.03***
Adj. R^2	18.62	16.55	19.95	30.87	4.95	2.06

is stronger for the CDS premia with a coefficient estimate of -0.58 for $\Delta s_{-1}^{\text{liq}}$ and -0.31 for s_{-1}^{liq}. This suggests that the pure liquidity premia's autocorrelation is not due to the impact of the factor x but a property of the data set.[42] In addition, Δs^{liq} reacts significantly to $\Delta cs_{-1}^{\text{liq}}$, and the negative sign of the coefficient estimate suggests that liquidity moves in opposite directions. Even though the estimate is small at -0.02, it is economically significant since cs^{liq} is on average much higher than s^{liq}.

The negative estimate for the relation between Δs^{liq} and $\Delta cs_{-1}^{\text{liq}}$ shows that the positive comovement of the liquidity premia in the base case model in Section 4.2.3 was in fact due to the impact of credit risk on the liquidity premia.

Reversely, the CDS pure liquidity premia do not seem to affect the bond pure liquidity premia. The adjusted R^2 is about twice as high for Δcs^{liq} at 19.18% and three times as high for Δs^{liq} with 27.00% than for Δcs^{def} and Δs^{def}, suggesting that the interdependence between the markets' liquidity remains significant even if the impact of credit risk is excluded. In comparison to the higher adjusted R^2 in the base case in Panel A of Table 4.2, the results in Panel A of Table 5.3 suggest that a substantial part of the variation in that case was due to changes in credit risk.

The changes of the bond and CDS correlation premia Δcs^{cor} and Δs^{cor} are also negatively autocorrelated and negatively correlated with their lagged level. The behavior is similar to that of Δcs^{def} and Δs^{def}. For Δcs^{cor}, this is due to the fact that x affects γ^b but y^b does not affect λ, i.e. that credit risk affects bond liquidity but not vice versa. Δs^{cor}, on the other hand, exhibits a different behavior with the autocorrelation coefficient estimates being close to 0 and the impact of $\Delta cs_{-1}^{\text{cor}}$ and cs_{-1}^{cor} on Δs^{cor} being significant at the 5% level only. The adjusted R^2 reflects this time series behavior as well; for Δcs^{cor}, the adjusted R^2 of 8.81% is close to that of Δcs^{def} while the value of 0.97% for Δs^{cor} is very small.

Rating Classes In the base case, the time series analysis in Table 4.2 revealed that the behavior of the premia differs between the investment and the subinvestment grade segment. The results of the Johansen VAR analysis for the investment grade segment in Panel B of Table 5.3 show that the dynamics of the premia are the same as in Panel A but that the size of the coefficients and the explanatory power decrease. This is similar to our result in Table 4.2. Δcs^{def} and Δs^{def} remain negatively autocorrelated and negatively correlated with their lagged level, but the level of the premia in one market does not affect the premia changes

[42] Unfortunately, it also suggests that the dynamics of the latent factors governing liquidity are not specified correctly. We have also included mean reversion in the latent factors, but this made identification of the processes in the calibration almost impossible.

in the other market significantly any more. The adjusted R^2 decreases by approximately 2 percentage points for both Δcs^{def} and Δs^{def} compared to the full sample.

The changes of the CDS pure liquidity premia Δs^{liq} now also exhibit a negative dependency on $\Delta cs^{\mathrm{liq}}_{-1}$ which, however, decreases to -0.01 and is only significant at the 10% level compared to the entire sample. As a result, the adjusted R^2 for Δs^{liq} decreases to 25.35% while that for Δcs^{liq} remains virtually unaffected. In comparison to the base case model, this suggests that the positive link between the liquidity premia in Table 4.2 for the investment grade segment was due to the effect of credit risk.

The correlation premia show almost the identical behavior in the investment grade segment as they do for the entire sample, only the adjusted R^2 is slightly higher.

Overall, the investment grade segment exhibits a lower connection between the premia in the bond and the CDS market. These findings suggest that the premia for investment grade reference entities remain affected by market-specific conditions in excess of the firm-specific ones. We further explore this possibility below.

Panel C of Table 5.3 shows the coefficient estimates for the subinvestment grade segment. For the changes of the pure credit risk premia Δcs^{def} and Δs^{def}, the coefficients and the explanatory power are almost double the size we find for the investment grade segment.

As expected from the results for the entire sample, the sign of the coefficient for the impact of $\Delta cs^{\mathrm{liq}}_{-1}$ on Δs^{liq} is negative and the estimate itself large at -0.08. Because of lower bond market liquidity, the CDS market becomes a more attractive substitute for taking on credit risk. In addition, cs^{liq}_{-1} negatively affects Δs^{liq} with a coefficient estimate of -0.02, further strengthening this result. The explanatory power for Δs^{liq} also increases to 30.87%. Δs^{liq} itself also has a slight reverse effect on Δcs^{liq}, but both the economic and the statistical significance of the coefficient estimate of -0.01 are limited. In comparison to the base case, we observe a strengthening of the negative impact of bond liquidity on CDS liquidity but less evidence for the reverse impact.

The correlation premia become more closely interconnected, but the explanatory power decreases for Δcs^{cor} and increases for Δs^{cor}. In comparison to the investment grade segment, the higher coefficient estimates and the higher adjusted R^2 imply that the bond and the CDS market for the subinvestment grade segment are more closely interconnected.

In summary, the time series analysis for the pure credit risk, the pure liquidity, and the correlation premia shows that the positive relation between the bond and CDS liquidity premia in Section 4.2.3 was caused by the implicit relation of the credit risk and liquidity intensities. If we disentangle the pure liquidity from the correlation-induced component of the liquidity component, we observe a negative relation between the pure liquidity premia which is stable across the different rating sectors.

Stability Analysis

Impact of Market-Wide Credit Risk and Liquidity Factors We first repeat the Johansen VAR analysis with exogenous variables in order to explore the impact of market-wide conditions on the time series relation between the two markets. As in Section 4.3.3, we choose the S&P Creditweek Corporate Bond Index yield spreads described in the previous chapter. Liquidity is proxied by the ECB Financial Market Liquidity Indicator. The results are displayed in Table 5.4.

As in the base case, the inclusion of the aggregate credit risk and liquidity measures hardly affects the dynamics of the firm-specific pure credit risk premia as measured by the increase of the adjusted R^2 and, excepting the relation of Δs^{def} with $\Delta cs^{\text{def}}_{-1}$ and $\Delta s^{\text{def}}_{-1}$, the size of the coefficient estimates. Both Δcs^{def} and Δs^{def} depend positively on market-wide credit risk and negatively on liquidity, but the increase of the adjusted R^2 from 9.95% to 10.91% shows that the explanatory power of the market-wide measures is small. The impact is stronger for the investment grade segment: the adjusted R^2 almost doubles from 7.67% to 12.65% for bonds and from 6.80% to 11.81% for CDS. For the subinvestment grade segment, the coefficient estimates are either insignificant or only significant at the 10% level. Clearly, the pure credit risk premia in the subinvestment grade segment almost completely depend on the reference entity's idiosyncratic default risk.

As in the base case analysis in Section 4.3.3, the impact of the market-wide measures on the pure liquidity premia remains higher than on the pure credit risk premia as measured by the increase of the adjusted R^2. We obtain a positive dependence on the credit risk and a negative one on the liquidity measure, and the adjusted R^2 for Δcs^{liq} increases by almost 10 percentage points for the entire sample. For the investment grade segment, Δcs^{liq} and Δs^{liq} both react positively to increases of credit risk and negatively to increases of liquidity, and the effect on the bond pure liquidity premium is more pronounced. This result is the same as in the base case. In the subinvestment grade segment, on the other hand, Δcs^{liq} reacts with strong increases to an increase in aggregate credit risk and with very slight decreases to an increase in overall market liquidity. For CDS pure liquidity premia, we observe a negative dependence on market-wide credit risk and a positive one on the market-wide liquidity increases. Therefore, the CDS market becomes more liquid during times of low

Table 5.4: **Impact of Market-Wide Credit Risk and Liquidity Factors**

The table shows the estimated coefficients for the VAR with exogenous variables. The rating class-specific S&P Creditweek Corporate Bond Index yield spread is used to proxy for credit risk, the ECB financial market liquidity indicator for liquidity. cs^{def} is the pure credit risk, cs^{liq} the pure liquidity component, and cs^{cor} the correlation component in the yield spread of a synthetical 5-year par bond. s^{def} is the pure credit risk, s^{liq} the pure liquidity, and s^{cor} the correlation component in the mid premium for a 5-year CDS contract. The dependent variables are the premium changes, the explanatory variables are the lagged premium changes, the lagged premium levels, and the credit risk and liquidity measures. The top row of each panel displays the number of reference entities for which 1) the augmented Dickey-Fuller test cannot reject a unit root in the premia time series at the 10% significance level, 2) the augmented Dickey-Fuller test can reject a unit root in the first differences at the 10% level, 3) the Johansen test cannot reject cointegration of the time series at the 10% level, 4) the augmented Dickey-Fuller can reject a unit root in the residuals at the 10% level. ***, **, and * denote significance at the 1%, 5%, and 10% level. Coefficients are for premia in basis points, the adjusted R^2 are in percentage points.

	Δcs^{def}	Δs^{def}	Δcs^{liq}	Δs^{liq}	Δcs^{cor}	Δs^{cor}
Panel A: All						
# Firms	159		159		158	
Δcs_{-1}	-0.95***	0.59***	-0.44***	-0.01***	-0.30***	0.01***
Δs_{-1}	0.70***	-0.33***	-0.01	-0.58***	0.12***	-0.03***
cs_{-1}	-0.06***	0.03***	-0.04***	0.00	-0.01***	0.01***
s_{-1}	0.05***	-0.03***	0.01*	-0.32***	0.00	-0.02***
Credit Risk	0.11***	0.10***	0.09***	0.10***	0.01*	0.00
Liquidity	-0.18***	-0.18***	-0.17***	-0.16***	-0.01*	0.00
Adj. R^2	10.91	9.99	28.38	31.10	8.87	0.98
Panel B: Investment Grade						
# Firms	151		150		143	
Δcs_{-1}	-0.40***	0.18***	-0.45***	0.00	-0.32***	0.01***
Δs_{-1}	0.14***	-0.08***	-0.01	-0.54***	0.04***	-0.02***
cs_{-1}	-0.02***	0.00	-0.03***	0.00	-0.01***	0.00
s_{-1}	0.00	-0.01***	-0.01	-0.14***	0.00	-0.02***
Credit Risk	0.07***	0.08***	0.08***	0.05***	0.01*	0.00
Liquidity	-0.20***	-0.20***	-0.15***	-0.07***	-0.01*	0.00
Adj. R^2	12.65	11.82	31.56	35.45	10.40	1.04
Panel C: Subinvestment Grade						
# Firms	8		9		5	
Δcs_{-1}	-2.55***	1.79***	-0.46***	-0.08***	-0.30***	0.03***
Δs_{-1}	2.29***	-1.51***	0.01	-0.64***	0.51***	-0.18***
cs_{-1}	-2.31***	1.86	-0.08***	-0.02***	-0.02***	0.01*
s_{-1}	2.34***	-1.88***	0.03	-0.45***	0.00	-0.03***
Credit Risk	0.74*	0.64	0.22***	-0.29***	0.04	0.00
Liquidity	-0.17	-0.48	-0.02**	0.63**	-0.22	-0.04
Adj. R^2	18.67	16.59	21.96	30.89	5.03	2.09

overall liquidity which agrees with the flight-to-liquidity effect described by Longstaff (2004) since, in comparison to the bond market, the CDS market is consistently more liquid.

For the correlation premia, the impact of the aggregate market measures is almost negligible. Δcs^{cor} is significantly affected by the credit risk and liquidity measures at the 10% level only, and Δs^{cor} is entirely unaffected. This reveals the correlation premia to be a pure measure of the firm-specific credit risk and liquidity.

Impact of Increasing and Decreasing Market-Wide Risk The last step in our empirical analysis of the extended model consists in the differentiation between phases of increasing and decreasing credit risk which we define as in Section 4.3.4. We estimate a VECM of the form

$$\begin{aligned}
\Delta cs_t^{\text{def}} &= u_1\left(cs_{t-1}^{\text{def}} + \rho_1 s_{t-1}^{\text{def}}\right) + \sum_{j=1}^{5} u_{2_j} \Delta cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} u_{3_j} \Delta s_{t-j}^{\text{def}} + \varepsilon_{1,t}, \\
\Delta s_t^{\text{def}} &= v_1\left(cs_{t-1}^{\text{def}} + \rho_1 s_{t-1}^{\text{def}}\right) + \sum_{j=1}^{5} v_{2_j} \Delta cs_{t-j}^{\text{def}} + \sum_{j=1}^{5} v_{3_j} \Delta s_{t-j}^{\text{def}} + \varepsilon_{2,t},
\end{aligned} \tag{5.5}$$

$$\begin{aligned}
\Delta cs_t^{\text{liq}} &= w_1\left(cs_{t-1}^{\text{liq}} + \rho_2 s_{t-1}^{\text{liq}}\right) + \sum_{j=1}^{5} w_{2_j} \Delta cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} w_{3_j} \Delta s_{t-j}^{\text{liq}} + \varepsilon_{3,t}, \\
\Delta s_t^{\text{liq}} &= x_1\left(cs_{t-1}^{\text{liq}} + \rho_2 s_{t-1}^{\text{liq}}\right) + \sum_{j=1}^{5} x_{2_j} \Delta cs_{t-j}^{\text{liq}} + \sum_{j=1}^{5} x_{3_j} \Delta s_{t-j}^{\text{liq}} + \varepsilon_{4,t},
\end{aligned} \tag{5.6}$$

$$\begin{aligned}
\Delta cs_t^{\text{cor}} &= y_1\left(cs_{t-1}^{\text{cor}} + \rho_3 s_{t-1}^{\text{cor}}\right) + \sum_{j=1}^{5} y_{2_j} \Delta cs_{t-j}^{\text{cor}} + \sum_{j=1}^{5} y_{3_j} \Delta s_{t-j}^{\text{cor}} + \varepsilon_{5,t}, \\
\Delta s_t^{\text{cor}} &= z_1\left(cs_{t-1}^{\text{cor}} + \rho_3 s_{t-1}^{\text{cor}}\right) + \sum_{j=1}^{5} z_{2_j} \Delta cs_{t-j}^{\text{cor}} + \sum_{j=1}^{5} z_{3_j} \Delta s_{t-j}^{\text{cor}} + \varepsilon_{6,t},
\end{aligned} \tag{5.7}$$

where, as in the base case, ρ_i, $i \in \{1, \ldots, 3\}$, are the cointegration coefficient and u_1, v_1, w_1, x_1, y_1, and z_1 are the coefficients of the error correction term. The results of the estimation are given in Table 5.5.

Table 5.5 shows that the relation between cs^{def} and s^{def} is, as in the base case, stable across the increasing and decreasing risk phases. The cointegration coefficient estimate is close to

Table 5.5: **Impact of Increasing and Decreasing Market-Wide Risk**

The table shows the estimated coefficients for the VECM in the error correction form in Equations (5.5) to (5.7). cs^{def} is the pure credit risk, cs^{liq} the pure liquidity component, and cs^{cor} the correlation component in the yield spread of a synthetical 5-year par bond. s^{def} is the pure credit risk, s^{liq} the pure liquidity, and s^{cor} the correlation component in the mid premium for a 5-year CDS contract. The dependent variables are the premium changes, the explanatory variables are the error correction terms and the lagged premium changes. ECT 1 refers to the error correction coefficient for the changes in the bond premium components in Equations (4.11) to (4.13) (u_1 for Δcs^{def}, w_1 for Δcs^{liq}, and y_1 for Δcs^{cor}). ECT 2 refers to the error correction coefficient for the changes in the CDS premium components in Equations (4.11) to (4.13) (v_1 for Δs^{def}, x_1 for Δs^{liq}, and z_1 for Δs^{cor}). ***, **, and * denote significance at the 1%, 5%, and 10% level. Coefficients are for premia in basis points, the adjusted R^2 are in percentage points.

	Increasing Risk Phase			Decreasing Risk Phase		
	Credit Risk Premia	Liquidity Premia	Correlation Premia	Credit Risk Premia	Liquidity Premia	Correlation Premia
Panel A: All						
Coint. Coef.	-1.02***	66.21***	-5.50***	-1.01***	-54.73***	-37.39***
ECT 1	-1.82***	-0.00***	-0.01***	-0.09***	-0.01***	0.00
Adj. R^2	15.47	8.91	7.82	4.42	17.98	6.02
ECT 2	-1.35***	-0.01***	0.01***	-0.02*	0.04***	0.01***
Adj. R^2	11.42	35.63***	1.05	3.80	29.89	2.58
Panel B: Investment Grade						
Coint. Coef.	-1.02***	68.96***	-9.15***	-1.00***	-43.21***	-53.12***
ECT 1	-0.14**	0.00	-0.04***	-0.01	0.00	0.00
Adj. R^2	7.25	7.60	16.59	5.55	17.25	3.45
ECT 2	0.07***	-0.05***	0.01***	0.05***	0.03***	0.01***
Adj. R^2	6.52	30.33	17.87	5.08	16.88	2.60
Panel C: Subinvestment Grade						
Coint. Coef.	-1.02***	2.90***	-4.74***	-1.02***	2.37***	-20.59***
ECT 1	-2.92***	-0.07***	0.08	-2.48***	-0.13***	-0.03**
Adj. R^2	23.09	15.67	0.28	17.17	36.12	13.72
ECT 2	-2.46***	-0.27***	0.01***	-1.90***	-0.16***	0.03***
Adj. R^2	17.17	38.39	1.30	15.10	40.79	7.03

-1 which shows that pure credit risk premia in both markets move jointly in spite of the impact of bond liquidity on s^{def}. The coefficient estimates for the error correction term, on the other hand, are considerably higher during phases of increasing credit risk. This result implies that the effect of the bond liquidity on Δs^{def} becomes dominated by the effect of credit risk for deteriorating market conditions which is further supported by the higher adjusted R^2 for periods with increasing risk.

The connection between cs^{liq} and s^{liq} differs across periods with increasing and decreasing risk. During increasing risk phases, the cointegration coefficient is positive, hence the pure liquidity premia tend to move in opposite directions. For the subinvestment grade segment, this finding also holds when risk decreases. Investment grade pure liquidity premia, on the other hand, move in the same direction when risk decreases. In comparison to the base case analysis in Table 4.6, this result underlines the impact of splitting up the liquidity premium into the pure liquidity premium and the correlation premium. When we do not account for the correlation in Section 4.3.4, the pure liquidity premia only move in opposite directions for the subinvestment grade segment in the increasing risk phase.

Comparing the error correction coefficients, we observe that Δcs^{liq} is affected more strongly in decreasing and Δs^{liq} in increasing risk phases. For Δs^{liq}, this is true both for the investment grade and the subinvestment grade segment, but Δcs^{liq} is not significantly affected by the error correction term in the investment grade segment. This is further evidence that the liquidity of the investment grade bond market is unaffected by that of the CDS market while the reverse is not true. For the subinvestment grade segment, liquidity premium deviations in one market have a consistently reverse effect on the other market's liquidity. As before, the bond market reacts less strongly than the CDS market. In particular when credit risk decreases, the sensitivity of the bond market becomes lower and that of the CDS market becomes larger on an absolute level.

The negative estimate for the cointegration coefficient of cs^{cor} and s^{cor} are consistent with our earlier finding that correlation premia are mostly due to the effect of the credit risk intensity on the liquidity intensity. Interestingly, the absolute value of the cointegration coefficient is higher when credit risk decreases. We take this as a sign that the dynamics of the CDS bid and ask premia become more dissimilar in increasing risk phases, therefore a smaller fraction of the CDS premia can be attributed to the correlation of the liquidity intensity with the default intensity.

Summarizing the results of Section 5.1, we find clear evidence that credit risk has an effect on liquidity both in the bond and the CDS market but that the reverse is not true. For all non-sovereign reference entities, credit risk increases liquidity premia, and we obtain a premium composition of 66% due to pure credit risk, 29% due to pure liquidity, and 5% due to correlation. The effect on CDS premia is more intricate since both the ask and the bid liquidity can be affected by credit risk. Overall, the CDS mid premium consists of on average 96% credit risk, 3% liquidity, and 1% correlation.

The small percentages associated with the correlation premia initially seem to suggest that explicitly modelling the correlation is not worthwhile, but the time series analysis reveals the importance of doing so. Subsuming the correlation between credit risk and liquidity in the liquidity premium gives misleading results about the relation of the liquidity of the bond and the CDS market. If we explicitly account for the correlation, the previous comovement between the liquidity premia is identified as a countermovement. This effect is especially pronounced for investment grade reference entities and increasing risk phases. Since the liquidity of the CDS market is higher than that of the bond market, this result agrees with the flight-to-liquidity effect described by Longstaff (2004) and Vayanos (2004). In the base case, the effect is obscured by the simultaneous dependence of the liquidity premia on credit risk and market-wide liquidity.

The correct identification of the relation between the liquidity premia is most important for trading strategies that are aimed at exploiting differences between the bond and the CDS market, e.g. in a basis trade as Bühler and He (2007) describe. Assuming that the liquidity of the markets moves in the same direction underestimates the actual risk of these strategies because the liquidity premia which are incurred to cancel out the initial positions are negatively associated.

5.2 The Delivery Option

The price of a default-risky security is affected simultaneously by the probability of a default and the value of the residual which can be recovered given that default occurs. Standard asset pricing models often assume that debt issues of the same issuer with identical seniority also have the same residual value contingent upon default, thus putting the focus exclusively on the default probability. As a result, the recovery rate is assumed to be fixed, usually at 40%, for all issuers and across all issues. Empirical evidence, however, shows that recovery rates are far from constant both over time and across different issuers. The Basel Committee on Banking Supervision has acknowledged the importance of this issue by recommending that market participants estimate both the risk of default and recovery in the case of default in the extended internal ratings based approach.

When assessing recovery rates, two modelling choices have to be made. First, a recovery regime[43] must be chosen. Second, a possibly random recovery rate must be determined. In this section, we focus on the effects of modelling the recovery rate as a random variable on bond yield spreads and CDS premia.

In particular, we extend the reduced-form model developed in Chapter 4 from the constant recovery rate assumption to a beta-distributed random recovery rate. This difference has an important implication for CDS premia since it introduces the CTD option into the CDS contract as described in Sections 2.3 and 3.4. Since a fixed, issuer-specific recovery rate under the recovery of face value (RFV) regime leads to identical post-default prices, the CTD option is worthless in the base case model. If, on the other hand, we suppose that post-default bond prices can differ in a non-deterministic way, the option to choose the cheapest deliverable asset has a positive value which leads to a potential increase in the CDS premium relative to the constant and identical recovery rate assumption. Allowing the recovery rate to vary stochastically across different issues of the same issuer thus allows us to gain insight into the differences between yield spreads on corporate bonds which only reflect their own post-default price, and CDS premia which are affected by the differences of the post-default prices of all deliverable bonds.

The contribution of this section is twofold. First, we determine a term structure of the default probability and of the post-default prices of corporate bonds for a single issuer. Most of the theoretical and empirical literature is concerned with a estimation of default probabilities and recovery rates for sovereign issuers since this group usually has a larger number of debt securities outstanding than corporate issuers. Zhang (2003) calibrates a reduced form-model to the term structure of US interest rate swap yields and CDS premia on Argentine sovereign debt and quantifies the CDS-implied recovery value at 73%. Pan and Singleton (2007) simultaneously determine default probabilities and recovery rates from the term structure of sovereign debt CDS premia for Mexico, Turkey, and Korea. The implied recovery rates fluctuate between 17% and 77%. Das and Hanouna (2007) derive a forward term structure of default probabilities and recovery rates using a structural-form model link between these curves, equity prices, and return volatilities. They obtain recovery rates which are inversely related to default probabilities (the mean recovery rate for the highes

[43]The term recovery regime is used in the literature to distinguish between the different bases with regard to which the recovery rate is measures, i.e. recovery of face value, recovery of treasury, and recovery of market value.

default risk quintile lies at 47.13%, the mean for the lowest quintile at 81.68%) and show a strong relation to the level of the risk-free interest rate and a measure of overall market risk. With regard to the corporate sector, Güntay et al. (2003) propose a model for estimating risk-neutral recovery rate distributions which can differ for junior and senior debt. Their empirical results show that the risk-neutral expected recovery rates fall below the observed industry average recovery rates by approximately 30%.

The second contribution in this section is the analysis of the differences between bond yield spreads and CDS premia in excess of the liquidity differences. In Section 3.4, we have explored the impact of a basic empirical proxy for the delivery option on CDS premia and yield spreads, but due to the close link to the bond liquidity, the results we obtained are somewhat ambiguous.

Our approach in this section is most closely related to Jankowitsch et al. (2007). These authors develop a reduced-form model in which all bonds of a given issuer are priced assuming that the *expected* post-default prices are identical. The value of a CDS contract, however, is determined under the assumption that the *actual* post-default bond prices can differ, and that the CDS premium reflects the expected minimum post-default bond price. The authors then determine the implied default probability of a given issuer from bond prices and subsequently infer the expected minimum post-default bond price from CDS premia conditional on the estimated default probability. The CDS market-implied expected minimum recovery rate lies between 8% and 47%. Furthermore, the model-implied CDS premia which do not take into account the CTD option are on average approximately 50% lower than the observed premia. A cross-sectional regression of the implied recovery rates on liquidity proxies suggests that there is no direct link between recovery rates and liquidity. However, the range of this implicit delivery option value estimate is difficult to interpret, in particular since it partly becomes negative and partly constitutes almost the entire CDS premium. Therefore, our approach differs from Jankowitsch et al. (2007) as we do not implicitly estimate the expected minimum recovery rate from CDS premia.

In the theoretical part of our analysis, we assume that the recovery rates for all bonds of a given issuer that are deliverable under the CDS contract are independently and identically beta-distributed random variables. We include the resulting terms for the bond-specific recovery rates and the minimal recovery rates into our reduced-from model from Section 4.1.1. Thus, we also account for stochastic liquidity in bond and CDS markets. The bond price reflects the same expected recovery rate for all bonds of a given issuer. In the CDS pricing equation, we explicitly consider the delivery of the defaulted bond with the lowest post-default price. Therefore, the CDS premium reflects the expected minimum recovery rate.

This approach allows us to quantify the size of the CTD option value in observed CDS premia under a stochastic recovery rate R while avoiding two problems incurred by Jankowitsch et al. (2007). First, since we explicitly determine the distribution of the minimal recovery rate, we cannot obtain negative CTD option values as the expected minimum recovery rate cannot exceed the expected recovery rate. Second, Jankowitsch et al. (2007) account only for the CTD option as a differentiating factor between bond prices and CDS premia. In order to be consistent, their approach should always yield higher CDS premia than bond yield spreads. However, our analysis in Chapter 3 revealed that bond yield spreads tend to be higher than CDS premia which cannot be explained by the CTD option. As we additionally account for bond and CDS liquidity, our model can be calibrated to the observed data and not only to a subset where CDS premia — for any reason — exceed yield spreads.

The empirical part of our analysis consists of three steps. In the first step, we analyze an original sample of 65 European firms that defaulted on senior unsecured debt between January 1, 2000 and December 31, 2006. We collect price quotes for at least two deliverable bonds during the 30 days after the default event which constitute the delivery period under a standard CDS contract. From these post-default prices, we estimate the parameters of the beta distribution. In the second step, we calibrate our extended model that accounts for the delivery of the cheapest defaulted bond to our earlier sample of bond prices and CDS premia for non-defaulted issuers from Chapter 3 and Chapter 4. Eventually, we analyze the estimated credit risk, liquidity, and CTD premia.

The remainder of this section is organized as follows. In Section 5.2.1, we discuss theoretical models and empirical evidence regarding post-default bond price behavior. Section 5.2.2 introduces the model extension which allows us to quantify the credit risk, liquidity, and CTD premia. The empirical analysis follows in Section 5.2.3.

5.2.1 Post-Default Prices

As described in Section 2.3, the economic rationale behind a CDS contract is that the protection seller agrees to refund the protection buyer for the loss incurred upon a given reference asset or a basket of such assets through the default of the issuing entity in exchange for periodical premium payments. In practice, the protection seller pays a specified cash amount, typically the face value of the asset, to the protection buyer if a credit event occurs.

The protection buyer, in turn, can deliver any asset out of the delivery basket. The remaining accrued CDS premium since the last payment date is paid to the protection seller, and the CDS contract ceases.

This procedure shows that at the time the CDS contract is entered into, for any possible given default time both the payment of the face value and the payment of the accrued premium is certain and its discounted present value can be computed. The value of the defaulted asset, however, is unknown prior to default. Therefore, it is necessary to make assumptions about the post-default price. From the specification of the CDS contract, the RFV regime naturally arises, but the recovery rate R itself is unknown ex ante. The CDS should therefore be valued with regard to the minimal recovery rate while each bond should be valued with regard to its own recovery rate distribution.

On the aggregate level, a higher recovery rate for debt issues with a higher seniority and higher collateral values is a stylized fact. Gupton et al. (2000) analyze syndicated loan recovery for senior secured and unsecured debt and find averages of 70% versus 52%. The effect of monitoring is explored by Asarnow and Edwards (1995) who show that recovery rates for standard loan contracts are 65% while structured loans recover on average 87%. In a study which explores the impact of the rating history prior to default, Moody's (2003) show that the length of the time interval during which a firm was rated subinvestment grade prior to default has neither a consistently positive nor a consistently negative impact on the average recovery rate.

However, empirical evidence on recovery rates of different defaulted debt issues from the same issuer is scarce even for the US debt market on which most of the recovery rate studies focus. Güntay et al. (2003) develop a pricing model for junior and senior debt which allows them to estimate different risk-neutral expected recovery rates from the market prices of debt issues. Gupton and Stein (2002) explicitly state that instrument-specific information is not included in the LossCalc™ model for recovery rates either because of lower explanatory power or data sufficiency issues. Acharya et al. (2003) analyze a sample of defaulted US bonds and bank loans and document that the coupon, issue size, and time-to-maturity do not significantly affect the recovery rate of a defaulted debt instrument.

For the European corporate debt market, no similar studies exist. This is partly due to the lower number of defaulted large firms with freely traded debt since non-traded bank loans constitute a much larger fraction of the corporate debt than in the US, as Moody's (2003) claims. A potentially more important reason lies in the differences between the bankruptcy codes. In the US, the absolute priority rule (APR) prevails both under chapter 7 and under chapter 11. If a debtor defaults on any debt class, all issues of the same and of higher seniority also default and become immediately due and payable. Therefore, all creditors holding debt from this issuer of the same and of higher seniority forfeit all right to future coupon payments and retain only the right to the face value. Only owners of secured debt retain the right to coupon payments until the bankruptcy settlement. Since all debt of the same seniority is settled in identical terms under the US bankruptcy code, issues of the same seniority tend to converge quickly to an identical price, regardless of their initial coupon and remaining time-to-maturity. A stochastic recovery rate which implies violations of the APR (some claims of the same seniority are settled more favorably than others) is therefore less likely.

The convergence of the prices of defaulted debt issues takes place rather quickly: For US reference entities, Moody's (2005) defines the default price as the 30-day post-default bid price and finds that the median bond price at the date on which a firm emerges from default (i.e. through a court settlement), which on average took 20 months, is identical to the median default bond price. The sample is, however, strongly skewed to the right with a ratio of the mean to the median value of 1.17. Düllmann and Trapp (2006) compare average annual recovery rates computed from prices for defaulted US bank loans to small and medium firms at emergence and at default and find that neither consistently exceeds the other over time. On average, however, they find that recovery rates at emergence are higher and exhibit a higher standard deviation. Guha (2003) studies defaulted bond prices for Enron and WorldCom. For Enron, bond prices have converged to a span of less than one USD on the 5th day preceding the default, and on the first day after the bankruptcy filing, all bonds are quoted at the identical bid price. A similar result holds true for WorldCom where bond prices differed by less than 25 cents on the day of the missed interest rate payment, and were identical on the date of the bankruptcy filing 7 calendar days later.

European bankruptcy codes differ from one another as well as from the US code regarding the settlement of different claims. We will discuss factors which may have a bearing on our valuation model, i.e. the treatment of accrued interest, the remaining time-to-maturity, and the priority of different claims.

Under the current German insolvency code,[44] coupon payments for defaulted claims accumulate at the original rate until the opening of the bankruptcy proceedings. Coupons which accumulate during the bankruptcy proceedings constitute subordinate claims. The French bankruptcy code[45] specifies that coupon payments are forfeited as of the opening of

[44] See Foerste (2006).

[45] See Sonnenberger and Dammann (2008), pp. 504-528, and Creditreform (2006).

the bankruptcy proceedings for debt instruments with an original time to maturity of one year or less; coupons on instruments with a longer time to maturity accumulate until the bankruptcy settlement. The Dutch liquidation-based bankruptcy law provides suspension of payments for firms with sufficiently good prospects to recover economic health within a short time period if there are no secured or preferred creditors. In the standard liquidation procedure, secured instruments are first satisfied by collateral sales, and the remaining secured claims, unsecured debt instruments, and coupon payments accruing during the bankruptcy proceedings are treated identically as unsecured claims.[46] The United Kingdom administrative receivership is only aimed at creditors with claims which are secured with a floating charge and ends after three months. If the realized value from the collateral sale or the going concern sale of the defaulted reference entity suffices to pay principal and coupon payments accumulated until this date, the administrative receivership ends. Holders of unsecured claims must subsequently file for liquidation whereas coupon payments stop upon the beginning of the liquidation process.[47]

Due to these differences between the bankruptcy codes, post-default bond prices in Europe may well exhibit a very different behavior than in the US. Average recovery rates across all debt classes for under different bankruptcy codes have been compared by the Worldbank (2005). In an analysis of data from Germany, France, the United Kingdom, and the US, they observe that default proceedings are resolved most quickly in the United Kingdom and in Germany with on average 1.0 and 1.2 years. For the US and France, they document an average time interval of 1.5 and 1.9 years until the resolution. The average recovery rates do not fully reflect this relation. While average recovery is highest in the United Kingdom with 84.6% and lowest in France with 47.4%, the US exhibits higher average recovery rates than Germany with 75.9% compared to 53.4%. The authors attribute this relation to the on average lower costs of the bankruptcy proceedings in the US.

5.2.2 Extended Model with Stochastic Recovery Rates

Value of the Cheapest-to-Deliver Option

The value of the CTD option arises from the fact that the protection buyer does not need to specify at the inception of the CDS contract which bond she will deliver if a credit event occurs at time τ. We assume that an issuer has a fixed number $K \geq 2$ of bonds outstanding which are deliverable under the CDS contract. For simplicity, we assume that the delivery

[46] See Creditreform (2005) and Creditreform (2006).
[47] See Davydenko and Franks (2008).

basket is time-invariant: If one bond matures, another bond with the same bond-specific random recovery rate $\tilde{R}_k$, $k = 1, \ldots, K$, is issued.[48] For a given bond k, the value of the CTD option at the default date τ relative to specified delivery of this bond naturally arises as the difference between the recovery rate of bond k and the minimal recovery rate across the delivery basket:

$$\widetilde{CTD}_k(\tau) = \tilde{R}_k(\tau) - \min_{k \in \{1,\ldots,K\}} \tilde{R}_k(\tau).$$

The expected value of the delivery option with respect to a specific bond k, given that default occurs at time τ, is therefore given by

$$CTD_k(\tau) = E\left[\tilde{R}_k(\tau)\right] - E\left[\min_{k \in \{1,\ldots,K\}} \tilde{R}_k(\tau)\right].$$

Instead of with respect to a specific bond, we define the value of the delivery option with respect to the entire delivery basket as the average across all bonds k, $k = 1, \ldots, K$, conditional on default at time τ:

$$CTD(\tau) = \underbrace{E\left[\frac{1}{K}\sum_{k=1}^{K} \tilde{R}_k(\tau)\right]}_{=E\left[\bar{R}(\tau)\right]} - \underbrace{E\left[\frac{1}{K}\sum_{k=1}^{K} \min_{k \in \{1,\ldots,K\}} \tilde{R}_k(\tau)\right]}_{=E\left[\min_{k \in \{1,\ldots,K\}} \tilde{R}_k(\tau)\right]}, \tag{5.8}$$

where $\bar{R}$ denotes the average recovery rate across the delivery basket (which, however, is itself a random variable).

As an alternative, we could also specify the value of the CTD option with regard to the entire delivery basket as the maximum or minimum across the delivery basket. This procedure would give us an upper and lower bound for the delivery option. The lower bound illustrates the difficulty regarding the result of Jankowitsch et al. (2007) of expected minimum recovery rates larger than 40%. By Jensen's inequality, the expected recovery rate is at least as large as the expected minimum recovery rate. If all expected recovery rates are assumed to equal 40%, a CDS-implied expected minimum recovery rate of 47% as Jankowitsch et al. (2007) find points at a misspecification.

[48] As explained in Section 2.3, the set of deliverable obligations usually is a subset of all outstanding bonds of the reference entity. In addition, the total number of outstanding bonds at the default date is unknown at the inception date of the CDS contract for two reasons. First, the reference entity can issue new bonds during the lifetime of the CDS. Second, a number of bonds may have matured before the default date. Since the default date is not known in advance, it is neither clear how many bonds have matured nor how many new ones have been issued before default occurs, i.e. the set of outstanding bonds is unknown the inception of the CDS contract. We abstract from this uncertainty.

The risk structure of the market is modelled as in the base case but with stochastic recovery rates added. The time-t price of bond k, $k \in \{1, \ldots, K\}$ with fixed coupon c paid at times $t_1, \ldots, t_n$, notional F, maturity in t_n, and recovery at θ_j $(t \leq \theta_1 < \ldots < \theta_N \leq t_n)$ is given by

$$
\begin{aligned}
CB_k(t) &= c \cdot \sum_{i=1}^{n} E_t\left[\tilde{P}(t,t_i)\,\tilde{D}(t,t_i)\,\tilde{L}^b(t,t_i)\right] + FE_t\left[\tilde{P}(t,t_n)\,\tilde{D}(t,t_n)\,\tilde{L}^b(t,t_n)\right] \\
&+ F \cdot \sum_{j=1}^{N} E_t\left[\tilde{R}_k(t,\theta_j)\,\Delta\tilde{P}(t,\theta_j)\,\tilde{D}(t,\theta_j)\,\tilde{L}^b(t,\theta_j)\right], \qquad (5.9)
\end{aligned}
$$

where $\tilde{R}_k(t,\theta_j)$ is the random recovery rate of bond k conditional upon default at time θ_j, E_t denotes the expectation with respect to the risk-neutral measure, and all other variables are defined as in Equation (4.1). The difference of Equation (5.9) to the base case consists in the additional uncertainty with regard to the bond-specific and time-dependent recovery rate.

The value of the fixed leg of the CDS contract is identical as in the base case:

$$
\begin{aligned}
CDS_{\text{fix}}(t) &= s^{\text{ask}}\left(\sum_{i=1}^{m} E_t\left[\tilde{P}(t,T_{i-1})\,\tilde{D}(t,T_i)\,\tilde{L}^{\text{ask}}(t,T_i)\right]\right. \\
&\left. + \sum_{j=1}^{M} \delta_j E_t\left[\Delta\tilde{P}(t,\theta_j)\,\tilde{D}(t,\theta_j)\,\tilde{L}^{\text{ask}}(t,\theta_j)\right]\right), \qquad (5.10)
\end{aligned}
$$

but the value of the floating leg now reflects the value of the CTD option. At θ_j, the CDS protection buyer delivers the bond with the lowest post-default price, that is the bond i where $\tilde{R}_i(t,\theta_j) = \min\{\tilde{R}_k(t,\theta_j) : k \in \{1, \ldots, K\}\}$. This leads to the following representation for the floating leg of the CDS contract:

$$
\begin{aligned}
CDS_{\text{float}}(t) &= F \sum_{j=1}^{M} E_t\left[\Delta\tilde{P}(t,\theta_j)\,\tilde{D}(t,\theta_j)\right. \\
&\left. - \min_{k \in \{1,\ldots,K\}} \tilde{R}_k(t,\theta_j)\;\tilde{L}^b(t,\theta_j)\;\Delta\tilde{P}(t,\theta_j)\,\tilde{D}(t,\theta_j)\right]. \qquad (5.11)
\end{aligned}
$$

The second summand in Equation (5.11) reflects the protection buyer's option to choose the bond with the cheapest post-default price after the credit event.

Setting equal Equation (5.10) and (5.11) yields the solution for the CDS ask premium:

$$s^{\text{ask}} = \frac{F \sum_j E_t \left[\left(1 - \min\limits_{k \in \{1,\ldots,K\}} \tilde{R}_k(t,\theta_j) \;\; \tilde{L}^b(t,\theta_j) \right) \Delta\tilde{P}(t,\theta_j)\, \tilde{D}(t,\theta_j) \right]}{\sum_i E_t \left[\tilde{P}(t,T_{i-1})\, \tilde{D}(t,T_i)\, \tilde{L}^{\text{ask}}(t,T_i) \right] + \sum_j \delta_j E_t \left[\Delta\tilde{P}(t,\theta_j)\, \tilde{D}(t,\theta_j)\, \tilde{L}^{\text{ask}}(t,\theta_j) \right]}. \tag{5.12}$$

The solution for the bid premium follows as

$$s^{\text{bid}} = \frac{F \sum_j E_t \left[\left(1 - \min\limits_{k \in \{1,\ldots,K\}} \tilde{R}_k(t,\theta_j) \;\; \tilde{L}^b(t,\theta_j) \right) \Delta\tilde{P}(t,\theta_j)\, \tilde{D}(t,\theta_j) \right]}{\sum_i E_t \left[\tilde{P}(t,T_{i-1})\, \tilde{D}(t,T_i)\, \tilde{L}^{\text{bid}}(t,T_i) \right] + \sum_j \delta_j E_t \left[\Delta\tilde{P}(t,\theta_j)\, \tilde{D}(t,\theta_j)\, \tilde{L}^{\text{bid}}(t,\theta_j) \right]}. \tag{5.13}$$

Specification of the Stochastic Structure

We assume that the recovery rates $\tilde{R}_k(t,\theta_j)$ for all bonds k, $k \in \{1,\ldots,K\}$, are independently and identically distributed. We also assume that the recovery rates lie between 0% and 100%[49] and model it as a standard beta-distributed random variable on the interval $[0,1]$. The density and the distribution function which we denote by $\beta(p(t,\theta_j), q(t,\theta_j))$ and $B(p(t,\theta_j), q(t,\theta_j))$ are explicitly given in Appendix 5.3.3.

As demonstrated in Appendix 5.3.3, the iid assumption allows us to write the distribution function of the minimal recovery rate $\tilde{R}^{\min}(t,\theta_j)$ as a function of $B(p(t,\theta_j), q(t,\theta_j))$:

$$\begin{aligned} \tilde{R}_k(t,\theta_j) &\sim B(p(t,\theta_j), q(t,\theta_j)), k \in k \in \{1,\ldots,K\} \\ \Rightarrow \tilde{R}^{\min}(t,\theta_j) &\sim 1 - [1 - B(p(t,\theta_j), q(t,\theta_j))]^K. \end{aligned}$$

Therefore, we have an explicit representation of the density and the distribution function of the minimal recovery rate.

The dynamics of the credit risk and liquidity intensities are defined as in the base case, and we model the dependence between the default intensity λ and the recovery rates only indirectly. As our empirical analysis in the next section will show, the mean and the standard deviation of the defaulted bond prices in the 30 calendar days after the default event depends on how quickly the creditworthiness of an issuer has deteriorated. The shorter the time

[49] If costs such as lawyers' fees or court fees are deducted from recovery rates, it is possible to arrive at values below 0%. If, on the other hand, bondholders are awarded a tangible asset in the default settlement, it is possible to arrive at a recovery exceeding 100%.

period between the downgrade of a reference entity to the subinvestment grade and the actual default, the higher is the variability across the post-default bond prices.

We therefore assume that λ and $\tilde{R}_k(t, \theta_j)$ evolve independently. In order to adjust for the dependency of the recovery rates' mean and variance on the creditworthiness of an issuer at the inception of the CDS contract, we assume that the distribution of $\tilde{R}_k(t, \theta_j)$ depends on the rating at time t. To capture the effect of the speed of the deterioration of the creditworthiness, we additionally assume that the distribution depends on the time between the inception of the contract and the potential default date, i.e. on $\theta_j - t$. Technically, we use a stepwise function for the mean and the variance which depends on the issuer's rating at time t and on $\theta_j - t$. These mean and variance levels are then used to determine the parameters $p(t, \theta_j)$ and $q(t, \theta_j)$ and, using these parameters, the expected minimum recovery rate.

As an illustrative example, assume that a two-year CDS contract is written on a reference entity which is rated investment grade at time t and has 5 bonds outstanding. Our empirical analysis shows that it is a plausible assumption that a quick deterioration of the creditworthiness which leads to a default in the first year is associated with lower and more diverse recovery rates, e.g. a mean recovery rate of 30% and a standard deviation across the recovery rates of 10%. If a default occurs in the second year, the recovery rates may be higher and less diverse with a mean of 35% and a standard deviation of 5%. We estimate the parameters $p(t, \theta_j)$ and $q(t, \theta_j)$ from the mean and the variance through the relation given in Appendix 5.3.3 and obtain for a default in the first year $p(t, t+1) = 6$ and $q(t, t+1) = 14$. For 5 outstanding bonds, this translates into an expected minimum recovery rate of 18.93%. For a default in the second year, the parameters equal $p(t, t+2) = 31.50$ and $q(t, t+2) = 58.50$ which translates into an expected minimum recovery rate of 29.27%.

Under the independence assumption, the analytical solutions for $E_t\left[\tilde{P}(t, \theta_j)\right]$ and $E_t\left[\tilde{L}^l(t, \theta_j)\right]$, $l \in \{b, \text{ask}, \text{bid}\}$, are the same as in the base case in Section 4.5.2. Substituting the expected recovery rate, the expected minimum recovery rate, and the expectations terms for the default probability and the liquidity discount factors in Equations (5.9), (5.12), and (5.13) yields the solutions for CB, s^{ask}, and s^{ask}:

$$
\begin{aligned}
CB(t) &= c \cdot \sum_{i=1}^{n} P(t, t_i) D(t, t_i) L^b(t, t_i) + FP(t, t_n) D(t, t_n) L^b(t, t_n) \\
&+ F \cdot \sum_{j=1}^{N} E\left[\tilde{R}(t, \theta_j)\right] \Delta P(t, \theta_j) D(t, \theta_j) L^b(t, \theta_j), \qquad (5.14)
\end{aligned}
$$

$$s^{\text{ask}} = \frac{F \sum_j \left(1 - E\left[\min\limits_{k\in\{1,\ldots,K\}} \tilde{R}_k\left(t,\theta_j\right)\right] \; L^b\left(t,\theta_j\right)\right) \Delta P\left(t,\theta_j\right) D\left(t,\theta_j\right)}{\sum_i P\left(t,T_{i-1}\right) D\left(t,T_i\right) L^{\text{ask}}\left(t,T_i\right) + \sum_j \delta_j \Delta P\left(t,\theta_j\right) D\left(t,\theta_j\right) L^{\text{ask}}\left(t,\theta_j\right)}, \tag{5.15}$$

$$s^{\text{bid}} = \frac{F \sum_j \left(1 - E\left[\min\limits_{k\in\{1,\ldots,K\}} \tilde{R}_k\left(t,\theta_j\right)\right] \; L^b\left(t,\theta_j\right)\right) \Delta P\left(t,\theta_j\right) D\left(t,\theta_j\right)}{\sum_i P\left(t,T_{i-1}\right) D\left(t,T_i\right) L^{\text{bid}}\left(t,T_i\right) + \sum_j \delta_j \Delta P\left(t,\theta_j\right) D\left(t,\theta_j\right) L^{\text{bid}}\left(t,\theta_j\right)}, \tag{5.16}$$

where P, L, and D are defined as in the base case.

These solutions can then be calibrated to our set of bond prices and CDS ask and bid quotes to obtain estimates of the default and liquidity intensities when the CTD option is accounted for.

Measures for Credit Risk, Liquidity, and CTD Option Premia

Regarding the premium decomposition, the bond yield spread is again split into two parts as in the base case. The pure credit risk premium cs^{def} follows from Equation (5.14) with

$$E_t\left[\tilde{R}_k\left(t,\theta_j\right)\right] = \frac{p\left(t,\theta_j\right)}{p\left(t,\theta_j\right) + q\left(t,\theta_j\right)},$$

for the (pre-estimated) parameters $p\left(t,\theta_j\right)$ and $q\left(t,\theta_j\right)$. The bond liquidity premium cs^{liq} is then defined as the difference between the total yield spread and cs^{def}.

The CDS premium, on the other hand, is decomposed into three parts. The first part s^{def} constitutes the default risk premium. We compute it from Equation (5.15) by setting the CDS liquidity discount factor equal to 1 and replacing $E_t\left[\min\limits_{k\in\{1,\ldots,K\}} \tilde{R}_k\left(t,\theta_j\right)\right]$ with $E_t\left[\bar{R}\left(t,\theta_j\right)\right]$. Therefore, cs^{def} and s^{def} again differ only because of the direct impact of the bond liquidity on s^{def}.

The CTD component in the CDS premium, s^{CTD}, is computed as the difference between s^{def} and the premium that results from Equation (5.15) when we use the expected minimum recovery rate but hold the CDS liquidity discount factor fixed at 1. The CDS liquidity premium s^{liq} then arises as the difference between the mid CDS premium $s^{\text{mid}} = \frac{s^{\text{ask}}+s^{\text{bid}}}{2}$, and the sum of s^{def} and s^{CTD}, where s^{ask} and s^{bid} follow from Equations (5.15) and (5.16) for CDS liquidity discount factors different from 1.

5.2.3 Empirical Analysis with Stochastic Recovery Rates

Post-Default Prices

Before we calibrate the model in Equations (5.15) to (5.16) to our original data sample, we need to pre-estimate the parameters of the recovery rate distribution in order to determine the expected minimum recovery rate. If we estimate the parameters from observed post-default bond prices, this implies that we use the physical distribution of recovery rates. Our model, on the other hand, is formulated with regard to risk-neutral expectations. Therefore, any input for the recovery rate distribution should also be determined with regard to the risk-neutral measure. To the best of our knowledge, only Güntay et al. (2003) develop a model for issue-specific risk-neutral recovery rates for different debt classes. However, it is not clear how this model could be generalized to stochastic recovery rates for the identical debt class.

Therefore, we follow the argument by Acharya et al. (2007) who assume that the price of an instrument at default is an unbiased estimate of its actual recovery at emergence. This is equivalent to assuming that the recovery rate dynamics are equivalent under the risk-neutral and the physical measure, i.e. that recovery risk is not priced. Even though this assumption is rather restrictive, the CTD option mostly gathers value through the standard deviation of the recovery rates which should not differ too strongly under the risk-neutral and the physical measures.

Relevant Time Interval We shortly discuss our choice of the post-default time interval which we take into account to determine the parameters of the recovery rate distribution. As described in Section 2.3, if a credit event occurs at time τ, either the protection buyer or the protection seller can deliver a "Notification of a Credit Event". After this notification, the protection buyer has 30 calendar days until specifying in the "Notice of Physical Settlement" which asset she will deliver. In the subsequent 30 calendar days of the settlement period, she can deliver this asset to the protection seller at any date. We now deduce which phases of the delivery process between the credit event and the actual delivery should affect the value of the CTD option in our model.

During 30-day settlement period, the protection buyer can time her buying date of the specified asset optimally. We do not take into account this timing component since it also pertains when a CDS is written on a single bond instead of a basket of deliverable obligations.

The credit event notification can take place up to 14 calendar days after the scheduled termination date of the CDS contract. This could theoretically be years after the credit event, thus making the CTD option value very difficult to determine. However, it is reasonable to assume that the credit event notification takes place immediately after the credit event, at least if the protection buyer and seller expect the same evolution of the recovery rates after the credit event over time: If the protection buyer and seller assume that the value of the cheapest deliverable bond decreases – as is usually the case – the protection seller wants to obtain the CTD bond as soon as possible. She therefore immediately sends the credit event notice to the protection buyer who then has 30 calendar days to specify which bond she intends to deliver. If, on the other hand, both assume that the CTD bond's price increases,[50] the protection buyer has an incentive to buy the CTD bond as soon as possible after the default event.

In summary, we believe that the 30 calendar days of the period between the credit event notification and the last possible date for the settlement notification constitute a reasonable upper limit for the lifetime of the CTD option.

Data All defaulted bond price data is collected from Bloomberg. We first identify all European-based reference entities that were downgraded to a non-performing rating with regard to any non-senior, non-subordinated debt issue by Moody's, S&P, or Fitch between January 1, 2000 and December 31, 2006. This gives us a sample of 72 firms. For each of these firms, we collect a rating history starting from January 1, 1995. As the default event, we choose the date of the earliest non-performing rating. Contrary to the simple default rating, the non-performing rating only includes the case of a missed coupon or principal payment *after* the relevant grace period has elapsed and is thus consistent with the definition of a credit event under the standard CDS contract specifications. If the earliest non-performing rating differs by more than three business days from the next downgrade for the remaining rating agencies, we determine which kind of default event has taken place and manually check the default date from the Bloomberg news archives.

In the next step, we identify the set of deliverable debt obligations as described in Section 2.3 and collect mid bond price quotes for the 30 calendar days which follow the default event. Non-EUR bond price quotes are converted into EUR values at the spot exchange rate. If no price quotes are observed for at least two deliverable bonds during this time interval, we drop the firm from our sample. If the "Notification of a Credit Event" had taken place at the default event, the absence of price quotes during this time interval

[50] Guha (2003) reports an increase of defaulted bond bid price quotes from the day on which it became public information that a potential merger bid for Enron would fail to the day following the bankruptcy filing.

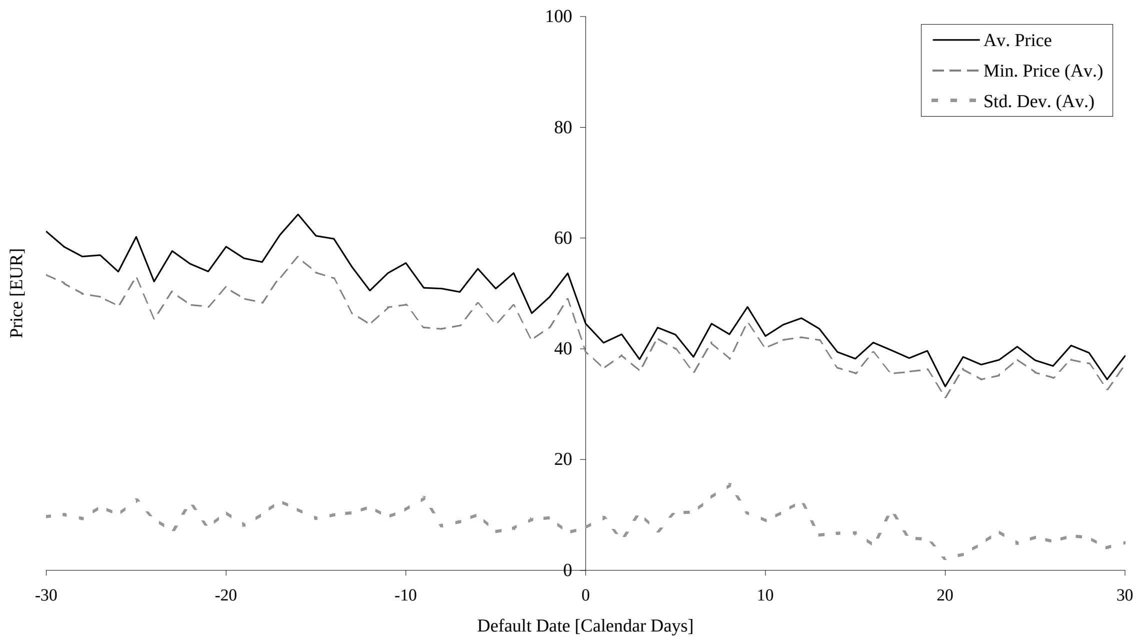
suggests that the maximal period until the "Notice of Physical Settlement" elapsed without any observed bond price quotes which effectively prohibits the valuation of the defaulted assets. This procedure leaves us with 65 firms[51] for which mid price quotes of on average 7 deliverable bonds were available after the default event.

Defaulted Bond Price Time Series For each of the 65 defaulted firms, we compute the average and the minimal bond price as well as the standard deviation across the delivery basket on each of the 30 days prior to the default event and the 30 subsequent days. The resulting time series of average and minimal bond prices and standard deviations for the average across all firms, one investment grade firm (Parmalat), and one subinvestment grade firm (Diamond Cable Communications) are presented in Figure 5.1.

Figure 5.1: **Defaulted Bond Prices**

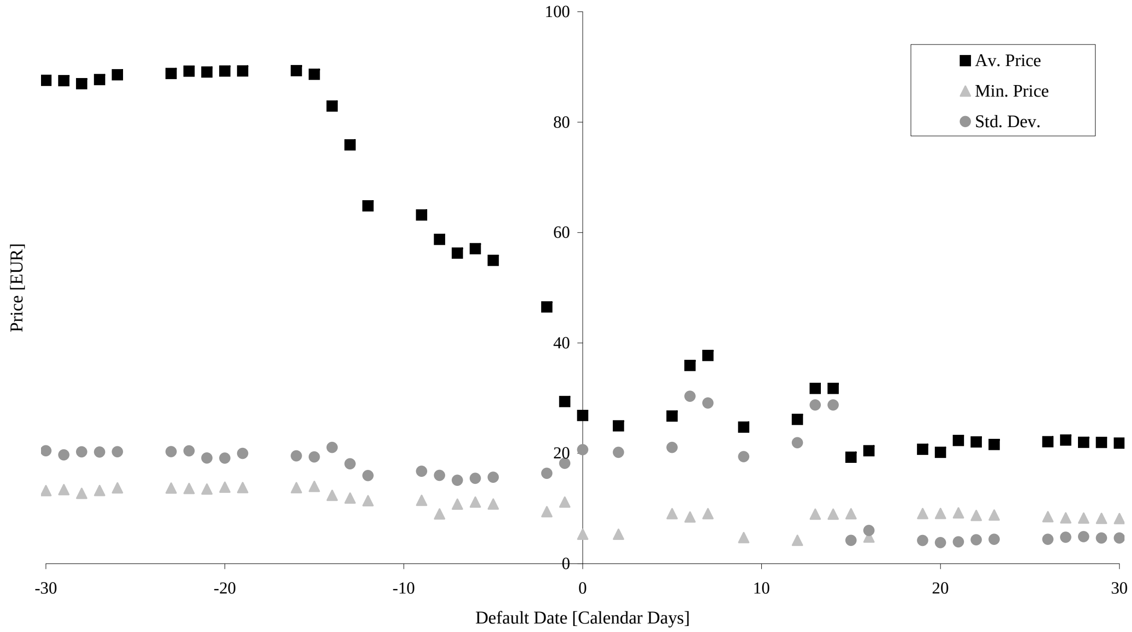
The figure shows the average and minimal bond price and the standard deviation across the bond prices for the 30 calendar days before and after the default event. The standard deviation is determined first for all bonds of a given issuer for a given date, then the average is computed across all issuers for which observations were available at that date. Panel A gives the average across all firms, Panel B for Parmalat, Panel C for Diamond Cable Communications. All values are in EUR.

Panel A: All Firms

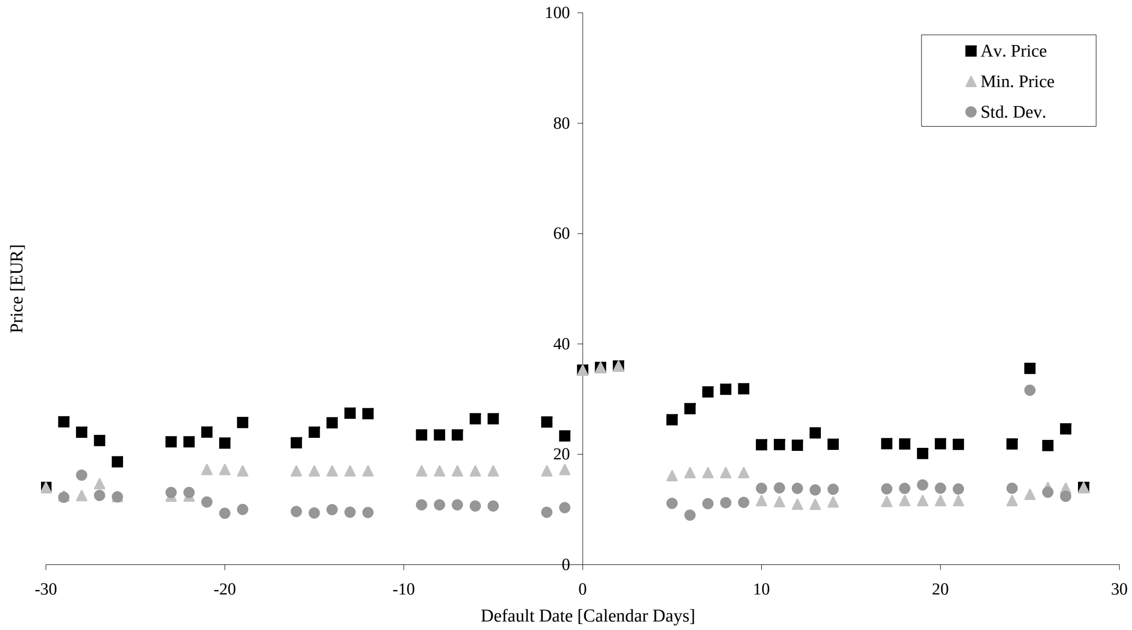


[51]Extending this period to the additional physical settlement period does not change the sample.

Panel B: Parmalat



Panel C: Diamond Cable Communications



Panel A of Figure 5.1 shows that the average and the minimal bond price tend to decrease throughout the depicted period. However, the decrease is not very strong in the delivery period with an average bond price of 42.47 EUR in the first 15 days after the default event and an average of 38.27 EUR during the second 15-day interval. This change of -9.90% is similar to that in the minimal bond prices which decrease by -8.94% from 39.39 EUR between the default and the 15th day after the default to 35.87 EUR from the 16th to the 30th calendar day. In addition, the default event does not lead to an immediate and steep decrease either in the average nor in the average minimal bond price. We obtain, however, an average mean bond price of 55.23 EUR in the 30 calendar days before the default event versus 40.49 EUR in the 30 days following the default. The average minimal prices decrease from 48.48 EUR to 37.71 EUR for the same time interval.

The average standard deviation of the bond prices initially increases after the default event but then decreases again towards the end of the delivery period. The average standard deviation from the first to the 15th day after the default event equals 9.50 EUR and decreases to 5.39 EUR between the 16th and the 30th calendar day. Comparing the 30 days before and after the default event, the standard deviation decreases from an average value of 9.80 EUR to 7.51 EUR.

These values correspond to the observed difference between the average and the minimal bond prices. During the 30 days before the default, the average and minimal bond prices on average differ by 6.76 EUR and by 2.79 EUR after the default. The difference is higher immediately after the default with 3.08 EUR during the first 15 days and 2.40 EUR in the second post-default interval. Altogether, we observe that across all firms, bond prices are only weakly affected by the default event itself but that the price range continues to decrease throughout the lifetime of the delivery option.

Panel B and C of Figure 5.1 demonstrate that the immediate effect of the default event strongly depends on how quickly the creditworthiness deteriorated.

Panel B shows the time series of average and minimal bond prices and the standard deviation across the delivery basket for the Parmalat default. Until December 9th, 2003 (t=-15), Parmalat was rated investment grade at BBB-. On December 18th, 2003 (t=-6) it became public knowledge that Parmalat had fraudulently claimed a 3.95 billion USD account balance with Bank of America, and the trading of Parmalat shares was halted at the Milan stock exchange. As a consequence, Parmalat was declared officially insolvent on December 24, 2003, and we choose this as the default date (t=0). The delivery basket for a standard CDS contract on Parmalat contained 35 obligations. As the behavior of the average bond price shows, the price deterioration started two weeks before the eventual default event. 15 calendar days before default, the average bond price still lay at 88.66 EUR and decreased to 29.37 EUR on the day before default. The minimal bond price and the standard deviation were almost constant during the 30 calendar days preceding default with a mean of 12.38 EUR and 18.53 EUR, respectively. After the default event, mean bond prices and the standard deviation tended to increase while the minimal bond price decreased, and the mean values were 29.97 EUR, 7.36 EUR, and 24.94 EUR, respectively. Starting from the 15th day after default, the prices were again almost constant with an average mean price of 21.41 EUR, a minimal price of 8.37 EUR, and a standard deviation of 4.54 EUR.

In comparison to the rapid price decrease before default and the subsequent period of high price volatility for Parmalat, the default event hardly had any effect on the mean and minimal bond prices as well as the standard deviation for the British telecommunications firm Diamond Cable Communications. Starting from 1995, Diamond Cable Communications exhibited a B rating and was downgraded to B- on February 1, 2002 and to CCC- on March 28, 2002. Together with its parent firm NTL Inc., Diamond Cable Communications filed for bankruptcy under a prearranged reorganization plan on May 8, 2002. NTL Inc. had already published its balance sheet statement showing 16.83 USD billion in total assets and 23.38 USD billion in total liabilities. Interest payments on senior notes were missed on April 1, 2002 (t=-2) and a financial restructuring was announced on April 16, 2002 (t=13).

Our default date is April 3, 2002, when the grace period of the missed interest rate payments elapsed. 30 bonds were deliverable under a standard CDS contract. Prior to the default, the mean and the minimal bond price as well as the standard deviation were almost constant with a mean of 23.66 EUR, 15.76 EUR, and 11.02 EUR, respectively. At the default date and for two subsequent days, price quotes for only one bond were available which increases the average and the minimal price to 35.25 EUR. Afterwards, bond prices were approximately constant with a mean of 29.86 EUR, 19.30 EUR, and 11.63 EUR for the average and minimal bond price and the standard deviation. Two bonds were priced within a 0.25 EUR span during the 30 days prior to the default, and one of them also had the minimal post-default price across the delivery basket until the end of the delivery period. In contrast, the bond which was cheapest before the Parmalat default was among the mean priced ones after the default event, and a bond which was in the mean price range before default subsequently had the lowest price.

Cross-Section of Defaulted Bond Prices and Expected Minimum Recovery Rates The differences between the post-default prices for Parmalat and Diamond Cable Communications suggest that if the creditworthiness deteriorates more quickly, the CTD option is more valuable. In order to capture this effect, we separate the sample by the time of the firm's downgrade to subinvestment grade before default. In particular, we first pool all firms that were rated investment grade one year before default versus all firms that were rated subinvestment grade one year before default. In the second step, we pool all firms that were rated investment grade two years before default but subinvestment grade one year before default versus all firms that were rated subinvestment grade two years before default. We repeat this procedure for the third and fourth year, from then on our sample does not change any more. We then determine the average post-default price, the minimal post-default price, and the standard deviation across all deliverable bonds for the 30 calendar days before the default event, the entire delivery period, the first 15 days, and the second 15 days of the delivery period.

Taking the average post-default price and the standard deviation as estimates for the true mean and standard deviation of the beta-distributed recovery rates, we extract the parameters of the beta distribution from the average and the standard deviation through the relation given in Appendix 5.3.3. Using these parameter estimates, we compute the expected minimum recovery rate for a delivery basket that contains the average number of deliverable obligations of the subsample. The difference between the mean and the expected minimum recovery rate then gives the value of the delivery option as defined in Equation (5.8) that would have applied if a standard CDS contract had been written on the entire delivery basket. In addition, we also display the average recovery rate of the senior unsecured bonds which we need as input for the bond pricing equation. The results of the estimation procedure are given in Table 5.6.

As Panel A of Table 5.6 shows, the average bond prices and the standard deviation across the bond prices are higher for investment grade bonds than for the subinvestment grade bonds in the 30 days prior to default. In conjunction with the higher number of deliverable obligations, this leads to a higher value of the CTD option which amounts to up to 44% of the average bond price. The expected minimum bond price of 38.00 EUR which is displayed in Panel A of Table 5.6 for firms that were rated investment grade one year prior to default is almost identical to the average minimal bond price of 38.15 EUR which was actually observed for these firms.

For the 30 days after the default event, Panel B shows that the difference between the

Table 5.6: **Defaulted Bond Prices**

The table presents the bond prices for 65 European firms which defaulted from 2000 to 2006, depending on the rating history. Values in the second column apply to firms rated investment grade one year prior to default, values in the third column to firms that were rated subinvestment grade one year prior to default. Column 4 applies to firms that were rated investment grade two years before default but subinvestment grade one year before default etc. $\bar{R}$ gives the average deliverable bond price, Std. Dev. the standard deviation across the deliverable bond prices, $\overline{R^{\text{sen}}}$ the average senior unsecured bond price, $\mathbf{E}\left[R^{\min}\right]$ the expected minimal bond price, and CTD the cheapest-to-deliver option value. All values are in EUR per 100 EUR face value.

Pre-Default	1 Year		2 Years		3 Years		4 Years	
Rating	IG	Sub-IG	IG	Sub-IG	IG	Sub-IG	IG	Sub-IG
# bonds	10	6	8	8	11	6	10	7
Panel A: Pre-Default Days 1-30								
$\bar{R}$	68.03	48.22	73.84	44.48	66.80	44.33	69.37	40.08
Std. Dev.	17.91	7.67	16.75	7.80	15.24	5.72	15.20	5.69
$\overline{R^{\text{sen}}}$	65.01	47.08	70.41	43.23	64.89	43.20	66.56	38.81
$\mathbf{E}\left[R^{\min}\right]$	38.00	38.53	47.16	33.52	40.86	37.13	43.94	32.50
CTD	30.03	9.69	26.68	10.96	25.94	7.20	25.43	7.58
Panel B: Post-Default Days 1-30								
$\bar{R}$	31.87	42.69	47.24	37.08	49.61	34.40	50.07	33.99
Std. Dev.	10.85	5.49	10.01	5.13	9.50	4.42	8.51	4.21
$\overline{R^{\text{sen}}}$	30.07	42.05	46.28	36.15	49.35	33.25	49.83	32.81
$\mathbf{E}\left[R^{\min}\right]$	16.52	35.79	33.13	29.92	34.64	28.89	37.05	28.40
CTD	15.35	6.90	14.11	7.16	14.97	5.51	13.02	5.59
Panel C: Post-Default Days 1-15								
$\bar{R}$	36.23	44.26	51.10	39.31	52.26	37.31	53.17	36.55
Std.Dev.	17.52	6.47	16.85	6.24	13.98	5.36	12.01	5.11
$\overline{R^{\text{sen}}}$	33.82	43.08	49.06	37.83	50.58	35.60	51.46	34.84
$\mathbf{E}\left[R^{\min}\right]$	12.27	36.13	27.22	30.60	30.15	30.63	34.61	29.77
CTD	23.96	8.13	23.88	8.71	22.11	6.68	18.56	6.78
Panel D: Post-Default Days 16-30								
$\bar{R}$	28.44	41.04	44.05	34.72	47.35	31.30	47.35	31.30
Std. Dev.	4.18	4.66	4.39	4.52	5.43	3.60	6.38	3.60
$\overline{R^{\text{sen}}}$	25.95	40.80	43.39	34.05	46.99	30.31	46.99	30.31
$\mathbf{E}\left[R^{\min}\right]$	22.23	35.19	37.85	28.42	38.79	26.82	37.60	26.68
CTD	6.21	5.85	6.20	6.30	8.56	4.48	9.75	4.62

average and the expected minimum bond price strongly decreases from 30.03 EUR to 15.35 EUR through the lower standard deviation for firms that were rated investment grade one year prior to default. For the remaining investment grade segment, the average CTD value lies at approximately 15 EUR and between 5.51 and 7.65 EUR for the subinvestment grade segment. We also find further evidence that the default event did not affect bond prices for firms that were rated subinvestment grade previously as strongly as it did for those which quickly deteriorated from an investment grade rating. For firms that were rated subinvestment grade one year prior to default, the average bond price only decreases from 48.22 EUR to 42.69 EUR.

Comparing the first and the second half of the delivery period in Panel C and D, we find that the average bond prices and the standard deviation decrease over time for both the investment and the subinvestment grade. This has the effect of changing the behavior of the expected minimum bond prices across the rating spectrum. In the investment grade segment, the expected minimum bond price is smaller in the first half. For the subinvestment grade segment, the lower expected minimum bond prices are attained in the second half of the delivery period. Since the protection buyer wants to deliver an asset at the cheapest possible price, she will on average deliver the subinvestment grade reference entities at a later time even though the value of the CTD option is always higher in the first half of the delivery period. In this case, the value of the delivery option does not directly affect the timing of the actual delivery.

The average senior unsecured bond prices consistently lie below the average across the entire delivery basket. This finding is consistent with our analysis in Section 2.3 where we discuss that the delivery basket additionally contains bonds of a higher seniority or those with additional creditor rights. The difference between the average across the delivery basket and the senior unsecured bonds is more pronounced in the 30 days preceding default which agrees with the economic intuition that most additional creditor rights become worthless through default.

Impact of Stochastic Recovery Rates on Credit Risk and Liquidity Premia

We now demonstrate how the average post-default bond prices and the expected minimum recovery rate across the entire delivery basket are used in the estimation of the model.

Calibration Procedure The calibration consists of three steps. In the first step, we determine the expected senior unsecured bond recovery rate and the expected minimum recovery rate across the potential delivery basket for each year until the maturity of the CDS contract conditional upon default happening in that year. If a reference entity is rated investment grade at the current date, the expected senior unsecured recovery rate $\overline{R^{\text{sen}}}$, the expected average recovery rate $\bar{R}$, and the standard deviation across the entire delivery basket conditional upon default happening within the next year are taken from the second column of Table 5.6. The recovery rate conditional upon default taking place in year 2 of the CDS contract is taken from the third column and so forth. We proceed in the same way for subinvestment grade reference entities.

Regarding from which panel of Table 5.6 the expected recovery rates $\overline{R^{\text{sen}}}$ and $\bar{R}$ and the standard deviation are chosen, we use the following procedure. Since the average of $\overline{R^{\text{sen}}}$ is always higher in the first 15 days after default, we use the values from Panel C for the bond pricing equation, assuming that bond holders try to sell the defaulted asset as soon as possible. For the CDS contract, we choose the combination yielding the smallest expected minimum recovery rate which, as discussed above, is in the first 15 days for investment grade rated reference entities (Panel C) and in the second 15 days for subinvestment grade rated ones (Panel D).

As the potential number of deliverable obligations, we do not use the values in Table 5.6. Instead, we choose the number of obligations which would be currently deliverable upon default under a standard CDS contract for the reference entity. From this number of bonds, the value of $\bar{R}$ from Table 5.6, and the standard deviation from Table 5.6, we compute the expected minimum recovery rate for each reference entity conditional upon default happening in a given year of the CDS contract. All values are then discounted to the default date at the default-free forward interest rate computed implicitly from the Nelson-Siegel-Svensson curve.[52]

In the second step of our calibration procedure, we initiate a base grid for the process parameters $\left(\alpha, \beta, \sigma, \mu^b, \eta^b, \mu^{\text{ask}}, \eta^{\text{ask}}, \mu^{\text{bid}}, \eta^{\text{bid}}\right)$. In the third step, we determine the values $\left(\lambda, \gamma^b, \gamma^{\text{ask}}, \gamma^{\text{bid}}\right)(t),\ t = 1, \ldots, 1548$, which simultaneously minimize the sum of squared errors between the time series of the observed and the theoretical CDS premia and bond yield spreads. As before, we determine the grid point associated with the smallest sum of squared errors and initiate a finer local grid around it. We then repeat the third step in

[52]The assumption that the average and standard deviation of the post-default bond price only depend on the rating history is rather restrictive. Sovereign debt, for example, often displays a different post-default price behavior from corporate debt or that for financial reference entities. However, our default sample does not contain a single financial or sovereign reference entity. Therefore, we make the assumption to keep our estimation results comparable to those of the base case result. In addition, the delivery option is likely to become more valuable for financial and sovereign reference entities since these generally have a higher number of deliverable bonds.

each point of the new grid. We stop iterating between the second and the third step when the minimal sum of squared errors twice decreases by less than 1% on two subsequent grid specifications.

Credit Risk, Liquidity, and CTD Premia: Cross-Sectional Results Given the estimates of the process parameters and intensities, we then compute the pure credit risk and liquidity premia for bonds and CDS as well as the CTD option component in the CDS premia as explained above. The results are displayed in Table 5.7.

As a comparison of Table 5.7 to the base case results in Table 4.1 shows, the credit risk premium cs^{def} in the bond yield spread decreases from an average of 52.21 bp to an average of 40.53 bp while the liquidity premium cs^{liq} increases from an average of 26.26 bp to an average of 37.94 bp. This signifies that 52% of the yield spread are due to credit risk and 48% due to liquidity.

The change arises in two ways. First, we assume that the risk-neutral expected recovery rate of the bond equals the average senior post-default bond price $\overline{R^{\mathrm{sen}}}$ in Panel C of Table 5.6. These values mostly exceed the recovery rate of 40% used in the base case. Due to the higher post-default price, the credit risk premium decreases if the default probability remains fixed because the bond holder loses a lower amount of money if default occurs. On average, a change of the expected recovery rate from 40% as in the base case to the average investment grade post-default price across 5 years of 47% from Table 5.6 leads to a decrease of about 13% for cs^{def}.

The second effect is due to the simultaneous calibration of our model to CDS premia and bond prices. Since a non-negative part of the CDS premium is by assumption caused by the CTD option, the remainder of the premium must be explained by the credit risk and the liquidity premium. Both the CDS bid and the ask premium reflect the CTD option value, therefore our measure of CDS liquidity is less likely to be affected because it is derived via the asymmetry of the bid and the ask premia regarding the credit risk component. Therefore, the proportion of the CDS premium – and, consequently, the yield spread – that is exclusively caused by credit risk decreases. In order to fit the observed bond prices, the liquidity premia must increase simultaneously.

Across the different industry sectors, this effect is most pronounced for the sovereign sector due to the higher number of deliverable bonds. The average of cs^{liq} increases from 2.17 bp to 13.26 bp, thus constituting 33% of the yield spread in comparison to 2% in the

Table 5.7: **Estimated Credit Risk, Liquidity, and CTD Premia**

The table shows the mean, standard deviation, minimum, and maximum for the credit risk, liquidity, and CTD premia components for each industry sector and rating class. cs^{def} is the credit risk and cs^{liq} the liquidity component in the yield spread of a synthetical 5-year par bond. s^{def} is the credit risk, s^{liq} the liquidity, and s^{ctd} the delivery option component in the mid premium for a 5-year CDS contract. The mean, standard deviation, minimum, and maximum are determined both over time and across observations within the industry sector, respectively rating class, on each date. All values are in basis points.

	Sectors			Rating Classes							
	Fin.	Non-Fin.	Sov.	AAA	AA	A	BBB	BB	B	CCC	All
cs^{def}	13.46	51.90	26.98	4.75	10.28	25.18	49.48	221.27	318.14	214.23	40.53
Std. Dev.(cs^{def})	15.79	104.14	99.39	5.74	9.48	27.32	62.28	252.51	187.25	66.55	90.83
min(cs^{def})	3.72	3.89	3.69	3.69	3.72	3.69	3.95	16.81	53.72	59.42	3.69
max(cs^{def})	313.61	1,630.00	736.83	47.03	295.85	284.85	1,128.06	1,630.00	1,026.96	371.45	1,630.00
cs^{liq}	15.52	49.68	13.26	1.93	15.50	30.97	56.74	84.51	99.14	71.61	37.94
Std. Dev.(cs^{liq})	29.37	56.98	12.33	3.55	30.47	45.01	61.43	73.82	64.49	16.82	50.90
min(cs^{liq})	0.55	0.66	-0.52	-0.52	0.55	0.66	0.59	0.47	0.34	0.30	-0.52
max(cs^{liq})	505.42	501.47	302.38	36.65	505.42	453.76	486.05	501.47	408.25	65.87	505.42
s^{def}	14.23	53.21	27.66	4.85	10.79	25.82	50.87	223.21	323.34	217.91	41.61
Std. Dev.(s^{def})	14.97	90.22	82.45	5.44	9.23	26.26	60.21	222.91	158.23	53.50	78.71
min(s^{def})	4.07	4.07	4.09	4.09	4.07	4.07	4.08	21.56	67.13	75.16	4.07
max(s^{def})	320.89	1,714.64	874.39	49.74	313.61	297.16	1,188.41	1,714.64	1,218.30	461.86	1,714.64
s^{liq}	0.75	2.70	2.00	-0.05	0.52	1.52	2.84	7.13	18.71	16.64	2.13
Std. Dev.(s^{liq})	1.60	17.33	12.92	0.36	1.07	2.85	7.99	62.59	58.70	35.44	14.57
min(s^{liq})	-53.81	-366.94	-81.89	-1.31	-53.81	-27.32	-366.94	-356.84	-360.70	-30.22	-366.94
max(s^{liq})	48.19	296.69	270.58	4.24	34.63	109.81	235.72	281.97	296.69	160.83	296.69
s^{ctd}	4.54	15.43	9.96	1.95	3.49	7.19	14.70	48.24	77.68	56.97	11.57
Std. Dev.(s^{ctd})	5.87	27.15	30.32	2.47	3.45	8.93	21.02	55.96	50.68	21.29	24.00
min(s^{ctd})	0.10	0.00	1.32	1.33	0.10	0.00	0.82	5.32	18.14	25.04	0.00
max(s^{ctd})	125.96	398.03	262.66	21.96	125.96	122.61	333.99	398.03	323.75	148.04	398.03

base case. For the financial sector, the mean of cs^{liq} increases from 41% to 54% of the yield spread, and the increase for the non-financial corporate sector registers from 33% to 49%.

For the subinvestment grade segment, the two effects described above affect the segmentation of the bond spread in different directions. The average subinvestment grade post-default price lies below 40%, thus leading to a potentially higher value of cs^{def}.[53] The CTD option effect continues to decrease cs^{def}, albeit to a smaller extent because of the lower number of deliverable bonds in the subinvestment grade sample. As Table 5.7 shows, the second effect prevails but is mitigated by the first effect. On average, cs^{def} amounts to 72% of the yield spread for the BB rating class, 76% for the B rating class, and 75% for the CCC rating class. In comparison to the investment grade rating classes where cs^{def} accounts for only 40% for the AA rating class, 45%, respectively 47%, for the A and BBB rating class, and 71% for the AAA rating class, the effect of bond liquidity remains limited for the subinvestment grade sample relative to the credit risk effect.

Naturally, the central results of Table 5.7 concern the distribution of the CDS premia across the credit risk, liquidity, and CTD premia. In comparison to Table 4.1, the credit risk premia s^{def} consistently decrease which agrees with the results for cs^{def}. For the entire sample, the average of 41.61 bp for s^{def} lies 11.08 bp below the estimate in the base case, and a comparison across the industry sectors and rating classes shows that the average decreases for every subset. A similar result applies for the minimum and maximum of s^{def}; the former decreases by 1.02 bp to 4.07 bp, the latter by 134.98 bp to 1,714.64 bp. With regard to the total decrease, the mean change of s^{def} is largest for the non-financial corporate sector and the B rating class with on average 15.53 bp and 75.01 bp. These results show that the higher the credit risk is, the higher is the impact of the CTD premium.

The average of the CDS liquidity premium s^{liq} also increases to 2.13 bp, but the small difference to the base case of 0.09 bp and a comparison of the different industry sectors and rating classes implies that the increase is not systematic. The sovereign sector and the AAA, BBB, and B rating class register a small decrease of the mean of s^{liq}, the remaining sectors slight increases.

Due to the unchanged liquidity premium, the CTD premium s^{CTD} is almost identical to the mean decrease of s^{def} with a mean of 11.57 bp. Overall, s^{CTD} fluctuates between 0.00 bp[54] and 398.03 bp with the maximum attained for the BB rating class and the non-financial corporate sector. The average of s^{CTD} is also highest for this sector at 15.43 bp and for the

[53] The same parameters as in the above example yield an associated increase of 5%.

[54] This value is obtained for a reference entity directly before the maturity of its penultimate bond. On the following day, the reference entity is excluded from the sample.

B rating class at 77.68 bp which approximately agrees with the largest average decreases for s^{def}. With regard to the premium decomposition, we observe that the credit risk premium accounts for 75% of the CDS premium. The liquidity proportion is, as in the base case, equal to 4%, and the delivery option accounts for on average 21% of the CDS premium.

These percentages are almost identical for all different industry sectors and rating classes. Due to its high number of deliverable bonds, the sovereign sector has the highest percentage for s^{CTD} at 25% and, consequently the lowest for s^{def} at 70% while the non-financial corporate sector exhibits proportions of 75% for s^{def} and 22% for s^{CTD}. Across the different rating classes, the investment grade segment tends to have a somewhat higher proportion for s^{CTD} between 29% for the AAA rating class and 21% for both the A and BBB rating class. The associated credit risk premia range between 72% and 75%. In the subinvestment grade segment, the lower number of bonds leads to a lower percentage of the CDS premium due the delivery option and thus to a higher percentage due to credit risk with values between 75% for the CCC rating class and 80% in the BB rating class.

The results of the time series analysis of the credit risk and liquidity premia are similar to those in the base case, and we do not present them here. The similarity to the base case is due to the way in which the value of the delivery option enters our model which becomes evident in Equations (5.12) and (5.13). The expected minimal recovery rate is determined from Table 5.6 for each potential default date, and the estimated credit risk and liquidity intensities are mostly scaled versions of the intensities in the base case. Therefore, the time series relation between the credit risk and liquidity premia is mostly unaffected by our inclusion of the CTD option. The time series relation between the CTD premia and the credit risk premia is also straightforward. There is a strong linear relation between the level and changes which is again due to the way in which we model the effect of the CTD option on the CDS premium.

Summarizing the results of Section 5.2, our most important findings are twofold. First, the average post-default prices for European issuers are decreasing through the delivery period of the CDS contract, but the minimal bond price exhibits a different behavior depending on the rating class. For subinvestment grade issuers, the minimum decreases over the delivery period, but the differences are limited. The investment grade segment exhibits a high bond price volatility immediately after the default event which leads to a higher potential value of the delivery option during the earlier part of the delivery period. On average, the minimal expected bond price lies at 26% of the face value for investment grade debt and 29% for subinvestment grade debt. The higher value for the subinvestment grade segment is due to the overall lower number of deliverable obligations.

Second, we obtain a CTD component that accounts for on average 17% to 29% of the CDS mid premium. Its absolute value is higher, the lower the rating of an issuer is, but relative to the mid premium, the impact is higher for the investment grade segment. The liquidity premia in the bond market become much larger when the CTD option is accounted for while they remain mostly unchanged in the CDS market. The overall demand pressure associated with positive values of s^{liq} which we identified both in the base case and in the case with explicitly correlated intensities remains unaffected by modelling the delivery option. This last result clarifies that the CTD option becomes subsumed in s^{def} when recovery rates are assumed to be constant and identical for all issues of a single issuer. When estimating default probabilities from CDS premia alone, it is therefore important to account for the CTD option in order to avoid miscalculations.

5.3 Appendix to Chapter 5

5.3.1 Analytical Solutions for the Discount Factors with Correlated Intensities

The dynamics of the default and liquidity intensities are defined as follows. First, we define the latent risk factors x and y^l through the following system of stochastic differential equations:

$$\begin{pmatrix} dx(t) \\ dy^b(t) \\ dy^{\text{ask}}(t) \\ dy^{\text{bid}}(t) \end{pmatrix} = \begin{pmatrix} \alpha - \beta x(t) \\ \mu^b \\ \mu^{\text{ask}} \\ \mu^{\text{bid}} \end{pmatrix} dt + \begin{pmatrix} \sigma\sqrt{x(t)}\, dW_x(t) \\ \eta^b\, dW_{y^b}(t) \\ \eta^{\text{ask}}\, dW_{y^{\text{ask}}}(t) \\ \eta^{\text{bid}}\, dW_{y^{\text{bid}}}(t) \end{pmatrix}, \tag{5.17}$$

with parameters α, β, $\sigma > 0$, μ^l, $\eta^l > 0$, and Brownian motions W_x and W_{y^l}, $l \in \{b, \text{ask}, \text{bid}\}$. The Brownian motions governing x and y^l, $l \in \{b, \text{ask}, \text{bid}\}$ are independent. The intensities λ and γ^l are then defined as linear combinations of the latent factors

$$\begin{pmatrix} \lambda(t) \\ \gamma^b(t) \\ \gamma^{\text{ask}}(t) \\ \gamma^{\text{bid}}(t) \end{pmatrix} = \begin{pmatrix} x(t) & + & g_b y^b(t) & + & g_{\text{ask}} y^{\text{ask}}(t) & + & g_{\text{bid}} y^{\text{bid}}(t) \\ f_b x(t) & + & y^b(t) & + & \omega_{b,\text{ask}} y^{\text{ask}}(t) & + & \omega_{b,\text{bid}} y^{\text{bid}}(t) \\ f_{\text{ask}} dx(t) & + & \omega_{b,\text{ask}} y^b(t) & + & y^{\text{ask}}(t) & + & \omega_{\text{ask,bid}} y^{\text{bid}}(t) \\ f_{\text{bid}} dx(t) & + & \omega_{b,\text{bid}} y^b(t) & + & \omega_{\text{ask,bid}} y^{\text{bid}}(t) & + & y^{\text{bid}}(t) \end{pmatrix}.$$

We only show the derivation for $E_t\left[\tilde{P}(t,\tau)\,\tilde{L}^b(t,\tau)\right]$, the other pricing factors are derived in the same way. The joint expectation for the discount factors $\tilde{P}(t,\tau)$ and $\tilde{L}^b(t,\tau)$ is given by:

$$\begin{aligned}
E_t\left[\tilde{P}(t,\tau)\cdot\tilde{L}^b(t,\tau)\right] &= E_t\left[\exp\left(-\int_t^\tau \lambda(s) + \gamma^b(s)\, ds\right)\right] \\
= \; & E_t\Bigg[\exp\Bigg(-\int_t^\tau (1+f_b)\, x(s) + (1+g_b)\, y^b(s) \\
& \quad + (g_{\text{ask}} + \omega_{b,\text{ask}})\, y^{\text{ask}}(s) + (g_{\text{bid}} + \omega_{b,\text{bid}})\, y^{\text{bid}}(s)\, ds\Bigg)\Bigg] \\
= \; & E_t\left[\exp\left(-\int_t^\tau (1+f_b)\, x(s)\, ds\right)\right]\cdot E_t\left[\exp\left(-\int_t^\tau (1+g_b)\, y^b(s)\, ds\right)\right] \\
& \cdot E_t\left[\exp\left(-\int_t^\tau (g_{\text{ask}}+\omega_{b,\text{ask}})\, y^{\text{ask}}(s)\, ds\right)\right]\cdot E_t\left[\exp\left(-\int_t^\tau (g_{\text{bid}}+\omega_{b,\text{bid}})\, y^{\text{bid}}(s)\, ds\right)\right] \\
=: \; & \underbrace{P(t,\tau,x;1+f_b)}_{:=P^b(t,\tau,x;f)}\underbrace{L\left(t,\tau,y^b;1+g_b\right) L\left(t,\tau,y^{\text{ask}};g_{\text{ask}}+\omega_{b,\text{ask}}\right) L\left(t,\tau,y^{\text{bid}};g_{\text{bid}}+\omega_{b,\text{bid}}\right)}_{:=L^b(t,\tau,y;g)},
\end{aligned}$$

where P^b and L^b are the solutions referenced in Section 5.1.1. The dynamics of the scaled latent risk factors $(1+f_b)\,x$, $(1+g_b)\,y^b$, $(g_{\text{ask}}+\omega_{b,\text{ask}})\,y^{\text{ask}}$, and $(g_{\text{bid}}+\omega_{b,\text{bid}})\,y^{\text{bid}}$ are identical to those of the original latent factors with the process parameters adjusted:

$$\begin{aligned}
d\,(1+f_b)\,x\,(t) &= [(1+f_b)\,\alpha-\beta\,(1+f_b)\,x\,(t)]\;dt+(1+f_b)\,\sigma\sqrt{x\,(t)}\;dW_x\,(t)\,,\\
d\,(1+g_b)\,y^b\,(t) &= (1+g_b)\,\mu^b\;dt+(1+g_b)\,\eta^b\;dW_{y^b}\,(t)\,,\\
d\,(g_{\text{ask}}+\omega_{b,\text{ask}})\,y^{\text{ask}}\,(t) &= (g_{\text{ask}}+\omega_{b,\text{ask}})\,\mu^{\text{ask}}\;dt+(g_{\text{ask}}+\omega_{b,\text{ask}})\,\eta^{\text{ask}}\;dW_{y^{\text{ask}}}\,(t)\,,\\
d\,(g_{\text{bid}}+\omega_{b,\text{bid}})\,y^{\text{bid}}\,(t) &= (g_{\text{bid}}+\omega_{b,\text{bid}})\,\mu^{\text{bid}}\;dt+(g_{\text{bid}}+\omega_{b,\text{bid}})\,\eta^{\text{bid}}\;dW_{y^{\text{bid}}}\,(t)\,,
\end{aligned}$$

with initial values $(1+f_b)\,x_0$, $(1+g_b)\,y_0^b$, $(g_{\text{bid}}+\omega_{b,\text{ask}})\,y_0^{\text{ask}}$, and $(g_{\text{bid}}+\omega_{b,\text{bid}})\,y_0^{\text{bid}}$.

Thus, the following well-known analytical solutions arise:

$$P\,(t,\tau,x;k) \;:=\; a_1\,(t,\tau;k)\cdot\exp\left[-a_2\,(t,\tau;k)\;k\,x\,(t)\right],$$

$$L\left(t,\tau,y^l;k\right) \;:=\; a_3^l\,(t,\tau;k)\cdot\exp\left[-a_4^l\,(t,\tau;k)\;k\,y\,(t)\right],$$

where

$$\begin{aligned}
a_1\,(t,\tau;k) &= \left(\frac{1-\kappa\,(k)}{1-\kappa\,(k)\exp\left[\phi\,(k)\,(\tau-t)\right]}\right)^{\frac{2\alpha}{\sigma^2}}\exp\left[\frac{\alpha\,(\beta+\phi\,(k))}{\sigma^2}\,(\tau-t)\right],\\
a_2\,(t,\tau;k) &= \frac{\phi\,(k)-\beta}{\sigma^2 k}+\frac{2\phi\,(k)}{\sigma^2\,k\,(\kappa\,(k)\exp\left[\phi\,(k)\,(\tau-t)\right]-1)},\\
a_3^l\,(t,\tau;k) &= \exp\left[\frac{k^2{\eta^l}^2\,(\tau-t)^3}{6}+\frac{k\mu^l\,(\tau-t)^2}{6}\right],\\
a_4^l\,(t,\tau;k) &= \tau-t,\\
\phi\,(k) &= \sqrt{2\sigma^2\,k+\beta^2},\quad \kappa\,(k)=\frac{\beta+\phi\,(k)}{\beta-\phi\,(k)}.
\end{aligned}$$

The bond and CDS pricing equations also contain $E_t\left[\tilde{P}\,(t,\tau_{i-1})\cdot\tilde{L}^b\,(t,\tau_i)\right]$. Since λ and γ^l are correlated, we also have to determine the expectation of this non-simultaneous discount factor. Without loss of generality, assume that $\tau_{i-1}=\tau_1$ and $\tau_i=\tau_2$, $\tau_1\leq\tau_2$.

Then, the definition of $\tilde{P}$ and $\tilde{L}^b$ implies that

$$\begin{aligned}
\tilde{P}(t,\tau_1)\cdot\tilde{L}^b(t,\tau_2) &= \exp\Bigg(-\int_t^{\tau_1} x(s)+g_b y^b(s)+g_{\text{ask}}y^{\text{ask}}(s)+g_{\text{bid}}y^{\text{bid}}(s)\,ds \\
&\quad -\int_t^{\tau_2} f_b x(s)+y^b(s)+\omega_{b,\text{ask}}y^{\text{ask}}(s)+\omega_{b,\text{bid}}y^{\text{bid}}(s)\,ds\Bigg) \\
&= \exp\Bigg(-\int_t^{\tau_1}(1+f_b)\,x(s)\,ds-\int_{\tau_1}^{\tau_2} f_b x(s)\,ds \\
&\quad -\int_t^{\tau_1}(1+g_b)\,y^b(s)\,ds-\int_{\tau_1}^{\tau_2} y^b(s)\,ds \\
&\quad -\int_t^{\tau_1}(g_{\text{ask}}+\omega_{b,\text{ask}})\,y^{\text{ask}}(s)\,ds-\int_{\tau_1}^{\tau_2}\omega_{b,\text{ask}}y^{\text{ask}}(s)\,ds \\
&\quad -\int_t^{\tau_1}(g_{\text{bid}}+\omega_{b,\text{bid}})\,y^{\text{bid}}(s)\,ds-\int_{\tau_1}^{\tau_2}\omega_{b,\text{bid}}y^{\text{bid}}(s)\,ds\Bigg).
\end{aligned}$$

The independence of the latent factors allows us to split up the joint expectation as

$$\begin{aligned}
E_t\left[\tilde{P}(t,\tau_1)\cdot\tilde{L}^b(t,\tau_2)\right] &= \underbrace{E_t\left[\exp\left(-\int_t^{\tau_1}(1+f_b)\,x(s)\,ds\right)\exp\left(-\int_{\tau_1}^{\tau_2} f_b x(s)\,ds\right)\right]}_{:=P^b(t,\tau_1,\tau_2,x;f)} \\
&\quad \underbrace{\begin{aligned}&\cdot E_t\left[\exp\left(-\int_t^{\tau_1}(1+g_b)\,y^b(s)\,ds\right)\exp\left(-\int_{\tau_1}^{\tau_2} y^b(s)\,ds\right)\right] \\
&\cdot E_t\Bigg[\exp\left(-\int_t^{\tau_1}(g_{\text{ask}}+\omega_{b,\text{ask}})\,y^{\text{ask}}(s)\,ds\right) \\
&\qquad \exp\left(-\int_{\tau_1}^{\tau_2}\omega_{b,\text{ask}}y^{\text{ask}}(s)\,ds\right)\Bigg] \\
&\cdot E_t\Bigg[\exp\left(-\int_t^{\tau_1}(g_{\text{bid}}+\omega_{b,\text{bid}})\,y^{\text{bid}}(s)\right) \\
&\qquad \exp\left(-\int_{\tau_1}^{\tau_2}\omega_{b,\text{bid}}y^{\text{bid}}(s)\,ds\right)\Bigg]\end{aligned}}_{:=L^b(t,\tau_1,\tau_2,y;g)}.
\end{aligned}$$

Applying the law of iterated expectation, we obtain

$$
\begin{aligned}
& E_t\left[\exp\left(-\int_t^{\tau_1}(1+f_b)\,x(s)\,ds\right)\exp\left(-\int_{\tau_1}^{\tau_2} f_b x(s)\,ds\right)\right] \\
= \;& E_t\left[\exp\left(-\int_t^{\tau_1}(1+f_b)\,x(s)\,ds\right)\underbrace{E_{\tau_1}\left[\exp\left(-\int_{\tau_1}^{\tau_2} f_b x(s)\,ds\right)\right]}_{=P(\tau_1,\tau_2,x;f_b)}\right] \\
= \;& a_1(\tau_1,\tau_2;f_b)\,E_t\left[\exp\left(-a_2(\tau_1,\tau_2;f_b)\;f_b\,x(\tau_1)\right)\exp\left(-\int_t^{\tau_1}(1+f_b)\,x(s)\,ds\right)\right],
\end{aligned}
$$

which, by the moment-generating function of x, has the following exponential-affine solution

$$
P(t,\tau_1,\tau_2,x;f_b,1+f_b) = a_1(\tau_1,\tau_2;f_b)\;b_1(t,\tau_1,\tau_2;f_b,1+f_b)\;\exp\left[-b_2(t,\tau_1,\tau_2;f_b,1+f_b)\;x(t)\right],
$$

where ϕ, a_1, and a_2 are defined as above and

$$
\begin{aligned}
b_1(t,\tau_1,\tau_2;k_1,k_2) \;=\; & \Bigg(\left[2\phi(k_2)\exp\left[\frac{\tau_1-t}{2}(\phi(k_2)+\beta)\right]\right] \\
& \cdot\Big[\sigma^2 a_2(\tau_1,\tau_2;k_1)\,k_1\left(\exp\left[\phi(k_2)(\tau_1-t)\right]-1\right)+\phi(k_2)-\beta \\
& \quad +\exp\left[\phi(k_2)(\tau_1-t)\right](\phi(k_2)+\beta)\Big]^{-1}\Bigg)^{\frac{2\alpha}{\sigma^2}},
\end{aligned}
$$

$$
\begin{aligned}
b_2(t,\tau_1,\tau_2;k_1,k_2) \;=\; & \Big[a_2(\tau_1,\tau_2;k_1)\,k_1\left[\phi(k_2)+\beta+\exp\left[\phi(k_2)(\tau_1-t)\right](\phi(k_2)-\beta)\right] \\
& \quad +2k_2\left(\exp\left[\phi(k_2)(\tau_1-t)\right]-1\right)\Big] \\
& \cdot\Big[\sigma^2 a_2(\tau_1,\tau_2;k_1)\,k_1\left(\exp\left[\phi(k_2)(\tau_1-t)\right]-1\right)+\phi(k_2)-\beta \\
& \quad +\exp\left[\phi(k_2)(\tau_1-t)\right](\phi(k_2)+\beta)\Big]^{-1}.
\end{aligned}
$$

Simultaneously, we obtain

$$
\begin{aligned}
& E_t\left[\exp\left(-\int_t^{\tau_1} k_1 y^l(s)\,ds\right)\exp\left(-\int_{\tau_1}^{\tau_2} k_2 y^l(s)\,ds\right)\right] \\
= \;& a_3^l(\tau_1,\tau_2;k_2)\,E_t\left[\exp\left(-a_4^l(\tau_1,\tau_2;k_2)\;k_2\,y^l(\tau_1)\right)\exp\left(-\int_t^{\tau_1} k_1 y^l(s)\,ds\right)\right],
\end{aligned}
$$

which has the exponential-affine solution

$$L^l\left(t,\tau_1,\tau_2,y^l;k_1,k_2\right) = a_3^l\left(\tau_1,\tau_2;k_2\right)\, b_3^l\left(t,\tau_1,\tau_2;k_1,k_2\right)\, \exp\left[-b_4^l\left(t,\tau_1,\tau_2;k_1,k_2\right)\, y^l\left(t\right)\right],$$

where a_3^l and a_4^l are defined as above and

$$\begin{aligned} b_3^l\left(t,\tau_1,\tau_2;k_1,k_2\right) &= \exp\Bigg[\frac{\eta^{l^2}k_1^2}{6}\left(\tau_1-t\right)^3 + \frac{\eta^{l^2}k_2a_4^l\left(\tau_1,\tau_2;k_2\right)-\mu^l}{2}k_1\left(\tau_1-t\right)^2 \\ &\quad + \left(\frac{\eta^{l^2}k_2a_4^l\left(\tau_1,\tau_2;k_2\right)}{2}-\mu^l\right)a_4^l\left(\tau_1,\tau_2;k_2\right)k_2\left(\tau_1-t\right)\Bigg], \\ b_4^l\left(t,\tau_1,\tau_2;k_1,k_2\right) &= a_4^l\left(\tau_1,\tau_2;k_2\right)k_2 + k_1\left(\tau_1-t\right). \end{aligned}$$

5.3.2 Correlation Factors for Credit Risk and Liquidity Intensities

The correlation between the changes of the credit risk intensity and the changes of the bond liquidity intensity is given by

$$\begin{aligned} Cor\left(d\lambda\left(t\right),d\gamma^b\left(t\right)\right) &= \left[f_b\sigma^2x\left(t\right)+g_b\eta^{b^2}+g_{\text{ask}}\omega_{b,\text{ask}}\eta^{\text{ask}^2}+g_{\text{bid}}\omega_{b,\text{bid}}\eta^{\text{bid}^2}\right] \\ &\quad \cdot\Bigg[\left(\sigma^2x\left(t\right)+g_b^2\eta^{b^2}+g_{\text{ask}}^2\eta^{\text{ask}^2}+g_{\text{bid}}^2\eta^{\text{bid}^2}\right) \\ &\quad \cdot\left(f_b^2\sigma^2x\left(t\right)+\eta^{b^2}+\omega_{b,\text{ask}}^2\eta^{\text{ask}^2}+\omega_{b,\text{bid}}^2\eta^{\text{bid}^2}\right)\Bigg]^{-\frac{1}{2}}, \end{aligned}$$

the correlation between the changes of the credit risk intensity and the changes of the CDS bid and ask liquidity intensity are:

$$\begin{aligned} Cor\left(d\lambda\left(t\right),d\gamma^{\text{ask}}\left(t\right)\right) &= \left[f_{\text{ask}}\sigma^2x\left(t\right)+g_b\omega_{b,\text{ask}}\eta^{b^2}+g_{\text{ask}}\eta^{\text{ask}^2}+g_{\text{bid}}\omega_{\text{ask,bid}}\eta^{\text{bid}^2}\right] \\ &\quad \cdot\Bigg[\left(\sigma^2x\left(t\right)+g_b^2\eta^{b^2}+g_{\text{ask}}^2\eta^{\text{ask}^2}+g_{\text{bid}}^2\eta^{\text{bid}^2}\right) \\ &\quad \cdot\left(f_{\text{ask}}^2\sigma^2x\left(t\right)+\omega_{b,\text{ask}}^2\eta^{b^2}+\eta^{\text{ask}^2}+\omega_{\text{ask,bid}}^2\eta^{\text{bid}^2}\right)\Bigg]^{-\frac{1}{2}}, \end{aligned}$$

and

$$\begin{aligned} Cor\left(d\lambda\left(t\right), d\gamma^{\mathrm{bid}}\left(t\right)\right) &= \left[f_{\mathrm{bid}}\sigma^2 x\left(t\right) + g_b \omega_{b,\mathrm{bid}} {\eta^b}^2 + g_{\mathrm{ask}}\omega_{\mathrm{ask,bid}} {\eta^{\mathrm{ask}}}^2 + g_{\mathrm{bid}} {\eta^{\mathrm{bid}}}^2\right] \\ &\cdot \left[\left(\sigma^2 x\left(t\right) + g_b^2 {\eta^b}^2 + g_{\mathrm{ask}}^2 {\eta^{\mathrm{ask}}}^2 + g_{\mathrm{bid}}^2 {\eta^{\mathrm{bid}}}^2\right)\right. \\ &\quad \left.\cdot \left(f_{\mathrm{bid}}^2 \sigma^2 x\left(t\right) + \omega_{b,\mathrm{bid}}^2 {\eta^b}^2 + \omega_{\mathrm{ask,bid}}^2 {\eta^{\mathrm{ask}}}^2 + {\eta^{\mathrm{bid}}}^2\right)\right]^{-\frac{1}{2}}. \end{aligned}$$

The correlation between the changes of the CDS ask and bid liquidity intensity equals

$$\begin{aligned} Cor\left(d\gamma^{\mathrm{ask}}\left(t\right), d\gamma^{\mathrm{bid}}\left(t\right)\right) &= \left[f_{\mathrm{ask}} f_{\mathrm{bid}}\sigma^2 x\left(t\right) + \omega_{b,\mathrm{ask}}\omega_{b,\mathrm{bid}} {\eta^b}^2 + \omega_{\mathrm{ask,bid}} {\eta^{\mathrm{ask}}}^2 + \omega_{\mathrm{ask,bid}} {\eta^{\mathrm{bid}}}^2\right] \\ &\cdot \left[\left(f_{\mathrm{ask}}^2 \sigma^2 x\left(t\right) + \omega_{b,\mathrm{ask}}^2 {\eta^b}^2 + {\eta^{\mathrm{ask}}}^2 + \omega_{\mathrm{ask,bid}}^2 {\eta^{\mathrm{bid}}}^2\right)\right. \\ &\quad \left.\cdot \left(f_{\mathrm{bid}}^2 \sigma^2 x\left(t\right) + \omega_{b,\mathrm{bid}}^2 {\eta^b}^2 + \omega_{\mathrm{ask,bid}}^2 {\eta^{\mathrm{ask}}}^2 + {\eta^{\mathrm{bid}}}^2\right)\right]^{-\frac{1}{2}}, \end{aligned}$$

the correlation between the changes of the bond liquidity intensity with the changes of the CDS ask and bid liquidity intensity are given by

$$\begin{aligned} Cor\left(d\gamma^b\left(t\right), d\gamma^{\mathrm{ask}}\left(t\right)\right) &= \left[f_b f_{\mathrm{ask}}\sigma^2 x\left(t\right) + \omega_{b,\mathrm{ask}} {\eta^b}^2 + \omega_{b,\mathrm{ask}} {\eta^{\mathrm{ask}}}^2 + \omega_{b,\mathrm{bid}}\omega_{\mathrm{ask,bid}} {\eta^{\mathrm{bid}}}^2\right] \\ &\cdot \left[\left(f_b^2 \sigma^2 x\left(t\right) + {\eta^b}^2 + \omega_{b,\mathrm{ask}}^2 {\eta^{\mathrm{ask}}}^2 + \omega_{b,\mathrm{bid}}^2 {\eta^{\mathrm{bid}}}^2\right)\right. \\ &\quad \left.\cdot \left(f_{\mathrm{ask}}^2 \sigma^2 x\left(t\right) + \omega_{b,\mathrm{ask}}^2 {\eta^b}^2 + {\eta^{\mathrm{ask}}}^2 + \omega_{\mathrm{ask,bid}}^2 {\eta^{\mathrm{bid}}}^2\right)\right]^{-\frac{1}{2}}, \end{aligned}$$

and

$$\begin{aligned} Cor\left(d\gamma^b\left(t\right), d\gamma^{\mathrm{bid}}\left(t\right)\right) &= \left[f_b f_{\mathrm{bid}}\sigma^2 x\left(t\right) + \omega_{b,\mathrm{bid}} {\eta^b}^2 + \omega_{b,\mathrm{ask}}\omega_{\mathrm{ask,bid}} {\eta^{\mathrm{ask}}}^2 + \omega_{b,\mathrm{bid}} {\eta^{\mathrm{bid}}}^2\right] \\ &\cdot \left[\left(f_b^2 \sigma^2 x\left(t\right) + {\eta^b}^2 + \omega_{b,\mathrm{ask}}^2 {\eta^{\mathrm{ask}}}^2 + \omega_{b,\mathrm{bid}}^2 {\eta^{\mathrm{bid}}}^2\right)\right. \\ &\quad \left.\cdot \left(f_{\mathrm{bid}}^2 \sigma^2 x\left(t\right) + \omega_{b,\mathrm{bid}}^2 {\eta^b}^2 + \omega_{\mathrm{ask,bid}}^2 {\eta^{\mathrm{ask}}}^2 + {\eta^{\mathrm{bid}}}^2\right)\right]^{-\frac{1}{2}}. \end{aligned}$$

5.3.3 Distribution of the Minimal Recovery Rates

For a standard beta distributed random variable $\tilde{R}$ which is limited between 0 and 1 with parameters $p > 0$ and $q > 0$, the density function β is given by

$$\beta(r; p, q) = \left[\int_0^1 t^{p-1}(1-t)^{q-1}\,dt\right]^{-1} r^{p-1}(1-r)^{q-1},$$

and the distribution function B is given by the incomplete beta function ratio:

$$B(r; p, q) = \left[\int_0^1 t^{p-1}(1-t)^{q-1}\,dt\right]^{-1} \int_0^r t^{p-1}(1-t)^{q-1}\,dt,$$

where $0 \leq r \leq 1$.

The expected value and the variance of $\tilde{R}$ are simple functions of the distribution parameters p and q:

$$\begin{aligned} \mathbf{E}\left[\tilde{R}\right] &= \frac{p}{p+q}, \\ Var\left[\tilde{R}\right] &= \frac{pq}{(p+q+1)(p+q)^2}. \end{aligned}$$

For K random variables $\tilde{R}_k$, $k = 1, \ldots, K$, which are iid distributed with density function β and distribution function B, it is well-known that the distribution function $B^{\min}$ of $\tilde{R}^{\min} = \min\{\tilde{R}_1 \ldots, \tilde{R}_K\}$ can be written as

$$\begin{aligned} B^{\min}(r) &= P\left(\min\{\tilde{R}_1 \ldots, \tilde{R}_K\} \leq r\right) = P\left(-\max\{-\tilde{R}_1 \ldots, -\tilde{R}_K\} \leq r\right) \\ &= P\left(\max\{-\tilde{R}_1 \ldots, -\tilde{R}_K\} > -r\right) = 1 - P\left(\max\{-\tilde{R}_1 \ldots, -\tilde{R}_K\} \leq -r\right) \\ &= 1 - P\left(-\tilde{R}_1 \leq -r \ldots, -\tilde{R}_K \leq -r\right) = 1 - P\left(\tilde{R}_1 > r \ldots, \tilde{R}_K > r\right) \\ &= 1 - P\left(\tilde{R}_1 > r\right) \cdot \ldots \cdot P\left(\tilde{R}_K > r\right) = 1 - P\left(\tilde{R}_1 > r\right)^K \\ &= 1 - \left(1 - P\left(\tilde{R}_1 \leq r\right)\right)^K = 1 - (1 - B(r))^K. \end{aligned}$$

The density function $\beta^{\min}$ of $\tilde{R}^{\min}$ follows as the derivative of the distribution function $B^{\min}$:

$$\beta^{\min}(r) = (1 - B(r))^{K-1} \cdot K \cdot \beta(r).$$

The expected value of $\tilde{R}^{\min}$ is then determined numerically by computing

$$E\left[R^{\min}\right] = K \cdot \int_0^1 r \cdot (1 - B(r))^{K-1} \cdot \beta(r)\,dr.$$

> Page after page of professional economic journals are filled with mathematical formulas leading the reader from sets of more or less plausible but entirely arbitrary assumptions to precisely stated but irrelevant conclusions.
>
> Wassiliy Leontief

Chapter 6

Concluding Remarks

In this thesis, we separate bond yield spreads and CDS premia into credit risk, liquidity, correlation, and delivery option components. Our main result is, contrary to conventional wisdom, that CDS markets are systematically affected by liquidity premium surcharges for protection buyers. The reason is a prevailing demand pressure that increases CDS ask premia more strongly than bid premia. Bond and CDS liquidity premia tend to exhibit a positive dependence on credit risk premia, but the precise behavior depends on the rating class. The cross-market relation of the liquidity premia can be consistently interpreted by demand relations between the bond and the CDS market, and our results are robust against the inclusion of the delivery option in CDS contracts.

In arguing against the standard perception of clear comovements in the bond and the CDS market, we expect to meet with criticism from skeptical readers. We thus conclude with some qualifying remarks.

First, our empirical analysis reveals that differences between the two markets are transient and easy to miss when weekly or monthly data is used. However, especially in deteriorating market conditions, trading strategies that rely on the comovement of bond yield spreads and CDS premia can result in severe and unexpected risk exposures that are canceled at a loss.

Second, our reduced-form model only allows us to determine price discount factors which we attribute to credit and liquidity risk because of the way they affect bond prices and CDS ask and bid premia. A shortcoming common to all reduced-form models is that it is not possible to conclusively prove that the discount factors effectively measure credit risk or liquidity only. Neglected risk factors automatically become subsumed in either the credit risk or the liquidity discount factor.

Third, we point out that our approach can only measure, but not endogenously explain the relation of credit risk and liquidity premia and of the liquidity premia across the two markets. The economic conclusions we draw from our results cannot be directly translated into testable hypotheses that have a clear foundation in market microstructure theory. This problem is especially irksome for the differences between financial and non-financial corporate reference entities and between the investment and subinvestment grade segment. The main accomplishment of this thesis lies in the documentation of these differences, and we appreciate the integration of market microstructure considerations and our pricing results as a promising area for future research.

Bibliography

V. Acharya, S. Bharath, and A. Srinivasan. Understanding the Recovery Rates on Defaulted Securities. http://faculty.london.edu/vacharya/pdf/acharya-bharath-srinivasan.pdf, 2003.

V. Acharya, S. Bharath, and A. Srinivasan. Does Industry-Wide Distress Affect Defaulted Firms? Evidence from Creditor Recoveries. *Journal of Financial Economics*, 85(3):787–821, 2007.

V. Acharya and T. Johnson. Insider Trading in Credit Derivatives. *Journal of Financial Econometrics*, 84(1):110–141, 2007.

Y. Amihud and H. Mendelson. Asset Pricing and the Bid-Ask Spread. *Journal of Financial Economics*, 17:223–249, 1986.

J. Andritzky and M. Singh. The Pricing of Credit Default Swaps During Distress. *Journal of Investment Management*, 5, 2007.

E. Asarnow and D. Edwards. Measuring Loss on Defaulted Bank Loans: A 24-Year Study. *The Journal of Commercial Lending*, 77(7):11–23, 1995.

D. Auerbach and D. Klotzbach. *Kreditderivate - Handbuch für die Bank- und Anlagepraxis*, chapter Die Bilanzierung von Kreditderivaten nach IFRS. Schaeffer-Poeschel, 2005.

D. Aunon-Nerin, D. Cossin, T. Hricko, and Z. Huang. Exploring for the Determinants of Credit Risk in Credit Default Swap Transaction Data: Is Fixed Income Markets' Information Sufficient to Evaluate Credit Risk? Working Paper, HEC-University of Lausanne and FAME, 2002.

S. Basak and D. Cuoco. An Equilibrium Model with Restricted Stock Market Participation. *Review of Financial Studies*, 11:309–241, 1998.

Basel Committee on Banking Supervision. International Convergence of Capital Measurement and Capital Standards: A Revised Framework (Basel II). http://www.bis.org/publ/bcbs107.htm, 2004.

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

C. Benkert. Explaining Credit Default Swap Premia. *Journal of Futures Markets*, 24(1): 71–92, 2004.

R. Blanco, S. Brennan, and I. Marsh. An Empirical Analysis of the Dynamic Relationship between Investment-grade Bonds and Credit Default Swaps. *Journal of Finance*, 60: 2255–2281, 2005.

D. Bongaerts, F. De Jong, and J. Driessen. Liquidity and Liquidity Risk Premia in the CDS market. Working Paper, University of Amsterdam, 2007.

British Bankers' Association. 2003/2004 Credit Derivatives Report. http://www.bba.org.uk, 2004.

British Bankers' Association. 2006 Credit Derivatives Report. http://www.bba.org.uk, 2006.

W. Bühler and X. He. Arbitrage in Credit Default Swap and Cash Bond Markets: An Empirical Study. Working Paper University of Mannheim, 2007.

J. Campbell, A. Lo, and A. MacKinlay. *The Econometrics of Financial Markets*. Princeton University Press, Princeton, New Jersey, 1997.

J. Campbell and G. Taksler. Equity Volatility and Corporate Bond Yields. *Journal of Finance*, 58(6):2321–2349, 2003.

J. Chan-Lau and Y. Kim. Equity Prices, Credit Default Swaps and Bond Spreads in Emerging Markets. *IMF Working Paper 04/27*, 2004.

L. Chen, D. Lesmond, and J. Wei. Corporate Yield Spreads and Bond Liquidity. *Journal of Finance*, 62(1):119–140, 2007.

R. Chen and L. Scott. Maximum Likelihood Estimation for a Multifactor Equilibrium Model of the Term Structure of Interest Rates. *Journal of Fixed Income*, 3(3):14–31, 1993.

P. Collin-Dufresne, R. Goldstein, and J. Martin. The Determinants of Credit Spread Changes. *Journal of Finance*, 61:2177–2207, 2001.

Committee on Payment and Settlement Systems. New Developments in Clearing and Settlement Arrangements for OTC Derivatives. http://www.bis.org/publ/cpss77.htm, 2007.

Counterparty Risk Management Policy Group II. Toward greater Financial Stability: A Private Sector Perspective. http://www.crmpolicygroup.org/docs/CRMPG-II.pdf, 2005.

Creditreform. Insolvenzen in Europa - 2004/05. Neuss, 2005.

Creditreform. Insolvenzen in Europa - 2005/06. Neuss, 2006.

M. Cremers, J. Driessen, I. Maenhout, and D. Weinbaum. Individual Stock-Option Prices and Credit Spreads. Yale ICF Working Paper No. 04-14, 2004.

M. Czaja, H. Scholz, and M. Wilkens. Interest Rate Risk of German Financial Institutions - The Impact of Level, Slope, and Curvature of the Term Structure. Catholic University of Eichstaett-Ingolstadt Working Paper, 2006.

S. Das and P. Hanouna. Credit Default Swap Spreads. *Journal of Investment Management*, 4(3):93–105, 2006.

S. Das and P. Hanouna. Implied Recovery. Working Paper, 2007.

S. Davydenko and J. Franks. Do Bankruptcy Codes Matter? A Study of Defaults in France, Germany and the UK. *Journal of Finance*, 63(2):565–608, 2008.

F. de Jong and J. Driessen. Liquidity Risk Premia in Corporate Bond Markets. Working Paper, University of Amsterdam, 2005.

Deutsche Bundesbank Monthly Report December 2004. Credit Default Swaps - Functions, Importance, and Information Content. http://www.bundesbank.de, 2004.

G. Duffee. The Relation Between Treasury Yields and Corporate Bond Yield Spreads. *Journal of Finance*, 53:2225–2241, 1998.

D. Duffie. Credit Swap Valuation. *Financial Analysts Journal*, January/February:73–87, 1999.

D. Duffie, N. Garleanu, and L. Pedersen. Valuation in Dynamic Bargaining Markets. Working Paper, GSB, Stanford, 2000.

D. Duffie and J. Liu. Recursive Valuation of Defaultable Securities and the Timing of Resolution of Uncertainty. *Annals of Applied Probability*, 6:1075–1090, 2001.

D. Duffie and K. J. Singleton. An Econometric Model of the Term Structure of Interest Rate Swap Yields. *Journal of Finance*, 52:1287–1321, 1997.

D. Duffie and K. J. Singleton. *Credit Risk: Pricing, Measurement, and Management.* Princeton Series in Finance. Princeton University Press, New Jersey, 2003.

K. Düllmann and A. Sosinska. Credit Default Swap Prices as Risk Indicators of Listed German Banks. *Financial Markets and Portfolio Management*, 21(3):269–292, 2007.

K. Düllmann and M. Trapp. Determinants of Recovery Rates for Bank Loans to US Corporate Borrowers. Working Paper, 2006.

K. Dunbar. US Corporate Default Swap Valuation: The Market Liquidity Hypothesis and Autonomous Credit Risk. University of Connecticut Working Paper 2007-08, 2007.

E. Elton, M. Gruber, D. Agrawal, and C. Mann. Explaining the Rate Spread on Corporate Bonds. *Journal of Finance*, 56:247–277, 2001.

W. Enders. *Applied Econometric Time Series.* John Wiley and Sons, Inc., New York, 1995.

J. Ericsson, K. Jacobs, and R. Oviedo-Helfenberger. The Determinants of Credit Default Swap Premia. Forthcoming Journal of Financial and Quantitative Analysis, 2008.

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

J. Ericsson, J. Reneby, and H. Wang. Can Structural Models Price Default Risk? New Evidence from Bond and Credit Derivative Markets. Working Paper, 2005.

J. Felsenheimer, P. Gisdakis, and M. Zaiser. *Active Credit Portfolio Management.* Wiley, Weinheim, 2006.

U. Foerste. *Insolvenzrecht.* C. H. Beck, München, 2006.

C. Francis, A. Kakodkar, and B. Martin. Credit Derivatives Handbook 2003. Fitch Ratings Credit Policy Special Report, 2004.

W. Gebhardt, S. Hvidkjaer, and B. Swaminathan. The Cross-Section of Expected Corporate Bond Returns: Betas or Characteristics? *Journal of Financial Economics*, 75(1):85–114, 2005.

M. Grinblatt. An Analytic Solution for Interest Rate Swap Spreads. Working Paper, Anderson School, UCLA, 1995.

R. Guha. Recovery of Face Value at Default: Empirical Evidence and Implications for Credit Risk Pricing. Working Paper, London Business School, 2003.

Y. Gündüz, T. Lüdecke, and M. Uhrig-Homburg. Trading Default Swaps via Interdealer Brokers: Issues towards an Electronic Platform. *Journal of Financial Services Research*, 32(3):141–159, 2007.

L. Güntay, D. Madan, and H. Unal. Pricing the Risk of Recovery in Default with Absolute Priority Rule Violations. *Journal of Banking and Finance*, 26(6):1001–1025, 2003.

G. Gupton, D. Gates, and L. Carty. Bank Loan Losses Given Default. *Moody's Global Credit Research, Special Comment*, 2000.

G. Gupton and R. Stein. LossCalc: Moody's Model for Predicting Loss Given Default (LGD). *Moody's Investors Service Special Comment – Global Credit Research*, 2002.

P. Harding. *A Practical Guide to the 2003 ISDA Credit Derivatives Definitions*. Euromoney Books, London, 2004.

G. Hong and A. Warga. An Empirical Study of Bond Market Transactions. *Financial Analysts's Journal*, 56:32–46, 2000.

P. Houweling, A. Mentink, and T. Vorst. Comparing Possible Proxies of Corporate Bond Liquidity. *Journal of Banking and Finance*, 29 (2005):1331–1358, 2004.

J. Hull, M. Predescu, and A. White. The Relationship between Credit Default Swap Spreads, Bond Yields, and Credit Rating Announcements. *Journal of Banking and Finance*, 28: 2789–2811, 2004.

B. Hurdal and A. Yarish. Mark-to-Market Accounting Undercuts Banks' Loan Heding. *The Risk Management Association Journal*, 85(8):28–31, 2003.

R. Jankowitsch, R. Pullirsch, and T. Veza. The Delivery Option in Credit Default Swaps. Working Paper, Vienna University of Economics and Business Administration, 2007.

S. Johansen. Statistical Analysis of Cointegration Vectors. *Journal of Economic Dynamics and Control*, 12:231–254, 1977.

S. Johansen. Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models. *Econometrica*, 49(6):1551–1580, 1991.

S. Johansen and K. Juselius. Maximum Likelihood Estimation and Inference on Cointegration - with Applications to the Demand for Money. *Oxford Bulletin of Economics and Statistics*, 52(2):169–210, 1990.

F. Joutz, S. Mansi, and W. Maxwell. The Dynamics of Corporate Credit Spreads. Texas Tech University Working Paper, 2001.

S. Kwan. Firm-Specific Information and the Correlation between Individual Stocks and Bonds. *Journal of Financial Economics*, 40:63–80, 1996.

H. Leland and K. Toft. Optimal Capital Structure, Endogenuous Bankruptcy and the Term Structure of Credit Spreads. *Journal of Finance*, 51:987–1019, 1996.

R. Litterman and J. Scheinkman. Common Factors Affecting Bond Returns. *Journal of Fixed Income*, 1(2):54–61, 1991.

F. Longstaff. Flight-to-Liquidity and Flight-to-Quality. *Journal of Business*, 77(3):511–526, 2004.

F. Longstaff, S. Mithal, and E. Neis. Corporate Yield Spreads: Default Risk or Liquidity? New Evidence from the Credit-Default Swap Market. *Journal of Finance*, 60(5):2213–2254, 2005.

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

L. Meng and O. ap Gwilym. The Characteristics and Evolution of Credit Default Swap Trading. The University of Wales School of Management and Business Research Paper 2006-3, 2006.

Moody's. Recovery Rates on Defaulted Corporate Bonds and Preferred Stocks, 1982-2003. *Moody's Investors Service, Special Comment*, pages 1–20, 2003.

Moody's. Bond Prices at Default and at Emergence from Bankruptcy for US Corporate Issuers. *Moody's Investors Service, Special Comment*, pages 1–12, 2005.

A. Nashikkar, M. Subrahmanyam, and S. Mahanti. Latent Liquidity and Corporate Bond Yield Spreads. New York University Stern School of Business Working Paper, 2007.

F. Packer and C. Suthiphongchai. Sovereign Credit Default Swaps. BIS Quarterly Review, December 2003, 2003.

Y. Pan and K. Singleton. Default and Recovery Implicit in the Term Structure of Sovereign CDS Spreads. Working Paper, 2007.

M. Pedrosa and R. Roll. Systematic Risk in Corporate Bond Credit Spreads. *Journal of Fixed Income*, 8(3):7–26, 1998.

E. Pollack. Assessing the Usage and Effect of Credit Derivatives. University of Pennsylvania Law School Working Paper, 2003.

A. Richa. Credit Derivatives: Settlement and other Operational Issues. University of Pennsylvania Law School Working Paper, 2007.

P. Sauerbier. *Bewertung von Anleihen in illiquiden Märkten.* PhD thesis, University of Mannheim, 2005.

M. Schueler and R. Galletto. Basis Trading. Working Paper, JP Morgan Credit Derivatives Marketing, 2003.

H. Scott. *International Finance: Transactions, Policy, and Regulation.* Foundation Press, New York, 2006.

J. Shulman, M. Bayless, and K. Price. Marketability and Default Influences on the Yield Premia of Speculative-Grade Debt. *Financial Management*, 22:132–141, 1993.

H. Sonnenberger and R. Dammann. *Französisches Handels- und Wirtschaftsrecht.* Verlag Recht und Wirtschaft, Frankfurt a. M., 2008.

D. Tang and H. Yan. Liquidity and Credit Default Swap Spreads. Working Paper, 2007.

C. Timmreck. *Kapitalmarktorientierte Sicherheitsäquivalente - Konzeption und Anwendung bei der Unternehmensbewertung.* Gabler, 2006.

D. Vayanos. Flight to Quality, Flight to Liquidity, and the Pricing of Risk. NBER Working Paper 10327, 2004.

J. Wooldridge. *Econometric Analysis of Cross Section and Panel Data.* MIT Press, Cambridge, Massachusetts, 2002.

Worldbank. Doing Business 2005 Report. http://www.doingbusiness.org, 2005.

F. Zhang. What Did the Credit Market Expect of Argentina Default? Evidence From Default Swap Data. Federal Reserve Board Working Paper, 2003.

H. Zhu. An Empirical Comparison of Credit Spreads between the Bond Market and the Credit Default Swap Market. *Journal of Financial Services Research*, 29(3):211–235, 2006.

Lebenslauf

Monika Trapp, geboren am 28.11.1978 in Mainz

Juni 1998	Abitur an der St. Lioba-Schule Bad Nauheim
Oktober 1998 - September 2001	**Universität Trier** Studium der Wirtschaftsmathematik
September 2000 - Juni 2001	**London School of Economics and Political Science** Auslandsstudium
Oktober 2001 - August 2004	**Universität Ulm** Studium der Wirtschaftsmathematik Abschluss: Diplom-Wirtschaftsmathematikerin
September 2004 - September 2008	**Universität Mannheim** Wissenschaftliche Mitarbeiterin Lehrstuhl für ABWL und Finanzierung