An Empirical Review of US Corporate Default Swap Valuation: The Implications of Functional Forms

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CHAPTER ONE

1.0 Introduction

The current financial literature disputes the exact period credit derivatives emerged as a tool for managing risks by banks and other lenders. However the majority seems to agree that credit derivatives evolved sometime between 1993 and 1995. Simply stated a credit derivative is designed to minimize risk and may be structured as a credit default swap (CDS), forward, or an option contract that transfers an asset's risk from one counter-party to another without transferring ownership of the underlying asset. Credit derivatives grew out of the banking sector's desire to find new innovative tools for use in reducing credit risks and for transferring these shocks more broadly throughout the financial system. The resultant effect was an increase in the sector's liquidity, and the diversifying of portfolio risks.

Kiff and Marrow (2000) suggest that credit derivatives should enhance the liquidity and efficiency of markets for risky products by facilitating risk transfer and price transparency. They are also of the view that credit derivative will also improve the price discovery process for credit risk by facilitating the trading of such risks for which cash markets are illiquid or are distorted by various factors. Given the preceding, the current recessionary economic climate of 2003 should result in a continuation in the phenomenal demand for credit derivatives as investors try to hedge their investment risk in a bad domestic and global economy.

For the time being at least, the benefits of credit derivatives seem to outweigh the risks, and as such, Alan Greenspan in an appearance before the council of foreign relations in November of 2002 suggested that financial instruments such as credit derivatives appear to have effectively spread losses from defaults by Enron, Global Crossing, Railtrack, Worldcom, Swissair, and sovereign defaulted Argentinean debt to a wider set of banks. As a result of this credit hedging, no major financial entity was bankrupted and banks operating in the industry with largely short-term leverage were able to transfer some of this liability to insurance firms, pension funds, or others with diffuse long term liabilities or no liabilities at all. This approach ensured that this fairly illiquid sector was not shut out of the credit market during that period of relatively high levels of corporate bankruptcies.

1.1 Credit Default Swaps

Credit default swaps were first introduced at the annual meeting of the International Swaps and Derivatives Association (ISDA) of 1992. Since then the global credit default swap market has experienced impressive growth and though this market is still relatively small, it is the fastest growing segment of the global derivatives market. Spurred by the recent Asian financial crisis, the traded volume in default swaps has increased dramatically. According to Reyfman and Toft (2001), globally, more than $1 Bln in default swap notional exposures to more than several dozen names is traded daily.

Credit default swaps offer protection against default of a pre-determined corporate bond issue. The CDS may be exercised either upon the occurrence of a default event or when spreads exceed certain predefined boundaries. In the event of default, a full recovery default swap will pay the principal and accrued interest in exchange for the defaulted bond. There are a number of variations of credit default swap contracts in existence, however the one that appears most popular is the one that is physically delivered, has full recovery, and carries no embedded options. As discussed elsewhere in this study, these swaps characteristically have two legs, the first is the premium leg and the second is a floating leg. The premium leg represents the stream of payments or spread to the protection seller and the floating or protection leg is the lump-sum payment to the protection buyer in the event of a default.

The credit default swap contract protects the holder of an underlying asset from counterparty risk or the losses caused by the occurrence of a credit even by the issuer. A number of studies most notably that of Hargreaves (2000) put the notional value of CDS at $400 Bln in 1999 and expect that this exponential growth will continue through 2003.

The Federal Reserves Board and the Office of the Comptroller of the currency, classifies credit derivatives as on and off balance sheet financial instruments that permit banking organizations to assume or transfer credit risk on a named or basket of assets. As discussed later in this section, the 1999 ISDA "Credit

Derivatives Definition" publication, which was amended in 2001, was a big move in standardizing the various terminologies in credit derivatives transactions.

Figure 1 displays a flowchart with a simplified illustration of a credit default swap transaction. The CDS is shown as a bilateral contract in which a periodic fee or premium is paid by a *protection buyer* to a *protection seller* in exchange for a contingent payment in the event there is the occurrence of a pre-specified credit event by the *reference entity*. The buyer either pays an upfront premium amount or makes periodic payments to the seller. The *protection buyer* of the *swap contract* obtains the right to sell the *reference obligation* for its *notional principal* when the credit event occurs.

There are a number of variations on the standard credit default swap. In a *single named credit default swap*; the payoff in the event of a default is a specific dollar amount. In a *basket credit default swap*, a group of *reference entities* are specified and the payout is based on a first, second or third-to default basis. It is important to note at this point that, a default swap will pay out only if the reference entity defaults; reductions in value unaccompanied by default do not compensate the buyer in any way. Also, the event of default must be verifiable by publicly available information or an independent auditor. Following a credit event, the generally accepted settlement convention is for the contract to be either physical or cash settled.

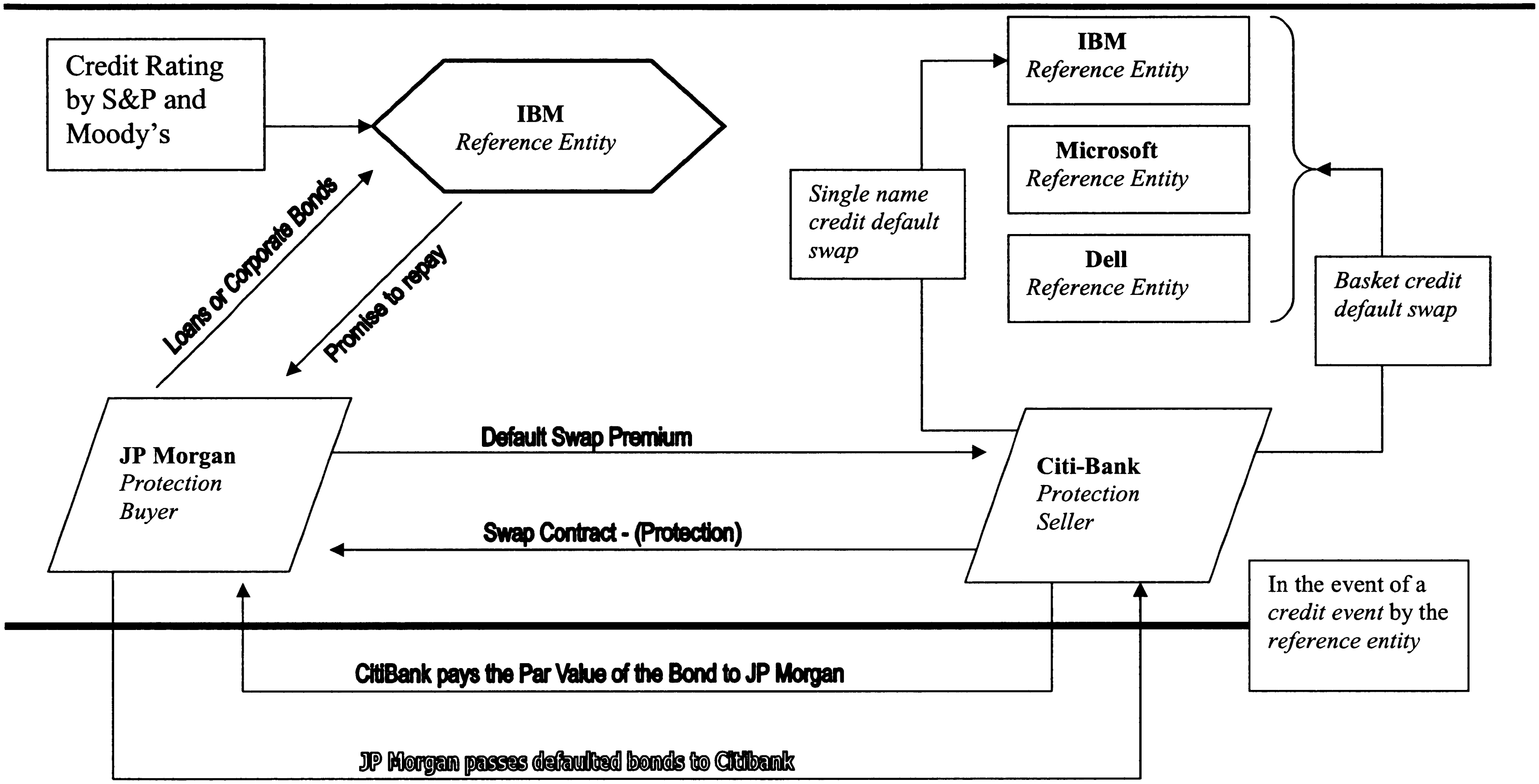
(a) A cash settlement where the buyer keeps the underlying asset(s), but is compensated by the seller for the loss incurred by the credit event. That is, the cash settlement would entail the protection buyer, receiving par minus the default price of the reference asset in cash, which is usually gathered via a poll of dealers.

(b) A physical settlement procedure, where the buyer delivers the reference obligation(s) to the seller, and in return, he receives the full notional amount or par value in cash.

In either case the value of the buyer's portfolio is restored to the initial notional amount.

In a *contingent credit default swap*, the payoff requires both a credit event and an additional trigger. The additional trigger might be a credit event with respect to another reference entity or a specified movement in some market variable. In a *dynamic credit default swap*, the notional amount determining the payoff is linked to the mark-to-market value of a portfolio of swaps.

Figure 1: Flowchart of a basic Credit Default Swap Transaction



Credit events that can trigger the payment of a credit default swap in exhibit 1 are (a) bankruptcy, (b) failure to pay, (c) obligation default, (d) obligation acceleration, (e) repudiation/moratorium, and (f) restructuring. These six credit events are based on ISDA's 1999 definition of credit events that can trigger payments on a credit default swap. Market participants have recently attempted to further narrow the list of events that could trigger payouts by eliminating so called Soft credit events. Such events, which are more akin to credit deterioration than default, have also often been the subject of competing interpretation. In April of 2002 European market participants followed the lead taken by US dealers and abandoned two such potential credit events (obligation acceleration and repudiation/moratorium).

In spite of these amendments, significant disagreement remains over the issue of debt restructuring. Although credit default swaps can be traded both with and without restructuring clauses, European banks have tended to offer contracts with ISDA's 1999 terminology, while since May 2001 US dealers have been offering contracts with a narrower definition of restructuring. The modified clause essentially limits the maturity and type of obligations that are deliverable after the occurrence of a restructuring; thereby reducing the opportunity of buyers of protection to exercise the cheapest to deliver option under physically settled credit default swaps.

Additional features in a default swap transaction worth discussing involve the handling of periodic payments and the occurrence of a default. In this instance the buyer is typically required to pay the part of the premium payment that has accrued since the last payment date, called the accrual payment. As discussed earlier, the credit event may apply to a single reference obligation, but more commonly the event refers to any one of a much broader class of debt securities, including bonds and loans. Similarly, the delivery of obligations in case of physical settlement can be restricted to a specific instrument, though more usually the buyer may choose from a list of qualifying obligations. Counter-parties can limit the value of the delivery option by restricting the range of deliverable obligations.

Table 1: The Credit Default, Interest rate and Currency Swap Market ($Blns)

Period	Total Interest Rate & Currency Swaps Outstanding	Year over Year Change	Credit Default Swaps Outstanding	Year over Year Change
1st half 01	57,305.00	-	631.50	-
2nd half 01	69,207.30	20.77%	918.87	45.51%
1st half 02	82,737.03	19.55%	1,563.48	70.15%
2nd half 02	101,318.49	22.46%	2,191.57	40.17%
1st half 03	123,899.63	22.29%	2,687.91	22.65%

Source: Bank of International Settlements Triennial Reports

1.2 The Credit Derivative Market and Credit Risks

The year 2002 was eventful for the credit derivatives market, because the default of Argentina and the collapse of Enron, lead investors to attach greater importance to the availability of liquid instruments for the hedging and trading of sovereign and corporate risk. Table 1 provides evidence to confirm the rapid growth of the Credit derivative market. The use of credit derivatives to hedge risks by BIS member banks and dealers in nearly 50 countries, has grown from $631.5 Billion in the 1st half of 2001 to $2,687.91 Billion through the first half of 20031, a rate of growth of approximately 325.64 percent over these five half yearly reporting periods.

Table 2 presents a composition of the global bond market. From this table it is apparent that the relative size of the government bond market has been steadily declining relative to the corporate bond market. This is evidenced in the contraction of the government bonds outstanding from 62.8 percent in 1990 to 52.9 percent in 2001, while the corporate bond market has grown from 27.5 percent in 1990 to 29.7 percent in 2001.

Greenspan (2002) stated that the current credit derivatives market is growing at a phenomenal rate. This observation is evidenced from table 2 which shows that the steady decline in sovereign debt and the concomitant growth in corporate debt may be indicating that investors have accepted credit derivatives as a very useful means of managing the relatively large and growing volume of credit risks that global markets handle daily. However despite the growth of the credit derivatives market, the credit default swap, which is the largest segment of the credit default market, is still significantly smaller than the derivative markets for interest rate and currency swaps, see table 1.

Table 2: Composition of the World Bond Market (In US$ Terms)

Year	World Bond Mkt	Govt Bond Mkt	% of the world Bond Mkt	Govt Bond* Mkt less Quasi-Govt & Agency	% of the world Bond Mkt	Corporate Bond Mkt	% of the world Bond Mkt	Foreign Bond Mkt	% of the world Bond Mkt	Euro Bond Mkt	% of the world Bond Mkt
1990	13,392.6	8,412.4	62.8%	na	-	3,680.8	27.5%	285.2	3.4%	1,012.3	7.6%
1991	14,926.1	9,294.6	62.3%	na	-	4,176.7	28.0%	312.6	3.4%	1,140.1	7.6%
1992	15,728.5	9,858.3	62.7%	na	-	4,351.3	27.7%	326.3	3.3%	1,190.7	7.6%
1993	17,606.6	10,976.4	62.3%	na	-	4,821.5	27.4%	426.9	3.9%	1,379.5	7.8%
1994	20,148.0	12,552.9	62.3%	na	-	5,431.9	27.0%	474.0	3.8%	1,679.0	8.3%
1995	22,150.7	13,617.4	61.5%	5,637.6	41.4%	6,002.4	27.1%	565.4	4.2%	1,942.8	8.8%
1996	23,351.8	14,034.9	60.1%	5,796.4	41.3%	6,286.9	26.9%	641.5	4.6%	2,352.6	10.1%
1997	23,688.9	13,926.2	58.8%	5,403.4	38.8%	6,362.7	26.9%	688.7	4.9%	2,708.8	11.4%
1998	26,858.2	15,405.3	57.4%	5,761.6	37.4%	7,400.5	27.6%	767.2	5.0%	3,131.2	11.7%
1999	28,574.2	16,237.7	56.8%	5,845.6	36.0%	8,267.9	28.9%	712.3	4.4%	3,479.4	12.2%
2000	29,804.1	16,314.6	54.7%	5,367.5	32.9%	8,645.5	29.0%	815.1	5.0%	4,155.3	13.9%
2001	31,348.5	16,571.7	52.9%	4,988.1	30.1%	9,312.8	29.7%	817.5	4.9%	4,550.3	14.5%

* Govt bond market has been broken into core components to highlight changes in sovereign debt instruments

Source: Merrill Lynch

The market for credit derivatives has grown in prominence not only because of its ability to disperse risk but also because of the information it contributes to enhance risk management by banks and other financial intermediaries. The rapid informal adoption of the use of credit derivatives, such as CDS for US corporate and sovereign risk diffusion by the finance community resulted in the Office of the Comptroller of the Currency (OCC) as early as 1996 issuing its consent and guidance to its 2,870 member banks[1] that use credit derivatives in an attempt to manage more efficiently the credit risk in their portfolio. Three years later in 1999 the International Swaps and Derivatives Association (ISDA) made its first formal attempt to standardize this new and emerging market by streamlining the existing documentation and definitions on default swap trading used in lending transactions, in its publication of the ISDA Credit Default Swap Derivative Definitions.

1.3 Counter-party Risk

With the exception of holders of default free US treasury instruments, investors in bonds faces the risk that the bond issuer will default on the debt. To hedge this risk investors turn to the market for credit derivatives. As previously discussed in section 1.2, credit derivatives allow investors to manage credit risk exposure of their portfolios or asset holdings, by providing insurance against deterioration in credit quality of the borrowing entity. If there is a technical default by the borrower or an actual default on the loan itself, and the bond is marked down in

[1] Office of the Comptroller of the Currency, "Credit Derivative Guidance Issued by OCC; New products used to manage Credit Risks," (August 1996)

price, the losses suffered by the investor can be recouped in part or in full through the payout made by the credit derivative.

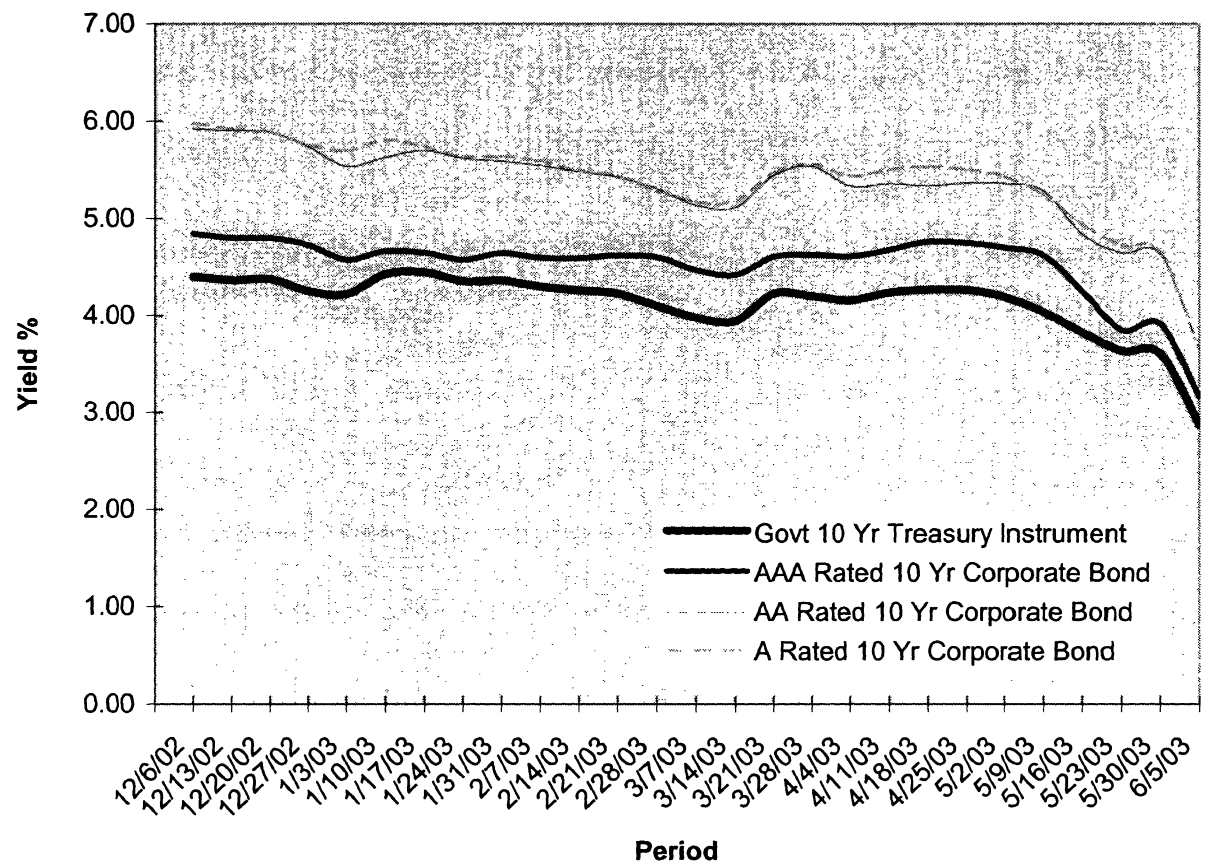
An investor is exposed to credit risk when one or more of the underlying reference entities in his portfolio experience a credit event either through inability to maintain the interest servicing or because of bankruptcy or insolvency leading to an inability to service the debt. Several observers have suggested that global markets are faced with much larger exposure to credit risk than to interest rate or currency risk. Credit risk fluctuates with business cycles and the economic circumstances of the business.

A number of measures of credit risks are available to investors for use in assessing the level of risk associated with potential borrowers. One measure is the credit rating assigned to each business by the rating agencies such as Moody's and standard and poor (S&P). These agencies undertake a formal periodic financial evaluation of all corporate and sovereign borrowers, after which a rating is announced. Moody's investor services ranking range from an AAA (Excellent corporate credit standing) to an A, which is a marginal credit position. Similarly the S&P ranks excellent corporate credit with a BBB ranking and marginal credit with a ranking of B. A more quantitative measure of credit risk is the credit risk premium, which is the spread between the yields on the same currency benchmark bonds and corporate bonds. Figure 2 illustrates the variability of the spread between the ten-year treasury instruments and the composite corporate AAA, AA and A bond rates. The chart shows a credit premium above the 10-year bench mark Treasury note for all corporate bonds, with the credit premium spread increasing as the credit quality deteriorates. The gap between the spread of the AAA and A rated bonds highlights this phenomenon. This premium between the triple A rated bonds and the double A rated is the compensation required by investors for holding risky bonds. The credit premium required will fluctuate across business and industries, depending on perceived credit risks and the state of the economy.

The pricing of credit derivatives today is closely tied to funding costs. The total rate of return swap is an obvious case, being not much more than a synthetic financing transaction or lease. Since the total return seller is effectively selling the underlying asset, the swap fee should be above the rate at which the seller can invest funds. Pricing a default swap is more complex because its economic performance is tied to specific credit events. However if it is assumed that the terms of the default swap cover all events that would affect the total rate of return on the underlying reference asset, a protection sale can be viewed as being equivalent to a fully funded long position in the reference asset. Hence the premium should be closely related to the spread between the expected total rate of return on the reference asset and the funding cost.

The wider the gap between the buyer's marginal funding cost and the seller's marginal reinvestment rate, the greater should be the incentive to trade credit derivatives.

Figure 2: Ten Year Treasury and Corporate Bond Yield



1.4 The Purpose and Contribution of this Study

One issue of growing importance both in academia and in the financial industry is corporate defaults and the accompanying credit risk. A review of the industry has shown that while overall quality of global credit has deteriorated; the volume of corporate bonds (corporate credit risk) has risen dramatically over the past few years. As previously discussed in section 1.2, the growing importance of the corporate debt component of the global debt market relative to government debt indicates a growth in global credit risk, which in itself partly explains the observed exponential growth in the use of credit default swaps. Since credit default swaps have become such important instruments in the development of the over the counter credit derivative market, this study will examine the pricing of credit default swaps using a reduced form model, when the payoff is contingent on default by a single or multiple reference entity and the presence of counter-party default risk[2].

Although many researchers have used reduced functional reduced forms with restricted assumptions for default probabilities, interest rates and recovery rates, this approach remains controversial[3]. An alternative is derived from the Heath Jarrow Morton (HJM) reduced form framework that is less restricted and where correlated defaults arise due to the fact that a firm's default intensities depend on some common

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[2] Altman et al (2002) in BIS Working papers #113 suggests that empirical evidence from reduced form models is limited.
[3] Hull and White

macro-economic factors.[4] The Heath Jarrow Morton (HJM) approach is quite popular in the literature, particularly in international finance models.

The goal of this study is to examine the empirical results of a standard Jarrow two-factor parameterization, and secondly, to extend this specification to allow the hazard rate to be a function of more than one state variable. In the Jarrow model the hazard rate is only a function of the default-free interest rate. Both specifications will be used in the pricing of market traded US corporate credit default swap. The estimates of the parameters will be compared across the standard and extended forms of the Jarrow reduced-form two-factor pricing model, across the CFSB dataset, and to the estimates obtained in similar studies to determine the relevance of these assumptions to the outcome of the results.

Jarrow's parameterization appears limited by the choice of sample size. Jarrow's sample was limited to a sample period of 52 days, 22 companies and 8 industries. For this study, the sample period will be based on 15 months of daily data, spanning 53 companies and 18 industries. The increased sample size should provide more robust estimators and better statistical significance of the outcome measure.

Additionally, the extended three-factor reduced form model will introduce a liquidity variable, which will allow the model to capture the effects of liquidity on credit default swap spreads. As of late, liquidity spreads are increasingly being viewed as a function of the volatility of the firm's assets and leverage, which are key determinants of credit risk. Finally, the study will examine whether swap rates

[4] In the Jarrow model the bankruptcy process follows a discrete state space Markov process in the firm's credit rating.

adequately reflect credit risks in the US corporate credit default swap market, and the effect of credit ratings on the overall explanatory power of both the standard and extended models. From this analysis, inferences could be made about the effectiveness of CDS pricing and the adequacy of swap rates in reflecting credit risks.

1.5 Hypotheses of the study

The study will test the following hypotheses;

(a) Market and credit risks are positively related, inseparable and dependent on the macro economy.

(b) Extending the Jarrow reduced form model to include a measure of liquidity of the corporate credit market will result in the CDS value being fully determined.

(c) The Hazard function parameter estimates are stable across sample periods.

(d) Liquidity has a positive relationship with CDS spreads and the spot rate.

1.6 Assumptions

(a) Markets are frictionless with no arbitrage opportunities;

(b) Constant exogenous recovery rate;

(c) The US Treasury is the default free rate;

(d) Default events and recovery rates are correlated and depend on the Macro Economy;

(e) The State variable is representative of several macro economic factors.

1.7 Organization of the study

The study is organized into six chapters. Chapter one provides a background to the study, giving some overview to credit derivatives, the credit derivatives market and credit risk. This background helps to develop the study's purpose and empirical contribution. Chapter two reviews the existing literature on credit derivatives pricing. The study reviewed a number of empirical approaches that have been used by various researchers and highlight the findings.

Chapter three looks at the theoretical foundation, exploring a number of theories that forms the underpinning of credit derivative pricing and credit risk. Chapter four, which is a discussion of the study's empirical procedures, presents the application of the pricing model to US corporate data. The chapter is divided into four sections, with section one discussing the data, section two outlining the choice of the default free interest rate, section three discusses the calibration of the model, the default-free interest and hazard rates dynamics. Wherein section four presents both the two-factor and extended model's valuation methodology.

Chapter five presents the result of the study's spot rate parameter estimation, the default intensity estimation and discusses the results. Chapter six concludes the study and uses the findings to make suggestions to policy and direction of future research.

CHAPTER TWO

2.0 Literature Review of Credit Default Swap Pricing

Over the last few years the pricing of bonds and other contingent claims that are the subject of default risks have been widely studied and presented in the finance literature. Following the increasingly common nomenclature in the financial literature on default, the primary types of models proposed to price these risky financial instruments are classified into two basic categories, the structural and the reduced form models.

The structural form model views bonds subject to credit risk as options written on the value of an underlying firm's assets, in so doing the models treats the bankruptcy or default process as endogenous by explicitly modeling the asset and liability structure of the company. In other words default endogenously occurs when the debt value of the firm exceeds the total value of the firm. Duffie and Singleton (1999) also suggest that these models are based on first passage of assets to a default boundary. These models have been used by Merton (1974), Chance (1990), Longstaff and Schwartz (1995), Leland and Toft (1996). Whereas structural models assume that the recovery processes are endogenously determined, these models have difficulty incorporating complex debt structures, hence different definitions of default for different debt classes. In addition these models are difficult to calibrate to market prices.

The reduced form models, which also have its proponents in industry and academia, are based on an assumed form of default intensity. In this class of valuation models default occurs unexpectedly and follows some random jump process. Belanger et al (2003) suggests that the reduced form models are less ambitious than structural models and uses risk neutral pricing of contingent claims and take the time of default as an exogenous random variable. In the event of a default the recovery rate is parameterized but does not take explicit account of hierarchy liabilities. Reduced form models are much easier calibrated to market data, however they have difficulty with the incorporation of realistic recovery assumptions.

2.1 Structural Models

In the structural model framework, stochastic process for both the value of assets and liabilities are specified and default is triggered whenever the value of assets falls below the value of liabilities. Though these class of models show success in fitting actual data, some parameterization of the structural approach uses only equity prices and balance sheet data to estimate the bankruptcy process' parameters. The rational is that debt markets are too illiquid and debt prices too noisy to be useful. However this implementation of the structural approach ignores the possibility of stock price bubbles as evidenced by the recent Internet bubble, and the misspecification that this omission implies. Additionally use of the structural approach requires information difficult to obtain since large portions of a firm's assets do not trade

2.1.1 First Generation Structural Models: The Merton approach

These models are based on the original framework developed by Merton (1974) using the principles of option pricing. A detail treatment of the Black-Scholes Option pricing framework is discussed in Appendix A. In such a framework, the default process of a company is driven by the value of the company's assets and the risk of a firm's default is therefore explicitly linked to the variability in the firm's asset value. The Merton model premises that default occurs when the value of a firm's assets is lower than that of its liabilities. Assuming that the company's debt is entirely represented by a zero-coupon bond, if the value of the firm at maturity is greater than the face value of the bond, then the bondholder gets back the face value of the bond. However, if the value of the firm is less than the face value of the bond, the equity holders get nothing and the bondholders get back the market value of the firm. The payoff at maturity of the bondholder is therefore equivalent to the face value of the bond minus a put option on the value of the firm, with a strike price equal to the face value of the bond and a maturity equal to the maturity of the bond. Following this basic intuition, Merton derived an explicit formula for default risky bonds, which can be used both to estimate the probability of default (PD) of a firm and to estimate the yield differential between a risky bond and a default-free bond[5].

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[5] In addition to Merton (1974), first generation structural-form models include Black and Cox (1976), Geske (1977), and Vasicek (1984). Each of these models tries to refine the original Merton Framework by removing one or more of the unrealistic assumptions. Black and Cox (1976) introduces the possibilities of more complex capital structures, with subordinate debt; Geske (1977) introduces interest paying debt; Vasicek (1984) introduces the distinction between short and long term liabilities, which now represents a distinctive feature of Kamakura Corp's KMV model.

Under the structural framework, all the relevant credit risk elements, including default and recovery at default are a function of the structural characteristics of the firm's asset volatility and leverage. The recovery rate is therefore an endogenous variable, as the creditor payoff is a function of the residual value of the defaulted company's assets. More precisely, under Merton's theoretical framework, the probability of default and the recovery rates are inversely related.

2.1.2 Second Generation Structural Models

Although the line of research that followed the Merton approach has proven very useful in addressing the qualitatively important aspects of pricing credit risks, it has been less successful in practical applications[6]. In response to these difficulties, an alternative approach was developed which still adopts the original framework developed by Merton as far as the default process is concerned, but eliminates the unrealistic assumption which suggests that default can occur only at the maturity of the debt when the firm's assets are no longer sufficient to cover debt obligations. Instead, it is assumed that default maturity occur at any time between the issuance and maturity of the debt and that default is triggered when the value of the firm's assets reaches a lower threshold level. These models include among others, Hull and White (1995) and Longstaff and Schwartz (1995)

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[6] Jones, Mason and Rosenfeld (1984) found that even for firms with very simple capital structures, it was no better than a Merton type model to price investment grade corporate bonds, than a naïve model that assumes no risk of default.

Despite these improvements with respect to the original Merton Framework, second generation structural form models still suffer from three main drawbacks, which represents the main reasons behind their relatively poor empirical performance. They still require estimates for the parameters of the firm's asset value, which is non-observable. Also, they cannot incorporate credit rating changes that occur quite frequently for default risky corporate debts. Finally, most structural form models assume that the value of the firm is continuous in time. As a result, the time of default can be predicted just before it happens and thus no surprise events.

2.2 Reduced Form Models

The attempt to overcome these difficulties of the structural models gave rise to reduced form models, that only uses market determined prices or parameters that can be estimated. These models include those developed by Litterman and Iben (1991), Mada and Unal (1995), Jarrow and Turnbull (1995), Jarrow, Lando and Turnbull (1997), Duffie and Singleton (1999) and Duffie (1998). Hence unlike the structural models the existing literature on implementing reduced form models concentrate on debt prices while ignoring equity prices Jarrow, Lando and Turnbull (1997) and Duffie and Singleton (1999). This occurs because the reduced form model assumes that default is an unpredictable event following some exogenous process and so does not require estimates of the value of the firm's assets. Most of the studies reviewed, present default as a random stopping time with stochastic or deterministic arrival intensity (hazard rate), while the recovery rate is usually assumed to be constant. Duffie and Singleton (1999) present a general framework to price default risky securities, wherein an exogenous hazard rate is imposed for the default event. Other leading frameworks such as the Jarrow, Lando, and Turnbull (1997) Markov chain model, extends the work of Litterman and Iben (1991) and Jarrow and Turnbull (1995) to include multiple credit ratings. Other important contributions were made by Duffie, Schroder, and Skiadas (1996), Lando (1998), Madan and Unal (1998) and Schönbucher (1998).

Reduced form models fundamentally differ from typical structural form models in the degree of predictability of the default. A typical reduced form model assumes an exogenous random variable drives default and the probability of default over any time interval is non zero. Default occurs when the random variable undergoes a discrete shift in its level. These models treat default as unpredictable Poisson events. The time at which the discrete shift will occur cannot be foretold on the basis of information available today.

Reduced form models introduce separate explicit assumptions on the dynamics of both the probability of default and recovery rates. These variables are modeled independently from the structural features of the firm, its asset volatility and leverage. Generally, reduced form models assume an exogenous recovery rate that is independent of the probability of default. More specifically, they take as primitives the behavior of the default-free interest rates, the recovery rates of defaultable bonds at default, as well as a stochastic intensity process for default. At each instant there is some probability that a firm will default on its obligation. Both this probability and the recovery rate in the event of default may vary stochastically through time. The stochastic processes determine the price of the credit risk. Although these processes are not formally linked to the firm's asset value, there is presumably some underlying relation thus Duffie and Singleton (1999) describe these alternative approaches as reduced form models.

Additionally, the empirical literature on reduced form models has focused on estimating the parameters of the following three processes, (a) the hazard process, (b) the spread process, and (c) the risk-free short rate process. Cumby and Evans (1997) considered both cross-sectional estimation of a constant hazard rate model and time series estimation of several stochastic specifications. Madan and Unal (1998) estimated recovery and hazard processes in a two-step procedure using Maximum likelihood estimation (ML) and Generalized Methods of Moments (GMM). Duffie (1998) applied ML with Kalman filtering to obtain parameter estimates of Cox, Ingersoll, and Ross (1985) processes from time-series data. Janosi, Jarrow, and Yildirim (2000) used non-linear least squares to estimate the hazard rate parameters from cross-sectional data.

Janosi *et al* (2000) specified a stochastic hazard rate that depends on the default free short rate and an equity index, whereas Jarrow (2001) estimated a constant hazard rate. The second approach refrains from modeling the default and recovery components of credit risk and directly estimates the spread process instead. Nielson and Ronn (1998) estimated a lognormal spread model using non-linear least squares on cross-sectional data. Tauren (1999) utilized GMM to estimate the credit spread dynamics as a Chan, Karolyi, Longstaff, and Sanders (1992) process. Dülmann and Windfuhr (2000) implemented a ML procedure with Kalman filtering to obtain parameter estimates of

Vasicek (1997) and CIR models for the instantaneous credit spreads. Duffie, Pedersen, and Singleton (2000) used an approximate ML method to estimate a multifactor model with Vasicek and CIR processes. The third approach considers the sum of the default free rate and the credit spread, and then estimates a model for the total risky rate. Duffie and Singleton (1997) used this approach to estimate the swap rate as a two-factor CIR process using Maximum Likelihood.

In the event of a default in the reduced form models by Jarrow and Turnbull (1995), Duffie and Singleton (1999) allows the bond to either, (a) survive and pay whatever was promised or (b) defaults and pays a recovery amount. Jarrow and Turnbull (1995) assume recoveries in the event of default and solve for the hazard rate (pseudo probability of default) by calibrating this parameter to guarantee that the model replicates an exogenously supplied credit spread. Das and Sundaram (1998) extract values of the recovery and hazard rates jointly from a bivariate model of the credit spread through use of a logit procedure. This procedure requires a time series of term structures to implement. Finally Duffie and Singleton (1999) model the credit risky interest rate as a default free interest rate plus a term that jointly adjusts for the hazard and recovery rates. This simplification is possible because they assume that recoveries in the event of a default are a fraction of the survival contingent value of a credit risky bond. This simplification allows one to model credit risky interest rates in the same way that we currently model credit risk free interest rates and reduces considerably the computational burden of implementing reduced form credit risk models.

Hull and White (2000, 2001) used a reduced form model to value credit default swaps that required them to develop estimates of the recovery rate and the probability of default in a risk neutral world. Once the recovery rate was estimated the probability of default was calculated from the prices of bonds issued by the reference entity or from the spread premium quoted for other CDS on the reference entity. They found that the pricing of vanilla CDS is relatively insensitive to the recovery rate providing the same recovery rate is used to estimate default probabilities and to value the credit default swap.

Hull and White's valuation of default swaps rests on the assumptions that default probabilities, interest rates and recovery rates are mutually independent, and relaxing these assumptions would require very complex models. However Jarrow (2001) refutes this claim with a reduced form model that allows default probabilities and recovery rates to be correlated and dependent on the macro economy. Thus the resulting reduced form model integrates market and credit risk with correlated defaults. The common macro factor used was the spot rate of interest, which was assumed to follow an extended Vasicek model in the Heath Jarrow Morton (HJM) framework.

This study will use the Jarrow (2001) Reduce form two-factor model to price credit default swaps with correlated credit and market risks, assuming both counter-party default risks and that the full term structure of the credit derivative spread is known.

2.3 Conclusion

The literature review summarized the development of credit risk models over the last 30 years, more specifically looking at how they treat the recovery rate and their relationship with the probability of default of an obligor. The models discussed together with their assumptions, advantages, drawbacks and empirical performances were outlined. The review later determined that given the drawbacks of the structural form models the reduced form models have proven to be a useful tool for analyzing the dynamics of credit default swap spreads. The review further found that the Jarrow reduced form two-factor model appeared to be one of the better reduced form models for evaluating credit default swap term structure and valuation.

CHAPTER THREE

3.0 Theoretical Foundations

The pricing of credit default swaps and other derivative securities whose payoff depends on the prices of some other underlying securities is based on the well known law of one price or no arbitrage condition. These models establish a number of simplifying assumptions, which are then used to derive the arbitrage free price, which is a function of the underlying security. As discussed in Chapter 2, the two main approaches to pricing credit derivatives are the structural models, which attempts to establish relationships between the capital structure of the issuer of securities underlying the credit derivative, and the reduced form method where pricing is done by postulating models for the stochastic process involved without any particular regard for the capital structure. The reduced form parameterization will be the model specified and estimated following Jarrow and Turnbull (1995).

3.1 Model Structure

This section lay out the model structure and the component parts of the model. Section 3.1.1 describes the general economy, Section 3.1.2 gives the financial market structure and section 3.1.3 gives the information structure available to investors.

3.1.1 The Economy

The general model of the economy is introduced in this section. For the study we consider a pure exchange, frictionless economy with a finite horizon [o, τ] for a fixed $\tau > 0$. Trading can be discrete or continuous and traded are default-free zero coupon bonds of all maturities, a default free money market account, and risky zero-coupon bonds of all maturities. The portfolio of bonds serves as the numeraire. The underlying uncertainty in the economy is represented by a filtered probability space ***(Ω, F, P)***, where ***Ω*** is the state space, ***F*** is the σ-algebra representing measurable events, and ***P*** is the empirical probability measure. Information evolves over the trading interval according to the augmented right continuous complete filtration $\{F_t: t \in [0, \tau]\}$ generated by $n \geq 1$ independent Brownian motions $\{W_1(t), W_2(t), \ldots, W_n(t): t \in [0, \tau]\}$ initialized at zero. We let $E(\bullet)$ denote expectation with respect to the probability measure ***P***.

3.1.2 The Financial Market Structure

The market is assumed to be frictionless, arbitrage-free and complete and as discussed in section 3.1 there are three types of assets that are traded in this economy, all with a face value of $1. For this market it is assumed that there exists an equivalent martingale measure (risk-neutral measure) **Q** making all the default free and risk zero coupon bond prices martingales, after normalization by the money market account. This assumption is equivalent to the statement that the markets for default free and risky debt are complete and arbitrage free.

Following Karoui and Martellini (2002), the risky asset's price is assumed to be;

$$\frac{dS_t}{S_t} = \mu dt + \sigma_t dW_t \qquad (1)$$

and the return on asset for the money market risk-free asset in continuous time is given by

$$B_t = \exp\left(\{\int_0^t r(s)ds\}\right) \text{ or in discrete time as } \frac{dB_t}{B_t} = r_t dt . \qquad (2)$$

where r_t is the risk free rate in the economy. Given the preceding asset price equations the following assumptions will be established:

Assumption 1. *The coefficients μ_t, r_t are bounded and deterministic functions of time and $r_t \geq 0$.*

Assumption 2. *The coefficients σ_t is a bounded, invertible, deterministic function of time and the universe σ_t^{-1} is also a bounded function.*

Under these assumptions, the market is complete and arbitrage free. Under the maintained assumption of arbitrage free and complete markets, the default free bond prices can be stated as the expected discounted value of a sure dollar received at time T, that is,

$$p(t, T) = \widetilde{E}_t\left(\frac{B(t)}{B(T)}\right) \qquad (3)$$

The fundamental insight of these credit risk pricing models is that under certain conditions an option's payoff can be exactly replicated by a particular dynamic investment strategy involving only the underlying security and risk-less debt. This particular strategy may be constructed as a European Option where there is no requirement for any cash infusion except at the start and allowing no cash withdrawal until the option expires. Since such a strategy replicates the options payoff at expiration, the initial cost of this perpetual or self-financing investment strategy must be identical to the option's price; otherwise an arbitrage opportunity will arise.

3.1.3 The Information structure

The filtration ***F*** represents the arrival of information over time. In the context of an uncertain time horizon and given the information available at time ***t***, conditional expectations and probabilities statements are denoted with respect to the equivalent probability measure by $\widetilde{\mathrm{E}}_t(\bullet)$ and $\widetilde{Q}_t(\bullet)$ respectively. In other words, the information set will be modeled in such a way that it encompasses at any date ***t*** information about past values of assets prices (Φ_t), and also information about whether the event of interest has occurred or not ($N_t \equiv \sigma(\tau \Lambda t)$.

Following Jarrow *et al* p(t, T) will be the time t price of a default-free zero-coupon bond paying a sure dollar at time T where $0 \leq t \leq T \leq t$. We assume that forward rates of all maturities exist and that they are defined in the continuous time case by $f(t, T)$ $\equiv \frac{-\partial}{\partial T} \log p(t,T)$. The default free spot rate denoted r_t is defined by $r_t \equiv f(t, t)$.

3.2 Derivative Pricing in the presence of Jumps

Jump processes, like continuous time are frequently used to produce a more realistic description of the underlying processes in asset pricing. This is because in some instances the underlying asset may undergo changes that can be better modeled as unanticipated finite jumps. The pricing of credit derivatives has two important occurrences of jumps that are important in pricing analyses. The first involves jumps in the underlying process of the derivative instrument, whilst the second occurrence concerns jumps in the value of the instrument itself as a result of changes in the underlying process. If the underlying processes are modeled as continuous drift diffusion processes, Ito's lemma will completely define the process of a function of the underlying process. Conversely, the effect of default of a firm is a sudden jump in the value of the firm and its liabilities, and should be described by a jump process (for example, a Poisson-process).

The Poisson Jump model is commonly used in finance to model either rare events or discrete unanticipated events such as stock price changes or the occurrence of default. The Poisson model states that the probability of the occurrence of one jump in the interval Δ_t is $h\Delta_t$ plus higher order terms, where h is called the jump intensity. In general the jump intensity may be a stochastic process and the probability of one jump over the infinitesimal interval dt is equal to $h_{(t)}dt$. The probability that no jump has occurred in the interval (O, T) is called the "Survival Probability" and is denoted by $P_{s(t)}$. The change in probability that no jump has occurred in the interval (O, T) is given by

$$dp_{s(t)} = -p_{s(t)}h_{(t)}dt \qquad (4)$$

Integrating this equation will give the survival Probability expression;

$$P_{s(t)} = e^{\left[-\int_0^{-1} h_{(s)} ds\right]} \quad (5)$$

The probability that at least one jump has occurred in the interval 0, t is simply $1 - P_{s(t)}$.

As mentioned in the preceding paragraph, the Poisson process can be used to model defaults, which are both rare and discrete. Usually the firm's default is modeled as the time of the first jump of a Poisson process. The parameter λ in the construction of the Poisson process is called the intensity of the process. The Poisson process may be characterized by the following properties.

- The Poisson process has no memory. The probability of n jumps in [t, t + s] is independent of N_t and the history of N before t. In particular a jump is more likely because the prior jump occurred at some earlier period.
- The inter-arrival time of a Poisson process $(\tau_{n+1} - \tau_n)$ are exponentially distributed with density;

$$P[(\tau_{n+1} - \tau_n) \text{ E } tdt] = \lambda e^{-\lambda t} dt \quad (6)$$

- Two or more jumps at exactly the same time have a probability of zero.
- The Poisson process is discontinuous.

3.3 Default Intensities and Survival Probabilities

At the macroeconomic level the average incidence of default depends strongly on the current state of the economy. Anecdotal evidence suggests that default rates are negatively correlated with real economic activity over the business cycle. Fons (1991) provided some empirical support for the correlation between the business cycle and default rates. Fons' (1991) study found a significant negative correlation between GNP growth rates and the deviation of actual speculative grade default rates from extended default rates.

The independent arrival of default risk over time is a fundamental assumption of the classic Poisson model. Intuitively, given a constant default intensity λ and a short time period Δ, the default time can be approximated as the first time that a coin toss results in "heads", given independent tosses of the coin, one each period, with each toss having a probability $\lambda\Delta$ of heads and $1 - \lambda\Delta$ of tails. This demonstration shows the unpredictable nature of a default simulation in the model. Following Duffie, Schroder, and Skiadas (1993), the stochastic default between counter-parties can be modeled as a *F*-stopping time τ^i valued in $[0, \infty]$. The default time for the swap is defined as $\tau^i = \tau^i \ \Lambda \ \tau^i$, the minimum of τ^i and τ^i. The event $\{ \tau > T\}$ is then the event of no default.

Though an obligor can default at any moment such occurrence are supposed to be a surprise. Further, since it is implausible to assume that default intensity is constant over time a simple extension of the basic Poisson model will allow for deterministically time varying intensities. For example, assuming the default intensity is a known constant $\lambda(1)$

during year 1, and with a rate λ(2) in year 2, conditional on surviving the first year. Then by Bayers's rule, the probability of survival for 2 years is

$$\boldsymbol{P_2 = P_1 P_{(2|1)} = e^{-[\lambda 1 + \lambda 2]}} \qquad (7)$$

More generally, over t number of years the probability of survival is represented by;

$$\boldsymbol{P_t = E_0[e^{-[\lambda 1 + \ldots + \lambda i]}]} \qquad (8)$$

where λ_i is the default intensity for year I which is uncertain but constant within each year. Under continuous time the deterministic continual variation in intensity can be represented by

$$P_t = e^{-\int_0^t \lambda(t)dt} \qquad (9)$$

Where λ_t is the intensity at time t.

Intensity based models that simulate default probabilities and timing defines default as the first arrival time **τ** of a Poisson process with some constant mean arrival rate called the intensity, denoted by **λ**. The process is characterized by;

- *A probability survival for t years of p(t) =* $e^{-\lambda t}$ *(meaning that the time to default is exponentially distributed.*
- *An expected time to default of 1/λ.*
- *The probability of default over a time period of length Δ, given survival to the beginning of this period is approximately Δλ for small Δ.*

As discussed earlier, default is modeled by a Poisson process, stopping at the first jump. The corresponding stopping time (Default time) is denoted by **τ** and the law of **τ** is exponential with parameter $\boldsymbol{\lambda_1}$. For each t < **τ**, $\boldsymbol{\lambda_1}$dt is the conditional probability of default. In the time interval (*t, t + dt*), having all information available up to *t*. Default is assumed to be independent of default free interest rates. From bankruptcy on, each promised payment is reduced to a known fraction $\delta \in [0, 1]$ denoted as a recovery rate.

3.4 Claims of the Investor

The modeling of the recovery rate process is a crucial component in any credit risk model. A common assumption in the academic literature for the recovery rate following Duffie and Singleton (1997) is that the value of a zero-coupon bond in default is proportional to its value just prior to default. An alternative assumption often used, is based upon the legal claims of bondholders in default. Under this assumption, the value of a zero coupon bond in default is proportional to the implicit accrued interest. For coupon bonds, the bondholders in default are accrued interest plus face value.

Following Jarrow (2001) and Hull and white (2000), when the recovery rate is greater than zero, it becomes necessary to make an assumption about the claim made by a bondholder in the event of a default. As stated earlier Duffie and Singleton (1997) assume that the claim is equal to the value of the bond immediately prior to default, however as pointed out by Jarrow (2001), these assumptions do not correspond to the way bankruptcy laws work in most countries. The best assumption is therefore that the claim made in the event of a default equals the face value of the bond plus accrued interest. Hence following approach two, we will let $v(t, T)$ be the time t price of a risky zero coupon bond promising to pay a dollar at time t where $t \leq T \leq \tau$. This promised dollar might not be paid in full if the firm is bankrupt[7] at time *T*. If bankrupt, the firm pays out only $\delta < 1$ dollar. The fraction δ, called the recovery rate, can depend on the seniority of the risky zero-coupon debt relative to the other liabilities of the firm.

Jarrow *et al* (1997) takes the recovery rate as an exogenously given constant. This constancy is imposed for simplicity of estimation and implies that the stochastic structure of credit spreads will be independent of the recovery rate, and dependent only on the stochastic structure of spot interest rates and the bankruptcy process. Let $\boldsymbol{\tau}^*$ represent the random time at which bankruptcy occurs. Then as discussed later, the price of the risky zero-coupon bond (presented below) is seen to be the expected discounted value of a risky dollar received at time *T*.

$$v(t, T) = \left(\frac{B(t)}{B(T)} (\delta 1_{\{\tau^* \leq T\}} + 1_{\{\tau^* > T\}}) \right) \tag{10}$$

where $1_{\{\tau^* \leq T\}}$ is the indicator function of the event $\{ \boldsymbol{\tau}^* \leq T\}$. If bankruptcy occurs prior to time t, it is assumed that claimholders will receive δ for sure at the maturity of the contract. This implies that the risky term structure simplifies and collapses to that of the default free bonds.

3.5 General Pricing Framework: pricing derivative instruments

A variety of alternative approaches to the valuation of default risk have been explored in the literature and implemented by practitioners. Most of these valuation

[7] Following Jarrow *et al,* Bankruptcy in this context covers any case of financial distress that results in the bondholders receiving less than the promised payment.

models use zero-coupon defaultable bonds as a central building block. This is partly because the prices of the risky coupon bond and the credit default swap are functions of the same recovery rate and default probabilities, hence the information extracted from both are theoretically equivalent. This is an important attribute since while CDS prices maybe easily observed directly, computing credit spreads involves the preliminary step of determining risk-free rates, which could be problematic since the CDS market tends to be illiquid. CDS prices are only quoted for a subset of reference entities that have issued bonds, and firm CDS prices are hard to find away from the most liquid points (typically five years).

To derive the price of a hypothetical derivative instrument, first assume a default-free investment with a promised payment of $1 at time T, where a conventional default free term structure model is used for valuation. The model is assumed to be structured similarly to a European styled option with no payouts until maturity, and a portfolio that is self-financing (self financing options are discussed in details in section 3.7.1). The model uses a short rate process ***r***, with a stochastic behavior that is modeled under risk neutral probability assessments, and is progressively measurable and integrable, so that an investor can place one unit of account in risk-less deposits at any time t and roll over the proceeds until time $s \geq t$ for a (time s) market value of $\exp\left(\int_t^s r_u du\right)$.

This stochastic process is defined as a set of random variables parameterized by time such as $\boldsymbol{S_t}$, $0 \leq t \leq T$, defined in a fixed probability space $\{\boldsymbol{\Omega}, \boldsymbol{F}, \boldsymbol{P}\}$[8]. A filtration $\{\boldsymbol{F_t}$:

[8] The reader can see for example Schonberger 2002 for more technical details on Stochastic calculus.

$t \geq 0\}$ of σ – algebra satisfying the usual conditions, is fixed and defines the information that is revealed by observing the evolution of the stochastic process over time t.

Risk neutral probabilities exist under extremely weak no arbitrage conditions and may be defined as the probability assessment under which the market value of a security is the expectation of the discounted present value of its cash flow, using the compounded short rate for discounting. If the short rate process changes only at continuous time intervals, then the value of a default free zero coupon bond maturing at date T with a promised payoff of $1 at maturity has a price at time T of;

$$\delta(t, T) = E_t^* \left[e^{-\int_t^T r(u)du} \right] \qquad (11)$$

Where E_t^* denotes a risk neutral expectation, that is conditional on information available at date t. This basic formulation of the continuous time pricing model problem consists of expressing the current value of a derivative security as an expectation of properly discounted future cash flows.

Risk neutral probabilities are often used in the pricing of default free securities so as to ensure that the computation of the expectation in the time t price is tractable. For these models to be empirically sound, markets must be financially complete, and in the event they are not there are some parametric specifications that are consistent with the pricing of traded securities.

For purposes of this analysis it is assumed that default on these bonds only occur on the coupon payment dates or maturity. This assumption simplifies the analyses, since it eliminates complex computations for claims on accrued interest payments for mid coupon date defaults. While this may appear somewhat unrealistic, Hull and White (2000) found that this assumption has little impact on extracted default probabilities.

Given the default-free zero-coupon bond price at time T, if the issuer defaults prior to the maturity date ***T***, then in addition to spot rate ***r*** interest rate risks are the additional uncertainty in both the timing and magnitude of the payoff to investors (section 3.7.2 provides a discussion of market and credit risks in CDS pricing). To simultaneously model these changes in derivatives pricing it is often convenient to view a zero coupon bond as a portfolio of two securities. The first is a security that pays $1 at date ***T*** if and only if the issuer survives to the maturity date T. The second is a security the pays the random amount ***R*** (recovery received at default) if default occurs before maturity. For parameterization of the pricing model, default time may be represented by ***τ***, where $1_{(\tau > 1)}$ is the indicator of the event that $\tau > t$, which has outcome $1 if the issuer doesn't default prior to time ***t*** and zero in the event of a default.

The price ***d(t, T)*** of this defaulted zero-coupon bond then becomes;

$$d(t, T) = E_t^* \left[e^{-\int_t^T r(u)du} 1_{(\tau > T)} \right] + E_t^* \left[e^{-\int_t^T r_s ds} R 1_{(\tau \le T)} \right] \quad (12)$$

If recovery after a credit event such as a default is zero then R=0, and the last term in equation 12 becomes zero so what is left will be the price of the survival contingent security which is presented as;

$$d_0(t, T) = E_t^* \left[e^{-\int_t^T r(u)du} 1_{(\tau > T)} \right] \quad (13)$$

Given this general derivative pricing framework, this study will characterize and evaluate the constant recovery price $d_0(t, T)$ under the Jarrow (2001) parameterization and extended reduced form model. This will involve characterizations of the joint distribution of the default-free term structure and the default probabilities.

3.5.1 Credit Default Swap Valuation: The Jarrow Model

This section presents the Jarrow econometric two-factor model for CDS pricing that will be used and then extended in this study. The default swap contract is being viewed as consisting of a fixed and a floating leg. The fixed leg contains the payments by a buyer to the seller and is known at the initiation of the contract. The floating leg on the other hand comprises the unknown potential payment that will be made by the seller to the buyer at some future date. For generality it is assumed that default events, treasury interest rates, and recovery rates are mutually independent, plus the claim in the event of default is the face value plus accrued interest.

When reduced form models are used to fit credit spreads it can be inferred that the state variable $r_{(t)}$ represents some common macro economic factors such as the Treasury term structure level and slope. As in Jarrow 2001, the study first utilizes a model where the economy is Markov in a single state variable, the spot rate of interest. The evolution of the spot rate process under this single factor deterministic CIR model can be represented as;

$$dr(t) = a[\ddot{r}(t) - r(t)]dt + \sigma_r dW(t) . \qquad (14)$$

Where:

(a) W_t is a standard Brownian motion under $\boldsymbol{P}$ initialized at $W(0) = 0$,

(b) $\ddot{r}(t)$ is a deterministic function chosen to match the initial zero coupon bond price curve,

(c) and where $a \neq 0$, and $\sigma_r > 0$ are constants.

The intensity function is assumed to be linear in the spot rate of interest and the evolution of the spot rate is given under the risk neutral probability Q.

$$\lambda_t = \lambda[(t), X_t] \tag{15}$$

Where :

(d) λ_0 is a deterministic function of time;

(e) λ_1 is a constant;

(f) $X_{(t)}$, state variable driving changes in default rates.

Jarrow's model constrains λ_0 to be a constant, however this study will look at possible functional forms where λ_0 is not a constant.

In calibrating the model to daily credit default swap premia we let $\boldsymbol{p(t, T)}$ be the time $\boldsymbol{t}$ price of a default free zero coupon bond paying a sure dollar at time $\boldsymbol{T}$ where $0 \leq t \leq T \leq t$. It is assumed that forward rates of all maturities exists and in the continuous case may be defined as;

$$f(t, T) \equiv \frac{-\partial}{\partial T} \log p(t,T). \tag{16}$$

The default free spot rate, denoted by $\boldsymbol{r(t)}$, is defined by $r(t) \equiv f(t, T)$.

Finally in its most general form, the fixed leg or cash payments C_T, called the default swap rate can be determined at time 0, following Jarrow (2001) as;

$$C_T = \frac{\left(\int_0^T \lambda(s) e^{-\int_0^s [r(u)+\lambda(u)] du} ds \right)}{\int_0^T v(0,s:0) ds} \tag{17}$$

Where the variable *(s)* is the credit default swap spread. The following section of this study will develop empirical versions of this model so as to simplify expression 17.

3.6 Market and Credit Risk

Credit risk is the risk of default or reductions in market value caused by changes in the credit quality of issuers or counter-parties. Figure 2 illustrates the credit risk associated with changes in spreads on corporate debt at various maturities. These changes, showing the direct effects of changes in credit quality on the prices of corporate bonds, also signal likely changes in the market values of over the counter derivative positions held by corporate counter-parties.

In reduced form models, also known as intensity based models, credit risk is jointly determined by the occurrence of default and the recovered amount at default. Economic theory tells us that market and credit risk are intrinsically related to each other and more importantly are not separable. If the market value of the firm's assets unexpectedly changes, generating market risk, this affects the probability of default, generating credit risk. This lack of separation between market and credit risk affects the determination of economic capital, which is of central importance to financial regulators. As it also affects risk adjusted return on capital used in measuring the performance of different groups within a bank.

3.9 Conclusion

Thus to implement the Jarrow reduced form model p(t, u) as well as estimates of the default process parameters (λ, δ) are needed. Chapter four lays out the theoretical foundations surrounding how these estimations may be performed. The chapter begins by developing the model components for the general economy, which then leads off into the financial market structure. The latter half of the chapter lays out a general CDS pricing framework, culminating in the Jarrow two-factor model that will be extended later.

CHAPTER FOUR

4.0 Overview

This chapter first describes the dataset used in the analyses, then leadoff into the empirical procedures. Since it was not possible to collect data on the volume of trading for the CDS, the analysis was based on quotes obtained on a cross section of corporate entities. Before fitting the Credit Default swap valuation model, a number of variables were first estimated, such as the spot rate parameters. Section 4.3 determines the forward rate curve and subsequent spot rate and liquidity parameters. Section 4.3.2 presents the Non-Linear OLS estimation procedures for the default parameter estimates. Section 4.4, the high point to this chapter, tests the valuation model by looking at the model's predictability. The chapter concludes with the extended three-factor model which introduces a liquidity parameter.

4.1 Description of the Data

To analyze the empirical specifications of the model in section 4.4, the study will require market data on defaultable swaps and default free interest rates. The data analyzed is based on weekly observations from December 31st 2002 to February 10th 2004, where $t = \frac{1}{365}, \ldots, \bar{t}$. The data is comprised of a mixture of 53 US dollar denominated AAA, AA, A, BBB, BB credit default swaps issued by 53 fortune 500 companies, across 18 industries chosen to stratify the various industry groupings such as cable/media, financial, insurance, U.S banks, telecom, energy, retail, technology and manufacturing. The CDS data set was obtained from Credit Suisse First Boston, a leading market maker for credit default swaps, which are spreads over weekly U.S. Treasury quotes. Quotations are available only on days when there is some level of liquidity in the market as evidenced either through trades or by active market making by a dealer. Bloomberg was then used to obtain bond characteristics such as maturity dates, coupon percentages and seniorities. Bloomberg was also used to obtain weekly U.S Treasury, note and bill prices that were needed for the parameter estimation of the spot rate process. The Credit Suisse First Boston credit default swap dataset is comprised of quotes for contracts of maturities 1 through 6 years. During the sample period there are 59 weeks of default swap quotes per reference entity.

In reality since most of the credit default swaps trading activity is within the 5-year time to maturity group, the price quotes on the 5 year CDS premia will be used in the study's pricing analyses. Default parameter estimates were calculated using ½ of the observable data; the remaining ½ was used for forecasting and out of sample testing of the predictability of the closed form model.

4.2 Choosing the Default Free Interest Rate

As stated in the preceding section the default swap valuation model requires a term structure for default free interest rates as input data. The preponderance of empirical papers uses the Government's Treasury rates as the default free curve. For this study it is assumed that the US Treasury rates are the benchmark zero default rates.

4.3 Calibration of the Model

The empirical formulation of the reduced form model discussed in section 3.7.1 requires data on the Treasury yield curve, the credit risky curve applicable to the term structure of the CDS, the binomial structure of the hazard rate and the recovery rate of the reference entity in the event of a default.

4.3.1 Spot Rate

In calibrating the model to match the observed default swap quote term structure, the study first estimated the parameters of the spot rate process. Following Jarrow *et al* (2001) the inputs to the spot rate process are the forward rate curves and the spot rate parameters (θ, α, σ). The forward rate curve is estimated from currently available prices for the spot rates of US treasury instruments[9]. In deriving the forward rate[10], the period T-1 to T forward rate is given by

$$f_{T-1,T} = \frac{(1+y_T)^T}{(1+y_{T-1})^{T-1}} \tag{18}$$

where y_T is the date T yield and y_{T-1} is the date T-1 yield. More generally, the forward rate from any date "t" to date T is given by

[9] Note that the spot and forward rate curves provide identical information. Having information on one leads easily to the construction of the other.
[10] Appendix B provides a Microsoft Excel Representation of the Excel Model used to calculate the study's forward rates.

$$(1+f_{t,T})^{T-t} = \frac{(1+y_T)^T}{(1+y_t)^t} \tag{19}$$

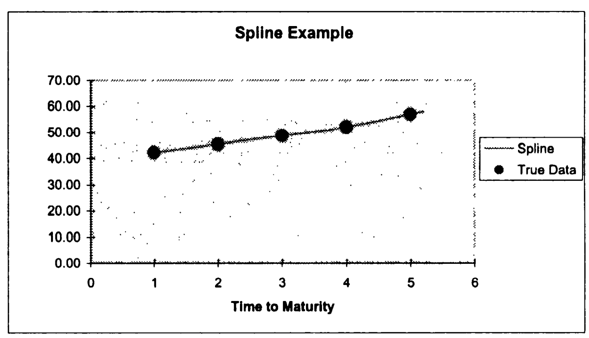
Solving for the forward rate, we obtain

$$f_{t,T} = \left(\frac{(1+y_T)^T}{(1+y_t)^t}\right)^{1/(T-t)} - 1 \tag{20}$$

A cubic spline piecewise interpolation is then fitted to the forward rate data to ensure the maximum smoothness of the forward rate curve. Figure 4 presents a CDS forward curve constructed from the corresponding spot CDS rates.

Figure 4: A Cubic Spline Piecewise interpolation

Time to Maturity	True Data	Time to Maturity	Spline
1	42.163	1.00	42.163
2	45.404	1.20	42.805
3	48.645	1.40	43.449
4	51.887	1.60	44.096
5	56.872	1.80	44.747
		2.00	45.404
		2.20	46.067
		2.40	46.730
		2.60	47.386
		2.80	48.027
		3.00	48.645
		3.20	49.240
		3.40	49.833
		3.60	50.453
		3.80	51.128
		4.00	51.887
		4.20	52.750
		4.40	53.702
		4.60	54.721
		4.80	55.785
		5.00	56.872
		5.20	57.959
		5.40	59.023
		5.60	60.042
		5.80	60.994
		6.00	61.857



The pricing of these interest sensitive instruments depend on the availability of several points on the forward curve that has to be obtained from a finite number of observed points in the market. Given this fact, if the researcher is able to fit an intuitively smooth forward rate curve, then this would result in a yield curve that provides a sound basis for implementing the no arbitrage term structure CIR model.

To interpolate between the collection of known forward rate points (x_0, y_0), (x_1, y_1), …, (x_{i-1}, y_{i-1}), (x_i, y_i), (x_{i+1}, y_{i+1}), …, and (x_n, y_n), a third degree polynomial is constructed between each point. The equation to the left of point (x_i, y_i) is indicated as f_i with a y value of $f_i(x_i)$ at point x_i. Similarly the equation to the right of point of point (x_i, y_i) is indicated as f_{i+1} with a y value of $f_{i+1}(x_i)$ at point x_i.

The cubic spline model demonstrated in Figure 4 was derived using Microsoft's Excel application. The cross-sectional forward rate points were used in the spline model to produce a smoothed forward rate curve.

For the spot rate parameter estimates, the procedure followed uses a no arbitrage term structure CIR model, which is essentially an extended Vasicek model. The CIR model was chosen because of its desirable mean reverting, Gaussian, affine and positive characteristics. These stochastic variable models implicitly assume that the term structure is flat or that all interest rates move up or down in line with each other. Additionally, these models can be readily extended to incorporate a multi-factor analysis, which will be exploited in later analyses.

Taking the time to maturity as T-t ε {3 months, 6 months, 1, 2, 3, 4, 5, 6, 10 years}, the longest time to maturity of a treasury bond closest to 30 years. A fairly simple specification of the model to be estimated in SAS can be represented as;

$$Treasury_t = Treasury_{t-1} + \kappa\,(\theta - Treasury_{t-1}) \qquad (21)$$

The sample variance, mean reversion parameter and long term mean is computed using the smoothed forward rate curves previously generated over the sample period. The parameter estimates and the standard errors for this non-liner regression are;

(a) $\kappa = 0.001714$ (0.0237)

(b) $\theta = 0.02967$ (0.1737)

(c) $\sigma_r = 0.0000684$ (0.00037)

4.3.2 Liquidity Parameter Estimates

To estimate the three-factor reduced form model the term structure estimates for the liquidity process was estimated empirically following the procedure of section 4.3.1. The sample's volatility, long-term mean and reversion factor were computed from the smoothed CSFB liquidity index forward rate curve. The estimates and standard error are presented below;

(d) $\kappa = 0.10$ (0.00321)

(e) $\theta = 0.80$ (0.02976)

(f) $\sigma_l = 0.0010$ (0.00002)

Chen *et al* (2004) found that changes in liquidity and credit ratings alone explain 33% of cross-sectional variations in investment and speculative grade bond spreads. Given the importance of liquidity in bond pricing, it is believed that the introduction of this parameter in the CDS pricing model will help to improve the explanatory power of the model and explain the cross-sectional variation in the CDS spreads. A review of the empirical literature indicates that the usage of a liquidity parameter in the pricing of credit default swaps has never been undertaken before, hence this approach will add to the growing CDS pricing debate and literature. Section 4.5 presents the extended hazard function, which incorporates the liquidity variable.

4.3.3 Default Parameter Estimates

Following a popular approach used by the academic literature, the issuer's default intensity can be modeled as following a stochastic Poisson process, characterized by jumps in the process. The study's default parameter estimates were obtained by using non-linear OLS to fit the term structures of default swap quotes to the estimated arbitrage free spot rate evolution. The non-linear regression procedure is implemented using both cross-sectional and time series observations of swap premia.

Given the spot rate parameter estimates of θ, α, and σ from the spot rate evolution process and the term structure of the swap prices, λ_0 and λ_1 in equation 22 are inverted, to obtain the parameter estimates (using a sums of squared error minimizing procedure).

$$\lambda_{(t)} = \max\left[\lambda_{0(t)} + \lambda_1 r_{(t)}, 0\right] \tag{22}$$

Where $\lambda_0(t) \geq 0$ is a deterministic function of time "t" and λ_1 is a constant. In this formulation, the (pseudo) probability of default per unit of time is assumed to be the maximum of a linear function of the spot rate $r(t)$ and zero. The maximum operator is needed in the expression to ensure that the intensity function doesn't become negative.

The intercept of the intensity process is a deterministic function that is restricted to be a constant. Since this model has only two parameters, there will be errors in matching the term structure of default swap quotes. Hence the parameters were chosen to minimize the sum of squared error between the theoretical and market quotes.

4.3.4 The Recovery Rate

There are two approaches for the specification of the recovery rate. The first is to consider it as just another parameter, and estimate it from the data along with the other parameters. The second method is to *a priori* fix a value. A number of researchers in the economic literature suggests that although the first method seems preferable, it turns out that it is hard to identify the recovery rate from the data, see Duffee (1998 p.203), Duffie and Singleton (1999, p. 705) and Houweling and Vorst (2001 p. 16). This may pose a problem for some applications; fortunately this does not affect the pricing of credit default swaps. Houweling and Vorst (2001) found that the pricing of default swap premium is relatively insensitive to the assumed recovery rate. As such the study assumes a constant recovery rate across the observation period.

4.4 Credit Default Swap Valuation

From the preceding analyses and given the constant recovery rate, $\delta_{(t)} = \delta$, where δ is a constant. The fair value of a named credit default swap can be easily computed using equation 23, as outlined in Jarrow (2001). As mentioned in section 4.1 the CDS data set was subdivided into 2 sets for estimation and forecasting. Dataset 2 will now be used to test the predictability of equation 23, to see how accurately the simulated prices match market prices.

$$C_T = \frac{\int_0^T [\lambda_0(s) + \lambda_1\{\mu_0(0,s) - (1+\lambda_1)\sigma_{01}(0,s)\}]v(0,s:0)ds}{\int_0^T v(0,s:0)ds} \qquad (23)$$

4.5 Extending the Jarrow Reduced Form Model

As discussed in Chapter One, section 1.4, this study will extend the Jarrow Reduced form two-factor model by including a variable to capture liquidity in the corporate credit market, which has become a significant component of the global credit market. Following Fleming (2003) liquidity is defined as a barometer of market conditions, which signals the willingness of market makers to commit capital and take risks in financial markets. In addition, Fleming (2003) found that of all the popularly used liquidity proxies (such as quotes and trade sizes), the bid-ask spread (the difference between bid and offer prices) is a superior measure for tracking liquidity. The credit liquidity data is obtained from the Credit Suisse First Boston's (CSFB) Liquid U.S. Corporate Index (LUCI), which is derived from daily, weekly and/or monthly bid ask data. The index is comprised of 543 issues with a total market capitalization of $545.93 Billion as of 11/01/02.

Given the spot rate parameter estimates from section 4.3.2 and the term structure of the swap prices, the non linear estimation process is repeated, but this time including a second explanatory variable, the LUCI – liquidity measure, denoted L_t. It is assumed that as liquidity increases in the corporate credit market, the price of the CDS will increase, hence the coefficient of L_t will be positive. Therefore the extended specification of the hazard function will be as follows;

$$\lambda_{(t)} = \max\left[\lambda_{0(t)} + \lambda_1 r_{(t)} + \lambda_2 l_{(t)}, 0\right] \tag{24}$$

Given the constant recovery rate of section 4.4, the fair value of a named credit default swap can be easily computed under the extended model now using equation 25, an extension to the Jarrow (2001) model.

$$C_T = \frac{\int_0^T \left[\lambda_0(s) + \lambda_1\{\mu_0(0,s) - (1+\lambda_1)\sigma_{01}(0,s)\} + \lambda_2\{\mu_0(0,s) - (1+\lambda_2)\sigma_{02}(0,s)\}\right] v(0,s:0)ds}{\int_0^T v(0,s:0)ds} \tag{25}$$

4.6 Conclusion

This chapter describes the data and lays out the empirical procedures of the study. The chapter starts out by reviewing the CSFB CDS dataset, which covers the sample period 12/1/02 to 2/10/04. The sample covers 53 companies across 18 industries. The empirical procedure lays out the processes for estimating the parameters of the Jarrow reduced form model, which will be used in chapter 5 in the CDS valuation exercises. In addition to the estimation of the Jarrow two-factor parameters, the chapter also develops on the three-factor model, describing the liquidity parameter and outlining the source of the data for this parameter. Both the spot rate and the liquidity term structure estimates are calculated and presented.

CHAPTER FIVE

5.0 Overview

This chapter first discusses the properties of the default swap dataset and then implements an approximate default swap pricing method often applied by financial market participants. The study then presents the results of applying a reduced form credit risk model to the data set. The chapter concludes by estimating the three-factor model and testing the model with both "in" and "out" sample data. Since it was not possible to collect data on the volume of trading for the CDS, the analysis was based on quotes obtained on a cross section of corporate entities.

5.1 Discussion of the Results

Figure 3 plots GECC CDS premia and the U.S. Treasury yields of corresponding maturity.

Figure 3: Credit default Swap Spreads

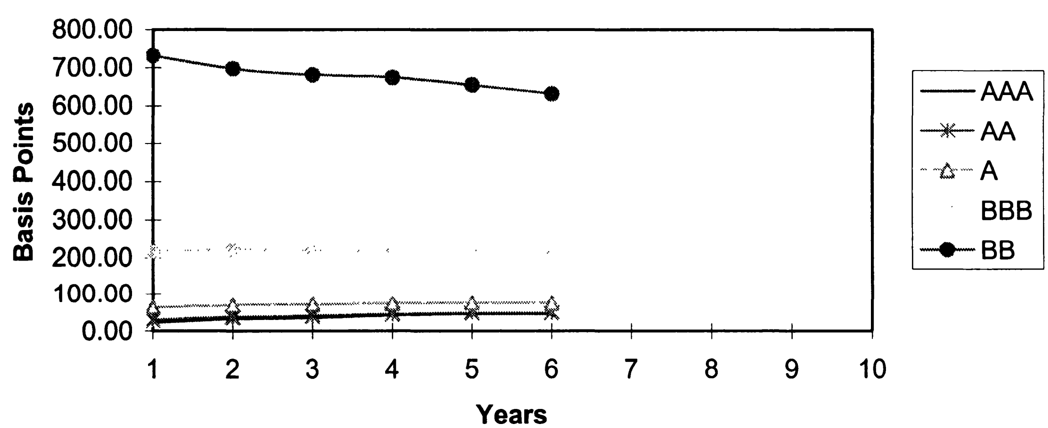


Table 3 summarizes characteristics of the sample's default swap quotes. The table shows the average CDS quotes by industry and credit rating over the observation period for each of the listed referenced entity. This information, which is also modeled in Figure 2, depicts the average premia curves for each rating category, and shows the spread above Treasury. The table also shows that the average cross-sectional spread for each entity increases with the maturity of the swap.

Table 4, which presents the sample's descriptive statistic, shows that the mean spread increases as credit rating increases for the 5yr CDS. This is important because anecdotal evidence suggests that credit rating is an important determinant of default premiums, and as Houweling et al (2002) suggests, "Average premiums move linearly with credit quality", so average premium appears to increase with an increase in credit quality. Table 5 presents the non-linear regression results of the average default swap parameters over the sample period, measured in basis points. The average intensity parameter estimates for λ_0 ranged from a low of 11.81 for E.I. Dupont to a high of 1694.91 for Qwest, whilst the λ_1 estimate ranged from a low of 0.011 for Visteon Corp to a high of 29.07 for Computer Associates of Long Island, NY. All parameters were found to be statistically different from zero, and with R^2 values above 90%. Since the study used estimated hazard functions derived from the credit default swap premia, it is believed that this will give a fairly good representation of the default and credit risk relationship. From the analyses, and consistent with Jarrow's findings, λ_1 is positive indicating that as interest rates increase, the likelihood of default also increases, an observation that conforms to economic principle.

The hazard rate functions of all 53 firms had root mean errors of less than 0 basis points. These fitting errors compares well since the root mean square error, a kind of generalized standard deviation, which measures differences between subgroups or relationships between variables is close to or less than zero. These small errors are evidence that the CDS valuation model is relatively successful in capturing both the level and variation in default and credit risks.

Using these estimated parameter values for the hazard function; the study then used the closed form expression in equation 23 to solve for the credit default premia. Summary statistics for the difference between the implied and the market credit default swap premia are reported in Table 6. These summary statistics include the average differences with their respective t-statistics, the minimum and maximum values of the difference, and the serial correlation of the difference. From table 6 the pricing errors range from being positive to slightly negative for the study's reference entities indicating that on average the model does a good job of pricing the CDS premia observed in the market. The t-statistics show that approximately 90 percent of the average differences of the sample is statistically significant.

Although, the average differences are generally all positive (except Lockheed Martin Corp, Rohm & Haas and Altria Grp), there is significant cross-sectional variation in the average differences across credit rating. For example in the AAA category, the average differences range from low values of 0.98 basis points for AIG to 45.12 basis points for GE and in the A category a low of 4.82 basis points for Dell to 45.82 basis points for Household Finance Corp, respectively. The cross-sectional mean and standard deviation of the average differences are 71.78 and 147.18 basis points respectively. This appears consistent with Duffie (1999) who suggests that reduce form models have difficulty explaining the observed term structure of credit spreads across firms of different qualities. In particular, such models have difficulty generating both relatively flat yield spreads when firms have low credit risk and steeper yield spreads when firms have higher credit risk. It is believed that this shortcoming can be overcome by extending the two-parameter hazard function model to incorporate a parameter that measures liquidity of the corporate credit market, since it is believed that the level of liquidity in the market place can have a significant effect on prices. The extension of the model to accommodate this liquidity parameter was discussed in Chapter 4, section 4.5 and the estimated results presented in section 5.1.1.

5.1.1 Results of the Extended Three-Factor Reduced Form Model

Table 7 presents the parameter estimates for the extended reduced form model discussed in chapter 4, section 4.5. CSFB Liquidity data measured in basis points was added to the original sample allowing the study to add a liquidity variable to the original model. Table 7 demonstrates that the average intensity parameter estimate for λ_0 ranged from a low of 3.873 for Citigroup to a high of 1693.57 basis points for Qwest. The estimates for λ_1 ranged from a low of 0.0268 for Ace Ltd to a high of 12.9324 for Computer Assoc, whilst the λ_2 estimate ranged from a low of 0.3731 for Ace Ltd to a high of 137.7015 for Computer Assoc. All estimates were statistically different from zero, with R^2 above the 90% level.

Consistent with the earlier discussion in section 5.1, the root mean error of the estimates were all less than zero, and λ_1 was found to be positive, indicating that as interest rates increases, the likelihood of default also rises. Thus resulting in the study's acceptance of hypothesis one. Additionally, the extended model also returned positive parameter estimates for λ_2, indicating that as liquidity increases the prices of the CDS also increases, thereby offsetting the excess liquidity in the market place. Also, the parameter estimates for λ_2 were larger that those obtained for λ_1 indicating that liquidity had a greater influence in explaining the CDS spreads than the spot rate. This is consistent with results obtained by Chen *et al* (2004) in their work in examining the importance of liquidity in corporate yield spreads.

Table 8 presents the variance of the implied and market CDS prices, based on the closed form expression in equation 25. The results also include summary statistics such as the t-Stats, Min and Max values of the differences between the implied and actual CDS prices. As with the earlier specification discussed in section 5.1, the pricing variance ranges from positive to slightly negative. This finding appears to compliment a recent study by Longstaff *et al* (2004) who suggests that the market prices of credit risk may be larger than observed. The cross-sectional standard deviation of 148.11 suggests that like the Jarrow model the extended model also shows significant variation across credit ratings. However, the model's cross-sectional mean of 67.49 indicates an improvement of the extended model's explanatory power over the original Jarrow model and thereby highlighting an implication of functional forms.

Given the variance of the implied to the observed market prices, the study can reject the hypothesis that the inclusion of the liquidity measure would fully determine the CDS valuation procedure. However, though the extended model did not fully determine the CDS valuation, its explanatory power did outperform the original Jarrow model. As evidenced from the discussion in the previous paragraph, the cross-sectional mean of 67.49 was a 4 basis point improvement over the Jarrow model's results in Table 5.

The average differences in CDS prices per business presented in Table 8, appear to be in distinct ranges along the lines of credit quality. The double AA's appear to range between 3.66 (DD) to 7.05 (WMT), the single A ranging from 4.44 (DELL) to 46.22 (DOW), BBB ranging from –40.58 (MOT) to 170.04 (FON), BB ranging from 186.69 (GPS) to 300.5 (GLW) and B 1012.88 (QUS). Cross-sectional variation on the other hand appears to move inversely with credit quality. This variation could be due in part to one or a combination of the following observations:

(a) Inadvertent under-pricing of credit risk by the major Hedge Funds;

(b) The models inability to capture the effects of institutional discounts which could lead to a net basis point reduction of current observed pricing;

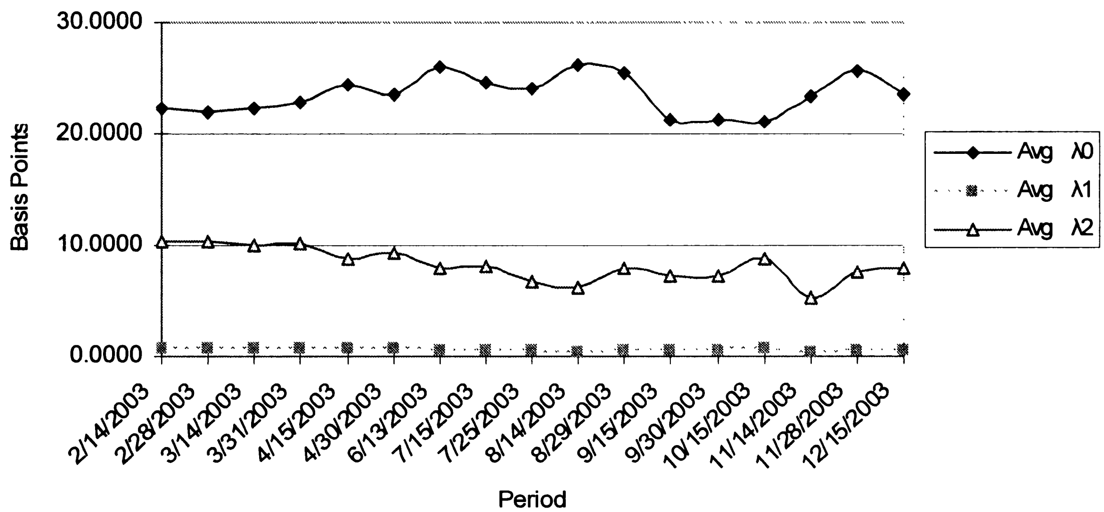
(c) Cross sectional variations could be due to credit rating changes among businesses, which was more evident during 1Q03.

(d) The CDS' own level of liquidity or illiquidity; Chen *et al* (2004) suggests that the liquidity effect in Bond spreads remains significant even after controlling for several yield spread factors such as credit ratings, maturity and tax effects.

5.1.2 Stability of the Study's Parameter Estimates

To determine the stability of the parameter estimates presented in both tables 5 and 7, the sample was subdivided into bi-weekly increments and the coefficients of the parameters estimated for each period. Table 9 presents the bi-weekly estimates for IBM, and figure 5 gives a graphical representation of the data.

Figure 5: IBM Hazard Function Parameter Estimates



From both table 9 and the exhibit in figure 5 it can be seen that the parameters appear stable across both the sample and the forecasting period.

This exercise was extended to include other reference entities so as to further test the reliability and stability of the parameter estimates. Table 10 presents the parameter estimates for both the first half of the dataset; 12/31/02 to 7/25/03 and the second half used for forecasting 7/28/03 to 02/10/04. The summary statistics presented in table 11 shows that both sets of estimates are highly correlated, and are not significantly different from each other[11]. Thereby indicating that all parameter estimates were stable across both periods of the study. This finding is thus consistent with Jarrow (2000) where the parameter estimates where shown to be consistent across the study period.

5.1.3 Testing the functional forms on both in and out-Sample Data

Tables 12 through 15 displays the effects of credit quality on CDS prices and through the model's *goodness of fit* (R^2), shows how well the forecasted models simulate observed prices in the market place. The results appear mixed for both models. While the in sample extended model appear to be far superior[12] to the in sample two factor model, the extended out of sample model appears to return a marginally better fit than the corresponding out of sample two factor model as indicated by the R^2 presented. In terms of pricing volatilities, both the Jarrow and extended out sample models indicated that a 1 basis point change in the observed model resulted in a less than 1 basis point change in observed prices. On the other hand, the in sample models produced a 1 for 1 basis point change, thereby indicating that as we move out of sample the model becomes less

[11] Since the study is only interested in whether the second sample is different from the first, a one tail test is relevant. The p-value of the observed statistic for λ_0 is 0.5. Since the value is greater than 0.05, the second sample is not significantly different from the first.

[12] The extended models in-sample R^2 of 93% was far superior to that of the Jarrow model which returned a 87% R^2

responsive to basis point changes. Additionally, the analyses involving the inclusion of credit quality proxies for both models was found to be significant indicating that credit quality is also an important variable in the pricing of credit default swaps.

The intercept, $\alpha_{0,}$ was found to be positive and greater than zero in all cases, suggesting the influence of other factors on CDS prices, other than the short rate and liquidity. The factors appear to be more apparent as the study moves from in sample to out-sample, which could be due to one or a combination of the cross sectional variation drivers discussed in section 5.1.1.

Table 3: Summary Statistics showing the average 1 to 6 year spreads of the listed reference entities and their associated credit ratings.

Industry	Issuer	Ticker	MDY	S&P	1Y	2Y	3Y	4Y	5Y	6Y
Retail - Food	Albertson's Inc	ABS	Baa1	BBB	73.90	74.76	75.61	76.47	80.93	79.58
Insurance	ACE Ltd	ACE	A3	BBB+	95.47	95.47	95.47	95.47	99.12	40.91
Insurance	American International Group	AIG	Aaa	AAA	13.49	17.49	20.49	23.49	33.50	26.49
Technology - Computer	Arrow Electronics Inc	ARW	Baa3	BBB-	300.14	300.99	301.84	301.27	289.66	286.27
US - Banks	Bank of America Corp	BAC	Aa3	A+	8.36	15.00	19.53	22.93	26.14	27.65
Brokers	Bear Stearns Cos Inc/The	BSC	A2	A	14.81	23.41	30.23	34.80	38.79	39.49
US - Banks	Citigroup Inc	C	Aa1	AA-	9.94	14.94	19.94	24.94	27.58	28.74
Technology - Computer	Computer Associates International Inc	CA	Baa3	BBB+	171.95	225.51	227.69	228.01	228.32	228.48
Cable/Media	Clear Channel Communications Inc	CCU	Baa3	BBB-	120.07	121.07	122.07	123.07	125.61	123.83
Finance Co's	Countrywide Home Loans Inc	CFC	A3	A	44.17	47.62	50.21	52.80	62.83	56.25
Cable/Media	Comcast Corp	CMCSA	Baa3	BBB	150.32	152.79	153.50	154.21	163.78	155.80
Cable/Media	COX Communications Inc	COX	Baa2	BBB	98.48	99.38	100.28	101.18	106.67	102.08
Hotels	Park Place Entertainment Corp	CZR	Ba1	BBB-	267.52	268.52	269.52	270.52	274.62	271.34
Chemicals	El Du Pont de Nemours & Co	DD	Aa4	AA-	12.51	13.51	15.51	16.51	23.08	18.01
Technology - Computer	Dell Inc	DELL	A4	A-	22.97	23.97	24.78	25.58	26.81	26.25
Chemicals	Dow Chemical Co/The	DOW	A3	A-	76.12	107.01	110.09	111.12	112.32	112.14
Retail - Non Food	Federated Department Stores	FD	Baa2	BBB+	74.49	75.36	76.21	78.73	77.66	79.36
Telecom	Sprint Capital Corp	FON	Baa4	BBB-	260.14	271.13	277.15	277.73	298.90	278.20
Finance Co's	General Electric Capital Corp	GE	Aaa	AAA	29.08	35.70	44.37	47.97	52.68	53.98
Telecom Equipment	Corning Inc	GLW	Ba2	BB+	504.28	505.08	462.41	504.16	499.76	499.79
Paper	Georgia-Pacific Corp	GP	Ba3	BB+	548.66	549.23	549.80	550.36	557.99	550.77
Retail - Non Food	Gap Inc/The	GPS	Ba4	BB+	317.15	318.15	319.15	320.15	330.41	320.94
Brokers	Goldman Sachs Group Inc	GS	Aa3	A+	20.18	29.29	36.28	40.87	45.46	46.96
Hotels	Hilton Hotels Corp	HLT	Ba1	BBB-	257.34	258.20	261.22	297.09	297.70	297.50
Finance Co's	Household Finance Corp	HSBC	A1	A	48.38	61.26	76.34	73.12	73.60	73.83
Technology - Computer	International Business Machines Corp	IBM	A1	A+	27.95	28.81	29.60	30.59	35.14	34.99
US - Banks	JP Morgan Chase & Co	JPM	A1	A+	30.89	37.18	41.14	44.73	48.26	49.79
Retail - Non Food	Nordstrom Inc	JWN	Baa2	A-	57.44	58.44	59.44	60.44	62.18	61.24
Finance Co's	MBNA America Bank	KRB	Baa1	BBB+	86.29	102.38	118.79	128.83	138.45	142.70
Brokers	Lehman Brothers Holdings Inc	LEH	A2	A	22.36	31.10	38.25	42.75	47.21	47.23
Aerospace	Lockheed Martin Corp	LMT	Baa3	BBB	34.49	35.49	36.49	37.49	39.49	38.36
Hotels	Marriott International Inc	MAR	Baa3	BBB+	78.22	79.22	80.22	81.22	82.94	81.99
Consumer Sectors	Mattel Inc	MAT	Baa2	BBB	35.20	36.19	37.08	37.97	41.14	38.63
Retail - Food	McDonald's Corp	MCD	A3	A	43.82	44.99	45.93	46.66	47.26	46.94
Brokers	Merrill Lynch & Co Inc	MER	Aa3	A+	40.00	43.50	45.57	47.33	48.57	49.37
Hotels	MGM Mirage	MGG	WR	BBB-	234.97	235.74	236.52	237.30	252.53	229.27
Tobacco	Altria Group Inc	MO	Baa3	BBB+	241.11	251.32	246.89	229.05	222.77	221.18
Telecom Equipment	Motorola Inc	MOT	Baa3	BBB	161.28	162.16	166.31	168.53	172.76	169.41
US - Banks	Bank One Corp	ONE	Baa3	A	10.60	16.93	20.90	24.49	27.43	29.04
Telecom	Qwest Corp	QUS	Ba3	B-	1696.09	1696.78	1697.48	1698.18	1698.41	1698.76
Energy	Transocean Inc	RIG	Baa2	A-	62.47	63.41	64.35	65.29	66.40	66.25
Chemicals	Rohm & Haas Co	ROH	A3	BBB+	28.58	28.58	28.58	28.58	34.03	13.58
Retail - Non Food	Sears Roebuck Acceptance	S	Baa1	BBB	194.29	195.12	205.31	208.07	212.70	208.71
Telecom	SBC Communications Inc	SBC	A2	A+	54.97	55.97	56.90	57.82	59.78	58.59
Retail - Food	Safeway Inc	SWY	Baa3	BBB	81.79	82.76	83.72	84.69	86.53	85.54
Retail - Non Food	Target Corp	TGT	A2	A+	41.10	42.10	43.10	44.10	46.18	44.90
Consumer Sectors	Toys R US Inc	TOY	Baa3	BBB-	317.97	318.87	322.68	323.52	329.64	324.24
Cable/Media	AOL Time Warner Inc	TWX	Baa1	BBB+	160.05	160.40	162.17	163.55	168.61	164.14
Auto Producers & Suppliers	Visteon Corp	VC	Baa2	BBB	310.48	310.48	310.48	310.48	319.07	55.48
Cable/Media	Viacom Inc	VIA	A3	A-	39.30	40.11	40.91	41.72	44.11	42.41
Telecom	Verizon Global Funding Corp	VZ	A2	A+	64.29	67.60	72.82	67.91	69.08	68.51
Retail - Non Food	Wal-Mart Stores Inc	WMT	Aa3	AA	14.12	16.38	18.47	19.86	20.16	20.40
Paper	Weyerhaeuser Co	WY	Baa3	BBB	81.70	82.68	83.66	84.64	87.12	85.58

Table 4: Discriptive statistics for credit default swap spreads. This table presents summary statistics for credit default swap spreads for the indicated firms. The spread is expressed in basis points, N denotes the number of observations, and the data presented includes the sample's mean, Std Dev, min and max spreads.

Industry	Issuer	Ticker	Maturity	MDY	S&P	Mean	Min	Max	Std Dev	N
Retail - Food	Albertson's Inc	ABS	5 Yr	Baa1	BBB	80.93	65.00	112.00	10.89	207
Insurance	ACE Ltd	ACE	5 Yr	A3	BBB+	99.12	65.00	150.00	22.99	207
Insurance	American International Group	AIG	5 Yr	Aaa	AAA	33.50	26.00	60.00	9.98	207
Technology - Computer	Arrow Electronics Inc	ARW	5 Yr	Baa3	BBB-	289.66	240.00	325.00	26.83	207
US - Banks	Bank of America Corp	BAC	5 Yr	Aa3	A+	26.14	18.00	34.00	4.21	207
Brokers	Bear Stearns Cos Inc/The	BSC	5 Yr	A2	A	38.79	24.00	50.00	7.09	207
US - Banks	Citigroup Inc	C	5 Yr	Aa1	AA-	27.58	18.00	38.00	5.39	207
Technology - Computer	Computer Associates International Inc	CA	5 Yr	Baa3	BBB+	228.32	87.00	425.00	103.32	207
Cable/Media	Clear Channel Communications Inc	CCU	5 Yr	Baa3	BBB-	125.61	74.00	170.00	27.69	207
Finance Co's	Countrywide Home Loans Inc	CFC	5 Yr	A3	A	62.83	33.00	90.00	17.75	207
Cable/Media	Comcast Corp	CMCSA	5 Yr	Baa3	BBB	163.78	88.00	235.00	42.60	207
Cable/Media	COX Communications Inc	COX	5 Yr	Baa2	BBB	106.67	57.00	159.00	34.71	207
Hotels	Park Place Entertainment Corp	CZR	5 Yr	Ba1	BBB-	274.62	205.00	450.00	42.33	207
Chemicals	EI Du Pont de Nemours & Co	DD	5 Yr	Aa4	AA-	23.08	12.00	32.00	6.83	207
Technology - Computer	Dell Inc	DELL	5 Yr	A4	A-	26.81	18.00	38.00	7.50	207
Chemicals	Dow Chemical Co/The	DOW	5 Yr	A3	A-	112.32	65.00	190.00	30.63	207
Retail - Non Food	Federated Department Stores	FD	5 Yr	Baa2	BBB+	77.66	40.00	120.00	24.53	207
Telecom	Sprint Capital Corp	FON	5 Yr	Baa4	BBB-	298.90	117.00	580.00	131.49	207
Finance Co's	General Electric Capital Corp	GE	5 Yr	Aaa	AAA	52.68	35.00	71.00	12.41	207
Telecom Equipment	Corning Inc	GLW	5 Yr	Ba2	BB+	499.76	250.00	1175.00	250.01	207
Paper	Georgia-Pacific Corp	GP	5 Yr	Ba3	BB+	557.99	385.00	655.00	77.03	207
Retail - Non Food	Gap Inc/The	GPS	5 Yr	Ba4	BB+	330.41	225.00	475.00	94.61	207
Brokers	Goldman Sachs Group Inc	GS	5 Yr	Aa3	A+	45.46	34.00	58.00	6.62	207
Hotels	Hilton Hotels Corp	HLT	5 Yr	Ba1	BBB-	297.70	185.00	400.00	45.18	207
Finance Co's	Household Finance Corp	HSBC	5 Yr	A1	A	73.60	37.00	147.00	30.86	207
Technology - Computer	International Business Machines Corp	IBM	5 Yr	A1	A+	35.14	26.00	46.00	5.55	207
US - Banks	JP Morgan Chase & Co	JPM	5 Yr	A1	A+	48.26	28.00	70.00	11.07	207
Retail - Non Food	Nordstrom Inc	JWN	5 Yr	Baa2	A-	62.18	36.00	89.00	12.35	207
Finance Co's	MBNA America Bank	KRB	5 Yr	Baa1	BBB+	138.45	70.00	220.00	42.17	207
Brokers	Lehman Brothers Holdings Inc	LEH	5 Yr	A2	A	47.21	36.00	60.00	7.15	207
Aerospace	Lockheed Martin Corp	LMT	5 Yr	Baa3	BBB	39.49	30.00	49.00	5.96	207
Hotels	Marriott International Inc	MAR	5 Yr	Baa3	BBB+	82.94	44.00	123.00	24.27	207
Consumer Sectors	Mattel Inc	MAT	5 Yr	Baa2	BBB	41.14	28.00	55.00	10.10	207
Retail - Food	McDonald's Corp	MCD	5 Yr	A3	A	47.26	30.00	70.00	11.82	207
Brokers	Merrill Lynch & Co Inc	MER	5 Yr	Aa3	A+	48.57	10.00	65.00	9.62	207
Hotels	MGM Mirage	MGG	5 Yr	WR	BBB-	252.53	200.00	285.00	38.84	207
Tobacco	Altria Group Inc	MO	5 Yr	Baa3	BBB+	222.77	133.00	490.00	82.98	207
Telecom Equipment	Motorola Inc	MOT	5 Yr	Baa3	BBB	172.76	105.00	245.00	51.78	207
US - Banks	Bank One Corp	ONE	5 Yr	Baa3	A	27.43	22.00	34.00	3.40	207
Telecom	Qwest Corp	QUS	5 Yr	Ba3	B-	1698.41	1390.00	2300.00	191.20	207
Energy	Transocean Inc	RIG	5 Yr	Baa2	A-	66.40	24.00	95.00	17.33	207
Chemicals	Rohm & Haas Co	ROH	5 Yr	A3	BBB+	34.03	26.00	44.00	6.00	207
Retail - Non Food	Sears Roebuck Acceptance	S	5 Yr	Baa1	BBB	212.70	45.00	415.00	112.94	207
Telecom	SBC Communications Inc	SBC	5 Yr	A2	A+	59.78	37.00	79.00	10.38	207
Retail - Food	Safeway Inc	SWY	5 Yr	Baa3	BBB	86.53	70.00	115.00	9.92	207
Retail - Non Food	Target Corp	TGT	5 Yr	A2	A+	46.18	27.00	62.00	11.50	207
Consumer Sectors	Toys R US Inc	TOY	5 Yr	Baa3	BBB-	329.64	213.00	455.00	79.55	207
Cable/Media	AOL Time Warner Inc	TWX	5 Yr	Baa1	BBB+	168.61	85.00	295.00	50.78	207
Auto Producers & Suppliers	Visteon Corp	VC	5 Yr	Baa2	BBB	319.07	255.00	420.00	38.85	207
Cable/Media	Viacom Inc	VIA	5 Yr	A3	A-	44.11	24.00	56.00	9.20	207
Telecom	Verizon Global Funding Corp	VZ	5 Yr	A2	A+	69.08	39.00	110.00	17.67	207
Retail - Non Food	Wal-Mart Stores Inc	WMT	5 Yr	Aa3	AA	20.16	12.00	29.00	5.89	207
Paper	Weyerhaeuser Co	WY	5 Yr	Baa3	BBB	87.12	63.00	115.00	15.97	207

Table 5: Estimation results from fitting the default parameter model to the CDS data. This table presents the parameter estimates and summary statistics from fitting the default parameter model to the CDS data of the indicated reference entities. N represents number of observations

Industry	Name	Ticker	λ0	Std Err	λ1	Std Err	SSE	N
Aerospace	Lockheed Martin Corp	LMT	34.7058	0.0013	1.6186	0.0011	0.000162	207
Auto Producers & Suppliers	Visteon Corp	VC	310.3470	0.0004	0.0119	0.0004	0.000018	207
Brokers	Bear Stearns Cos Inc/The	BSC	30.6186	0.0110	10.9374	0.0090	0.011200	207
Brokers	Goldman Sachs Group Inc	GS	32.0478	0.0035	9.1722	0.0029	0.001170	207
Brokers	Lehman Brothers Holdings Inc	LEH	32.2879	0.0037	9.6633	0.0030	0.001260	207
Brokers	Merrill Lynch & Co Inc	MER	44.4367	0.0020	2.5546	0.0016	0.000377	207
Cable/Media	Clear Channel Communications Inc	CCU	118.5022	0.0015	1.3982	0.0012	0.000212	207
Cable/Media	Comcast Corp	CMCSA	145.7656	0.0015	3.7810	0.0012	0.000212	207
Cable/Media	COX Communications Inc	COX	98.3409	0.0013	1.7418	0.0011	0.000156	207
Cable/Media	AOL Time Warner Inc	TWX	156.9695	0.0014	3.3757	0.0011	0.000178	207
Cable/Media	Viacom Inc	VIA	39.6932	0.0006	1.1132	0.0005	0.000032	207
Chemicals	El Du Pont de Nemours & Co	DD	11.8137	0.0032	2.4743	0.0056	0.000940	207
Chemicals	Dow Chemical Co/The	DOW	76.6548	0.0077	20.3096	0.0063	0.005570	207
Chemicals	Rohm & Haas Co	ROH	28.3258	0.0004	0.2270	0.0004	0.000018	207
Consumer Sectors	Mattel Inc	MAT	35.6312	0.0011	1.1411	0.0009	0.000107	207
Consumer Sectors	Toys R US Inc	TOY	309.0396	0.0068	9.6162	0.0055	0.004250	207
Energy	Transocean Inc	RIG	61.6709	0.0019	2.3991	0.0015	0.000330	207
Finance Co's	Countrywide Home Loans Inc	CFC	46.3288	0.0031	4.4694	0.0026	0.000910	207
Finance Co's	General Electric Capital Corp	GE	24.7763	0.0853	17.1077	0.0698	0.679200	207
Finance Co's	Household Finance Corp	HSBC	56.9268	0.0443	9.6985	0.0362	0.182900	207
Finance Co's	MBNA America Bank	KRB	89.9395	0.0357	28.0848	0.0292	0.119000	207
Hotels	Park Place Entertainment Corp	CZR	268.0196	0.0007	1.3397	0.0005	0.000041	207
Hotels	Hilton Hotels Corp	HLT	255.0995	0.0026	2.0040	0.0021	0.000640	207
Hotels	Marriott International Inc	MAR	77.7804	0.0017	2.1855	0.0014	0.000280	207
Hotels	MGM Mirage	MGG	233.4045	0.0011	1.3967	0.0009	0.000122	207
Insurance	ACE Ltd	ACE	95.3911	0.0004	0.0705	0.0004	0.000017	207
Insurance	American International Group	AIG	15.8681	0.0378	6.0295	0.0309	0.133300	207
Paper	Georgia-Pacific Corp	GP	549.6794	0.0004	0.1077	0.0003	0.000017	207
Paper	Weyerhaeuser Co	WY	82.3221	0.0010	1.2026	0.0008	0.000095	207
Retail - Food	Albertson's Inc	ABS	73.3099	0.0012	1.6712	0.0010	0.000142	207
Retail - Food	McDonald's Corp	MCD	41.5855	0.0016	1.9936	0.0013	0.000236	207
Retail - Food	Safeway Inc	SWY	82.1964	0.0011	1.3772	0.0009	0.000119	207
Retail - Non Food	Federated Department Stores	FD	72.6291	0.0013	1.6630	0.0010	0.000145	207
Retail - Non Food	Gap Inc/The	GPS	316.4637	0.0031	2.4027	0.0025	0.000867	207
Retail - Non Food	Nordstrom Inc	JWN	57.2070	0.0016	2.0101	0.0013	0.000243	207
Retail - Non Food	Sears Roebuck Acceptance	S	181.3734	0.0255	13.0097	0.0209	0.061000	207
Retail - Non Food	Target Corp	TGT	41.9114	0.0009	1.0782	0.0007	0.000077	207
Retail - Non Food	Wal-Mart Stores Inc	WMT	16.1852	0.0010	2.4955	0.0008	0.000097	207
Technology - Computer	Arrow Electronics Inc	ARW	301.1422	0.0009	0.6221	0.0007	0.000076	207
Technology - Computer	Computer Associates International Inc	CA	158.9766	0.0414	29.0715	0.0339	0.160200	207
Technology - Computer	Dell Inc	DELL	23.4879	0.0011	1.3579	0.0009	0.000116	207
Technology - Computer	International Business Machines Corp	IBM	28.0197	0.0020	1.5029	0.0016	0.000361	207
Telecom	Sprint Capital Corp	FON	269.9719	0.1092	11.1312	0.0894	1.113500	207
Telecom	Qwest Corp	QUS	1694.9090	0.0011	1.0531	0.0009	0.000116	207
Telecom	SBC Communications Inc	SBC	55.7107	0.0010	1.1413	0.0008	0.000085	207
Telecom	Verizon Global Funding Corp	VZ	64.1669	0.0019	2.4741	0.0016	0.000352	207
Telecom Equipment	Corning Inc	GLW	503.3090	0.0008	0.8663	0.0006	0.000058	207
Telecom Equipment	Motorola Inc	MOT	154.4495	0.0223	7.6754	0.0183	0.046600	207
Tobacco	Altria Group Inc	MO	192.4846	0.0063	16.6310	0.0052	0.003710	207
US - Banks	Bank of America Corp	BAC	24.2035	0.0072	1.9266	0.0059	0.004880	207
US - Banks	Citigroup Inc	C	13.5996	0.0088	7.6993	0.0072	0.007260	207
US - Banks	JP Morgan Chase & Co	JPM	23.0750	0.0053	6.9724	0.0044	0.002650	207
US - Banks	Bank One Corp	ONE	21.7804	0.0031	4.4055	0.0026	0.000906	207

Table 6: Summary Statistics for the differences between simulated and Market CDS spread: This table reports summary statistics for the difference between the premia implied by the fitted CDS valuation model and the market spreads for the indicated firms.

Industry	Name	Ticker	S&P	Avg Diff	t-Stat	Min	Max	Corr
Aerospace	Lockheed Martin Corp	LMT	BBB	-8.62	-21.78	-14.13	3.85	0.28
Auto Producers & Suppliers	Visteon Corp	VC	BBB	48.08	10.18	-29.64	158.38	0.81
Brokers	Bear Stearns Cos Inc/The	BSC	A	17.05	28.23	2.13	33.48	0.85
Brokers	Goldman Sachs Group Inc	GS	A+	15.83	30.10	1.22	31.07	0.85
Brokers	Lehman Brothers Holdings Inc	LEH	A	15.62	25.44	1.11	31.67	0.89
Brokers	Merrill Lynch & Co Inc	MER	A+	15.08	33.01	2.83	24.41	0.84
Cable/Media	Clear Channel Communications Inc	CCU	BBB-	63.95	82.26	42.35	78.51	0.80
Cable/Media	Comcast Corp	CMCSA	BBB	83.26	53.68	36.79	109.09	0.86
Cable/Media	COX Communications Inc	COX	BBB	55.11	73.45	40.16	70.10	0.56
Cable/Media	AOL Time Warner Inc	TWX	BBB+	98.14	62.61	56.46	124.16	0.81
Cable/Media	Viacom Inc	VIA	A-	17.84	73.87	6.77	22.74	0.40
Chemicals	EI Du Pont de Nemours & Co	DD	AA-	4.31	38.09	0.65	7.61	0.32
Chemicals	Dow Chemical Co/The	DOW	A-	51.72	25.62	11.28	96.14	0.83
Chemicals	Rohm & Haas Co	ROH	BBB+	-0.46	-1.50	-5.37	10.95	0.63
Consumer Sectors	Mattel Inc	MAT	BBB	11.62	41.19	4.78	18.25	-0.06
Consumer Sectors	Toys R US Inc	TOY	BBB-	118.57	41.93	44.87	160.45	0.69
Energy	Transocean Inc	RIG	A-	20.02	25.04	3.88	35.26	0.73
Finance Co's	Countrywide Home Loans Inc	CFC	A	6.21	5.62	-18.68	25.50	0.47
Finance Co's	General Electric Capital Corp	GE	AAA	45.12	63.96	33.53	59.88	0.93
Finance Co's	Household Finance Corp	HSBC	A	45.82	60.15	31.76	63.42	0.95
Finance Co's	MBNA America Bank	KRB	BBB+	82.03	42.00	52.74	126.37	0.92
Hotels	Park Place Entertainment Corp	CZR	BBB-	80.26	47.82	59.79	129.73	0.83
Hotels	Hilton Hotels Corp	HLT	BBB-	89.68	26.91	12.74	155.63	0.97
Hotels	Marriott International Inc	MAR	BBB+	35.96	83.43	25.68	42.81	0.73
Hotels	MGM Mirage	MGG	BBB-	65.69	20.06	-39.62	120.26	0.81
Insurance	ACE Ltd	ACE	BBB+	38.41	49.03	18.49	61.59	0.82
Insurance	American International Group	AIG	AAA	0.98	1.50	-13.05	16.32	0.89
Paper	Georgia-Pacific Corp	GP	BB+	258.97	34.32	69.82	369.98	0.95
Paper	Weyerhaeuser Co	WY	BBB	23.07	95.69	17.03	29.61	-0.15
Retail - Food	Albertson's Inc	ABS	BBB	8.27	13.80	-6.48	17.70	0.54
Retail - Food	McDonald's Corp	MCD	A	21.48	49.84	9.22	27.47	0.56
Retail - Food	Safeway Inc	SWY	BBB	17.00	28.45	4.01	25.96	0.45
Retail - Non Food	Federated Department Stores	FD	BBB+	35.73	115.82	25.92	40.96	0.09
Retail - Non Food	Gap Inc/The	GPS	BB+	187.31	39.70	94.64	249.89	0.92
Retail - Non Food	Nordstrom Inc	JWN	A-	28.91	89.83	22.86	35.75	0.83
Retail - Non Food	Sears Roebuck Acceptance	S	BBB	167.34	122.20	138.59	188.38	0.92
Retail - Non Food	Target Corp	TGT	A+	19.22	68.41	12.33	24.46	0.23
Retail - Non Food	Wal-Mart Stores Inc	WMT	AA	7.73	41.66	3.48	12.07	0.92
Technology - Computer	Arrow Electronics Inc	ARW	BBB-	132.13	24.37	36.96	214.04	0.92
Technology - Computer	Computer Associates International Inc	CA	BBB+	120.97	68.44	60.27	166.40	0.68
Technology - Computer	Dell Inc	DELL	A-	4.82	46.43	3.38	7.29	-0.27
Technology - Computer	International Business Machines Corp	IBM	A+	5.09	10.85	-3.00	14.18	0.97
Telecom	Sprint Capital Corp	FON	BBB-	172.97	116.66	142.78	207.64	0.57
Telecom	Qwest Corp	QUS	B-	1013.18	32.08	306.30	1532.82	0.92
Telecom	SBC Communications Inc	SBC	A+	18.26	39.81	4.24	25.35	-0.59
Telecom	Verizon Global Funding Corp	VZ	A+	25.51	66.17	10.99	33.92	0.01
Telecom Equipment	Corning Inc	GLW	BB+	300.74	75.84	254.45	380.70	0.93
Telecom Equipment	Motorola Inc	MOT	BBB	89.66	49.96	51.73	125.42	0.96
Tobacco	Altria Group Inc	MO	BBB+	-0.14	-0.02	-130.25	105.34	0.90
US - Banks	Bank of America Corp	BAC	A+	7.22	17.95	-3.24	15.46	0.60
US - Banks	Citigroup Inc	C	AA-	6.64	11.28	-5.18	21.61	0.95
US - Banks	JP Morgan Chase & Co	JPM	A+	6.97	9.54	-7.67	24.22	0.94
US - Banks	Bank One Corp	ONE	A	8.03	17.65	-2.37	17.89	0.95
	Overall Average Difference			**71.78**				

Table 7: Estimation results from fitting the extended default parameter model to the CDS data. This table presents the parameter estimates and summary statistics from fitting the default parameter model to the CDS data of the indicated reference entities.

Industry	Name	Ticker	λ0	Std Err	λ1	Std Err	λ2	Std Err	SSE	N
Aerospace	Lockheed Martin Corp	LMT	32.6726	0.1275	0.6608	0.0595	8.1760	0.5106	0.002050	207
Auto Producers & Suppliers	Visteon Corp	VC	310.2315	0.0159	0.0642	0.0074	0.4649	0.0638	0.000032	207
Brokers	Bear Stearns Cos Inc/The	BSC	17.5182	0.9485	4.7627	0.4429	52.6900	3.7984	0.113600	207
Brokers	Goldman Sachs Group Inc	GS	20.8214	0.7236	3.8825	0.3379	45.1476	2.8979	0.066100	207
Brokers	Lehman Brothers Holdings Inc	LEH	20.4526	0.7639	4.0867	0.3567	47.5964	3.0591	0.073700	207
Brokers	Merrill Lynch & Co Inc	MER	41.2456	0.2001	1.0513	0.0934	12.8322	0.8014	0.005060	207
Cable/Media	Clear Channel Communications Inc	CCU	116.7345	0.1110	0.5656	0.0518	7.1079	0.4446	0.001560	207
Cable/Media	Comcast Corp	CMCSA	141.1391	0.2984	1.6011	0.1394	18.6055	1.1952	0.011200	207
Cable/Media	COX Communications Inc	COX	96.2624	0.1445	0.7622	0.0675	8.3595	0.5787	0.002640	207
Cable/Media	AOL Time Warner Inc	TWX	152.8202	0.2663	1.4206	0.1244	16.6866	1.0665	0.008960	207
Cable/Media	Viacom Inc	VIA	38.3075	0.0884	0.4604	0.0413	5.5728	0.3538	0.000986	207
Chemicals	EI Du Pont de Nemours & Co	DD	8.9398	0.2241	1.1194	0.1046	11.5597	0.8974	0.006340	207
Chemicals	Dow Chemical Co/The	DOW	51.7951	1.6030	8.5960	0.7485	99.9750	0.4194	0.324500	207
Chemicals	Rohm & Haas Co	ROH	28.0520	0.0216	0.0980	0.0101	1.1011	0.0866	0.000059	207
Consumer Sectors	Mattel Inc	MAT	33.9605	0.1182	0.6234	0.0552	6.7196	0.4734	0.001770	207
Consumer Sectors	Toys R US Inc	TOY	297.5656	0.7990	4.2083	0.3731	46.1480	3.1997	0.080600	207
Energy	Transocean Inc	RIG	58.6696	0.1877	0.9853	0.0877	12.0690	0.7518	0.004450	207
Finance Co's	Countrywide Home Loans Inc	CFC	40.9811	0.3705	1.9490	0.1730	21.5078	1.4838	0.017300	207
Finance Co's	General Electric Capital Corp	GE	4.8534	2.6767	7.7172	1.2499	80.1296	10.7194	0.904900	207
Finance Co's	Household Finance Corp	HSBC	44.4724	1.4340	3.8315	0.6695	50.0825	5.7415	0.259600	207
Finance Co's	MBNA America Bank	KRB	56.4812	2.5371	12.3134	1.1847	134.5734	10.1604	0.812900	207
Hotels	Park Place Entertainment Corp	CZR	266.3694	0.1054	0.5622	0.0492	0.6363	0.4222	0.001400	207
Hotels	Hilton Hotels Corp	HLT	253.4696	0.1532	0.7672	0.0715	7.9351	0.6135	0.002960	207
Hotels	Marriott International Inc	MAR	75.0372	0.1733	0.8932	0.0809	11.0310	0.6941	0.003790	207
Hotels	MGM Mirage	MGG	231.6432	0.1091	0.5670	0.0510	7.0826	0.4371	0.001500	207
Insurance	ACE Ltd	ACE	95.2983	0.0129	0.0268	0.0060	0.3731	0.0515	0.000021	207
Insurance	American International Group	AIG	9.4234	1.1833	2.9869	0.5525	25.9351	4.7387	0.176800	207
Paper	Georgia-Pacific Corp	GP	549.5541	0.0143	0.0487	0.0067	0.5039	0.5074	0.000026	207
Paper	Weyerhaeuser Co	WY	80.8130	0.0947	0.4917	0.0442	6.0683	0.3792	0.001130	207
Retail - Food	Albertson's Inc	ABS	71.3279	0.1394	0.7370	0.0651	7.9718	0.5583	0.002450	207
Retail - Food	McDonald's Corp	MCD	39.0696	0.1595	0.8084	0.0745	10.1171	0.6387	0.003210	207
Retail - Food	Safeway Inc	SWY	80.4655	0.1083	0.5618	0.0506	6.9603	0.4335	0.001480	207
Retail - Non Food	Federated Department Stores	FD	70.6502	0.1396	0.7303	0.0652	7.9592	0.5590	0.002460	207
Retail - Non Food	Gap Inc/The	GPS	313.6535	0.2171	1.0779	0.1014	11.3032	0.8694	0.005950	207
Retail - Non Food	Nordstrom Inc	JWN	54.6641	0.1573	0.8123	0.0735	10.2253	0.6301	0.003130	207
Retail - Non Food	Sears Roebuck Acceptance	S	164.8331	1.2044	5.2189	0.5624	66.5099	4.8232	0.183200	207
Retail - Non Food	Target Corp	TGT	40.5566	0.0846	0.4401	0.0395	5.4479	0.3386	0.000903	207
Retail - Non Food	Wal-Mart Stores Inc	WMT	13.1395	0.1976	1.0604	0.0923	12.2485	0.7915	0.004930	207
Technology - Computer	Arrow Electronics Inc	ARW	300.3578	0.0510	0.2526	0.0238	3.1542	0.2043	0.000329	207
Technology - Computer	Computer Associates International	CA	124.7417	2.6828	12.9324	1.2528	137.7015	10.7438	0.909000	207
Technology - Computer	Dell Inc	DELL	21.7935	0.1067	0.5597	0.0498	6.8137	0.4272	0.001440	207
Technology - Computer	International Business Machines	IBM	26.2773	0.1360	0.6815	0.0635	7.0084	0.5446	0.002340	207
Telecom	Sprint Capital Corp	FON	256.7359	3.1637	4.8877	1.4773	53.2505	12.6695	1.264000	207
Telecom	Qwest Corp	QUS	1693.5700	0.0841	0.4224	0.0393	5.3849	0.3366	0.000892	207
Telecom	SBC Communications Inc	SBC	54.2895	0.0870	0.4719	0.0406	5.7148	0.3484	0.000956	207
Telecom	Verizon Global Funding Corp	VZ	61.0530	0.1932	1.0073	0.0902	12.5215	0.7739	0.004720	207
Telecom Equipment	Corning Inc	GLW	502.2265	0.0687	0.3564	0.0321	4.3529	0.2751	0.000596	207
Telecom Equipment	Motorola Inc	MOT	32.6726	0.1275	0.6608	0.0595	8.1760	0.5106	0.002050	207
Tobacco	Altria Group Inc	MO	172.1310	1.3123	7.0407	0.6128	81.8533	5.2552	0.217500	207
US - Banks	Bank of America Corp	BAC	22.2048	0.2651	0.9830	0.1238	8.0432	1.0618	0.008880	207
US - Banks	Citigroup Inc	C	3.8731	0.6165	3.1180	0.2879	39.1104	2.4689	0.048000	207
US - Banks	JP Morgan Chase & Co	JPM	14.3361	0.5454	2.8558	0.2547	35.1411	2.1840	0.037600	207
US - Banks	Bank One Corp	ONE	16.5174	0.3647	1.9250	0.1703	21.1675	1.4605	0.016800	207

Table 8: Summary Statistics for the differences between the Extended Simulated and Market CDS spread: This table reports summary statistics for the difference between the premia implied by the fitted CDS valuation model and the market spreads for the indicated firms.

Industry	Name	Ticker	S&P	Avg Diff	t-Stat	Min	Max
Aerospace	Lockheed Martin Corp	LMT	BBB	-9.07	-38.65	36.65	37.74
Auto Producers & Suppliers	Visteon Corp	VC	BBB	48.23	17.49	310.49	310.59
Brokers	Bear Stearns Cos Inc/The	BSC	A	14.15	46.02	43.83	51.56
Brokers	Goldman Sachs Group Inc	GS	A+	13.35	48.92	43.10	49.44
Brokers	Lehman Brothers Holdings Inc	LEH	A	13.01	40.64	43.93	50.60
Brokers	Merrill Lynch & Co Inc	MER	A+	14.37	53.65	47.51	49.23
Cable/Media	Clear Channel Communications Inc	CCU	BBB-	63.56	139.34	120.18	121.11
Cable/Media	Comcast Corp	CMCSA	BBB	82.23	90.30	150.32	152.93
Cable/Media	COX Communications Inc	COX	BBB	54.65	118.82	100.45	101.68
Cable/Media	AOL Time Warner Inc	TWX	BBB+	97.22	104.44	161.04	163.36
Cable/Media	Viacom Inc	VIA	A-	17.53	114.39	41.03	41.79
Chemicals	EI Du Pont de Nemours & Co	DD	AA-	3.68	33.61	14.81	16.61
Chemicals	Dow Chemical Co/The	DOW	A-	46.22	44.65	101.13	115.16
Chemicals	Rohm & Haas Co	ROH	BBB+	-0.52	-2.93	28.60	28.76
Consumer Sectors	Mattel Inc	MAT	BBB	11.70	60.28	37.34	38.35
Consumer Sectors	Toys R US Inc	TOY	BBB-	116.04	68.70	320.66	327.48
Energy	Transocean Inc	RIG	A-	19.35	42.97	64.56	66.17
Finance Co's	Countrywide Home Loans Inc	CFC	A	5.03	7.70	51.73	54.89
Finance Co's	General Electric Capital Corp	GE	AAA	17.78	29.39	45.49	57.93
Finance Co's	Household Finance Corp	HSBC	A	43.06	113.72	68.56	74.90
Finance Co's	MBNA America Bank	KRB	BBB+	74.63	83.78	123.87	143.83
Hotels	Park Place Entertainment Corp	CZR	BBB-	77.56	80.17	267.35	268.18
Hotels	Hilton Hotels Corp	HLT	BBB-	89.08	46.21	257.50	258.73
Hotels	Marriott International Inc	MAR	BBB+	35.35	137.13	80.41	81.88
Hotels	MGM Mirage	MGG	BBB-	65.3	34.33	235.08	236.02
Insurance	ACE Ltd	ACE	BBB+	38.39	84.04	95.48	95.52
Insurance	American International Group	AIG	AAA	-0.45	-1.27	23.22	27.96
Paper	Georgia-Pacific Corp	GP	BB+	258.94	58.80	549.81	549.89
Paper	Weyerhaeuser Co	WY	BBB	22.73	148.84	83.77	84.58
Retail - Food	Albertson's Inc	ABS	BBB	7.83	21.10	75.33	76.52
Retail - Food	McDonald's Corp	MCD	A	20.92	75.09	43.98	45.31
Retail - Food	Safeway Inc	SWY	BBB	16.62	45.24	83.85	84.78
Retail - Non Food	Federated Department Stores	FD	BBB+	35.29	168.72	74.64	75.82
Retail - Non Food	Gap Inc/The	GPS	BB+	186.69	67.81	319.37	321.11
Retail - Non Food	Nordstrom Inc	JWN	A-	28.35	154.15	59.62	60.96
Retail - Non Food	Sears Roebuck Acceptance	S	BBB	163.69	212.81	197.00	205.60
Retail - Non Food	Target Corp	TGT	A+	18.92	104.62	43.21	43.93
Retail - Non Food	Wal-Mart Stores Inc	WMT	AA	7.05	75.67	19.19	20.92
Technology - Computer	Arrow Electronics Inc	ARW	BBB-	131.96	41.73	301.89	302.31
Technology - Computer	Computer Associates International Inc	CA	BBB+	113.39	112.59	194.14	215.04
Technology - Computer	Dell Inc	DELL	A-	4.44	56.91	25.12	26.04
Technology - Computer	International Business Machines Corp	IBM	A+	4.70	17.68	29.84	30.94
Telecom	Sprint Capital Corp	FON	BBB-	170.04	214.34	283.42	291.34
Telecom	Qwest Corp	QUS	B-	1012.88	54.96	1696.17	1696.87
Telecom	SBC Communications Inc	SBC	A+	17.95	58.80	57.08	57.86
Telecom	Verizon Global Funding Corp	VZ	A+	24.82	88.87	67.14	68.80
Telecom Equipment	Corning Inc	GLW	BB+	300.5	130.20	504.35	504.94
Telecom Equipment	Motorola Inc	MOT	BBB	-40.58	-43.59	36.65	37.74
Tobacco	Altria Group Inc	MO	BBB+	-4.64	-1.43	212.53	224.02
US - Banks	Bank of America Corp	BAC	A+	6.78	28.76	26.56	28.11
US - Banks	Citigroup Inc	C	AA-	4.49	15.13	22.85	27.98
US - Banks	JP Morgan Chase & Co	JPM	A+	5.04	13.50	31.46	36.15
US - Banks	Bank One Corp	ONE	A	6.86	28.73	27.10	30.22
	Overall Average Difference			**67.49**			

Table 9: IBM Bi-Weekly Parameter estimates

IBM Parameter Estimates			
Period	$\lambda 0$	$\lambda 1$	$\lambda 2$
2/14/2003	22.2959	0.7436	10.2984
2/28/2003	21.9816	0.7474	10.3250
3/14/2003	22.2823	0.7130	9.8935
3/31/2003	22.8409	0.7484	10.1640
4/15/2003	24.3387	0.6456	8.7738
4/30/2003	23.6326	0.6319	9.2089
6/13/2003	26.0429	0.5570	7.8030
7/15/2003	24.5499	0.5817	7.9767
7/25/2003	24.0159	0.4786	6.6187
8/14/2003	26.1965	0.4347	6.0563
8/29/2003	25.4501	0.5587	7.8853
9/15/2003	21.2023	0.5233	7.2132
9/30/2003	21.1972	0.5222	7.2221
10/15/2003	21.0978	0.6197	8.6406
11/14/2003	23.4318	0.3738	5.3193
11/28/2003	25.6189	0.5486	7.5701
12/15/2003	23.5962	0.5468	7.7982

Table 10: Estimation results from fitting the default parameter model to the CDS dataset in Sample 1 and Sample 2. This table presents the parameter estimates and summary statistics from fitting the default parameter model to the CDS data of the indicated reference entities.

Industry	Name	Ticker	Sample 1							Sample 2						
			λ0	Std Err	λ1	Std Err	λ2	Std Err	SSE	λ0	Std Err	λ1	Std Err	λ2	Std Err	SSE
Aerospace	Lockheed Martin Corp	LMT	32.673	0.128	0.661	0.060	8.176	0.511	0.002	31.097	0.034	0.269	0.059	7.081	0.174	0.001
Brokers	Bear Stearns Cos Inc/The	BSC	17.518	0.949	4.763	0.443	52.690	3.798	0.114	15.148	0.193	1.797	0.335	42.175	0.993	0.041
Brokers	Goldman Sachs Group Inc	GS	20.821	0.724	3.883	0.338	45.148	2.898	0.066	14.893	0.217	2.012	0.377	47.455	1.115	0.052
Brokers	Lehman Brothers Holdings Inc	LEH	20.453	0.764	4.087	0.357	47.596	3.059	0.074	18.148	0.210	1.968	0.365	45.892	1.081	0.049
Cable/Media	Comcast Corp	CMCSA	141.139	0.298	1.601	0.139	18.606	1.195	0.011	134.889	0.108	1.006	0.188	23.709	0.557	0.013
Chemicals	EI Du Pont de Nemours & Co	DD	8.940	0.224	1.119	0.105	11.560	0.897	0.006	4.960	0.089	0.809	0.232	19.775	0.741	0.019
Chemicals	Dow Chemical Co/The	DOW	51.795	1.603	8.596	0.749	99.975	0.419	0.325	51.505	0.418	7.899	0.727	91.550	2.153	0.193
Chemicals	Rohm & Haas Co	ROH	28.052	0.022	0.098	0.010	1.101	0.087	0.000	27.661	0.007	0.043	0.012	1.188	0.034	0.000
Energy	Transocean Inc	RIG	58.670	0.188	0.985	0.088	12.069	0.752	0.004	45.350	0.083	0.677	0.144	17.444	0.426	0.008
Finance Co's	Countrywide Home Loans Inc	CFC	40.981	0.371	1.949	0.173	21.508	1.484	0.017	40.719	0.117	1.053	0.203	22.174	0.603	0.015
Finance Co's	General Electric Capital Corp	GE	4.853	2.677	7.717	1.250	80.130	10.719	0.905	7.824	0.335	9.403	0.869	86.669	2.780	0.263
Hotels	Hilton Hotels Corp	HLT	253.470	0.153	0.767	0.072	7.935	0.614	0.003	250.494	0.094	0.745	0.163	14.338	0.483	0.010
Insurance	American International Group	AIG	9.423	1.183	2.987	0.553	25.935	4.739	0.177	10.460	0.285	1.410	0.494	33.014	1.464	0.089
Retail - Food	Safeway Inc	SWY	80.466	0.108	0.562	0.051	6.960	0.434	0.001	78.201	0.031	0.255	0.054	6.559	0.160	0.001
Retail - Non Food	Wal-Mart Stores Inc	WMT	13.140	0.198	1.060	0.092	12.249	0.792	0.005	10.926	0.062	0.583	0.108	13.536	0.321	0.004
Technology - Computer	Dell Inc	DELL	21.793	0.107	0.560	0.050	6.814	0.427	0.001	21.301	0.026	0.215	0.045	5.352	0.132	0.001
Technology - Computer	International Business Machines	IBM	26.277	0.136	0.681	0.064	7.008	0.545	0.002	27.743	0.042	0.335	0.073	6.434	0.217	0.002
Telecom	Verizon Global Funding Corp	VZ	61.053	0.193	1.007	0.090	12.522	0.774	0.005	57.628	0.054	0.429	0.093	11.437	0.277	0.003
US - Banks	Bank of America Corp	BAC	22.205	0.265	0.983	0.124	8.043	1.062	0.009	24.207	0.097	0.483	0.169	6.764	0.501	0.010
US - Banks	Citigroup Inc	C	3.873	0.617	3.118	0.288	39.110	2.469	0.048	3.519	0.137	1.108	0.238	29.093	0.704	0.021
US - Banks	Bank One Corp	ONE	16.517	0.365	1.925	0.170	21.167	1.461	0.017	15.540	0.012	1.102	0.213	23.263	0.630	0.017

Table 11: Summary statistics of the default parameter estimates in Sample 1 and Sample 2. The table demonstrates no significant difference between both samples estimates, thus affirming the stability of both sample period estimates.

Parameter	Mean of Parameter Estimates	Variance	t-Stat	p-Value (One Tail)	p-Value (Two Tail)	Correlation
Sample 1 $\lambda 0$	44.482	3297.361	0.114	0.455	0.910	0.998
Sample 2 $\lambda 0$	42.486	3186.491				
Sample 1 $\lambda 1$	2.339	5.461	1.005	0.160	0.321	0.919
Sample 2 $\lambda 1$	1.600	5.874				
Sample 1 $\lambda 2$	26.014	683.445	-0.052	0.479	0.959	0.980
Sample 2 $\lambda 2$	26.424	616.184				

Table 12 :Regression of observed CDS prices on estimated Out-Sample two-factor model prices and credit rating. The table reports the results of the two-factor model with and without the credit quality proxy. Prices are in basis points and parameter estimates were found to be significant.

$$\sum \left[ActPx = \alpha_0 + \beta_1 SimPx + \varepsilon_t \right]$$

Variable	Coefficient	Std Error	t-Stat
Intercept	19.02815***	0.889	21.400
Simulated Price	0.418741***	0.003	136.690
Credit Rating	N/A	N/A	N/A
R^2 0.7044			
N 7473			

$$\sum \left[ActPx = \alpha_0 + \beta_1 SimPx - \beta_2 Rtg + \varepsilon_t \right]$$

Variable	Coefficient	Std Error	t-Stat
Intercept	10.67433***	1.117	9.560
Simulated Price	0.402535***	0.003	121.490
Credit Rating	-19.86455***	1.633	-12.170
R^2 0.7120			
N 7473			

*** Significant at the 1%

Table 13 :Regression of observed CDS prices on estimated In-Sample two-factor model prices and credit rating. The table reports the results of the two-factor model with and without the credit quality proxy. Prices are in basis points and parameter estimates except Alpha_0 (the intercept) were found to be significant.

$$\sum\left[ActPx = \alpha_0 + \beta_1 SimPx + \varepsilon_t\right]$$

Variable	Coefficient	Std Error	t-Stat
Intercept	1.179	0.680	1.740
Simulated Price	1.047***	0.006	189.110
Credit Rating	N/A	N/A	N/A
R^2 0.8697			
N 7473			

$$\sum\left[ActPx = \alpha_0 + \beta_1 SimPx - \beta_2 Rtg + \varepsilon_t\right]$$

Variable	Coefficient	Std Error	t-Stat
Intercept	0.292	0.693	0.420
Simulated Price	1.023***	0.007	150.600
Credit Rating	-6.8875***	1.128	-6.100
R^2 0.8706			
N 7473			

*** Significant at the 1%

Table 14 :Regression of observed CDS prices on estimated Out-Sample three-factor model prices and credit rating. The table reports the results of the three-factor model with and without the credit quality proxy. Prices are in basis points and parameter estimates were found to be significant.

$$\sum \left[ActPx = \alpha_0 + \beta_1 SimPx + \varepsilon_t \right]$$

Variable		Coefficient	Std Error	t-Stat
Intercept		19.84621***	0.884	22.450
Simulated Price		0.418339***	0.003	137.070
Credit Rating		N/A	N/A	N/A
R^2	0.7155			
N	7473			

$$\sum \left[ActPx = \alpha_0 + \beta_1 SimPx - \beta_2 Rtg + \varepsilon_t \right]$$

Variable		Coefficient	Std Error	t-Stat
Intercept		12.09131***	1.114	10.850
Simulated Price		0.403097***	0.003	121.610
Credit Rating		-18.44595***	1.636	-11.270
R^2	0.7203			
N	7473			

*** Significant at the 1%

Table 15 :Regression of observed CDS prices on estimated In-Sample three-factor model prices and credit rating. The table reports the results of the three-factor model with and without the credit quality proxy. Prices are in basis points and parameter estimates except Beta 2 (Credit Rating) in model 2 were found to be significant.

$$\sum \left[ActPx = \alpha_0 + \beta_1 SimPx + \varepsilon_t \right]$$

Variable	Coefficient	Std Error	t-Stat
Intercept	4.23***	1.459	2.9
Simulated Price	0.971***	0.004	240.4
Credit Rating	N/A	N/A	N/A
R^2 0.9260			
N 7473			

$$\sum \left[ActPx = \alpha_0 + \beta_1 SimPx - \beta_2 Rtg + \varepsilon_t \right]$$

Variable	Coefficient	Std Error	t-Stat
Intercept	5.19***	1.925	2.700
Simulated Price	0.972***	0.004	221.160
Credit Rating	-2.09	2.733	-0.76
R^2 0.9260			
N 7473			

*** Significant at the 1%

CHAPTER SIX

6 Conclusion

Over the past few years, financial markets have been marked by increased volatility and risk, due in part to the decline of credit quality brought on by unfavorable economic shocks. As a result of this scenario, there has been a sharp rise in the use of credit default swaps by investors to reduce credit and market risks.

Given the growing importance of the credit default swap market and the prices paid by default protection seekers; this study thus examines both a three-factor model for credit default swap valuation and the Jarrow (2001) two-factor mean reverting model. The three-factor model extends Jarrow (2001) two-factor model by adding three important features. First, the dataset used is more extensive and provides far more data points for analysis. Secondly, the Ornstein-Uhlenbeck process is replaced by a CIR process, which allows the study to retain the Jarrow (2001) mean reverting properties, while making the model arbitrage free. Thirdly, a second explanatory variable; liquidity, is introduced to the model, because it is conjectured that the level of liquidity in the CDS market plays a significant role in the valuation of the CDS premia.

Both models were implemented empirically and the study found clear evidence from both models that the implied cost of credit risk is significantly higher than the market value for most of the companies of the sample. However when the implied premia results of both models were compared, the extended three-factor

Model did a better job in matching the observed market data, suggesting that the addition of the liquidity variable improved the explanatory power of the model. Additionally, though the extended model exhibited only a marginal improvement over the Jarrow two-factor model, this small basis point improvement could potentially be translated into pricing improvements between both models to the tune of millions of dollars given the size and volume of daily CDS trading in the derivatives market.

The study also found that both models displayed wide cross-sectional variation. This variation could be due in part to one or a combination of the following observations:

(a) Inadvertent under-pricing of credit risk by the major Hedge Funds;

(b) The models inability to capture the effects of institutional discounts which could lead to a net basis point reduction of current observed pricing;

(c) Cross sectional variations that are due to credit rating changes among businesses, which were probably more evident during 1Q03, after a number of notable bankruptcy scandals.

(d) The CDS' own level of liquidity or illiquidity; the liquidity effect in the credit default spreads remains significant even after controlling for yield spread factors such as credit ratings.

From a policy standpoint, if Hedge Funds and Investment banks are under-pricing the cost of credit risk then these actions could seriously undermine the levels of investor risks in the market place. Such actions would not allow investors to adequately gauge the cost of risky investments and could result in significant losses to stakeholders and investors if the underlying bonds default.

Economic theory suggests that market and credit risk are related to each other and not separable. The results of both models in the study have affirmed this view. The parameters of the hazard function were found to be positive for both estimated parameter, suggesting that credit and market risks are positively related. Comparisons with other research on existing reduced form models (where default-risky term structures were estimated separately from the default free term structure), show similar results with positive hazard function parameters.

As mentioned earlier, though the three-factor reduced form model adds valuable characteristics to the existing reduced form models in the literature, it only outperforms Jarrow's model by a small amount, in terms of the overall explanatory function of the model. Also, while these improvements are realizable, the magnitude is dependent on a number of unknown quantities, such as institutional discounts, at the time pricing is made. Interestingly, the study found that the liquidity estimates were positively associated with both the CDS spread premia and the spot rate. These results have important implications both for asset pricing as well as corporate finance, as these add to the rapidly growing literature on the effects of liquidity on CDS prices.

The empirical results also showed that both models obtained small cross-sectional variation in the high yield credit grade, however for both models the level of cross-sectional variation increases with a decline in credit quality. Additionally, both models had analogous root mean errors of less than zero basis points, which infers that both models were relatively successful in capturing the levels of variation in default and credit risk. However, while the three-product model achieved better results when valuing short term maturity, it would be interesting to see if future extensions of this model could conduct valuations of longer term maturities to determine the efficiency of the model in pricing both long and short term maturities.

Finally, it can also be concluded that credit quality is also an important variable in the pricing of credit default swaps, and as such it is being suggested that future models proxy credit quality term structure, which should help to reduce the cross-sectional variations seen in this study.

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Appendix A

The Black-Scholes Option Pricing Model

The Black-Scholes model has been the cornerstone and general framework from which modern derivatives pricing models have taken off. The problem of pricing derivatives is to find a pricing function $D(S_t, t)$ that relates the price of the derivative product to S_t, the price of the underlying asset, and possibly to some other factors such as market and credit risk.

Below is a derivation of the Black-Scholes equation via a fairly intuitive partial derivative equation approach. Consider a European style option[13], written on an underlying asset, such as a stock or bond that trades in the market at price S_t and some payoff function $\Lambda(S)$ has been specified, which determines the value of the option at expiration time T. For $t < T$, the option value V should depend on the underlying price S_t and the time t. The only parametric information on this portfolio available to the investor at the onset of this investment contract is the initial price $V(S, t)$ and the option's value at expiration which suggests that $V(S, t) = \Lambda(S)$. After the deal is structured and time passes, the value of the option changes, because the expiration date approaches and possible fluctuation in the underlying asset price. So, across a short random time interval δ_t and using a Taylor series expansion, V can be represented as:

$$\delta V = V_t\delta_t + V_s\delta S + 1/2 V_{ss}(\delta S)^2 + \ldots \qquad (26)$$

[13] These options can only be exercised on the expiration date of the Option. Thus any value it has for t<T comes from passively waiting to receive this possible payout.

The neglected terms are of order $(\delta_t)^2$, $\delta S\delta_t$, and $(\delta S)^3$and higher. Random walks and Brownian motion may be used to explain the rational of retaining terms of order $(\delta S)^2$ while eliminating the other terms.

Now given the preceding discussion the option's price can be determined by creating a replicating portfolio, which has a specific investment strategy involving only the stock and a cash account that will yield exactly the same eventual payoff as the option in all possible future scenarios. Its present value must therefore be the same as the present value of the option, and if the present value of the stock is determined, the option's should be easily obtained.

Therefore for a given portfolio Π consisting of ϕ_t shares of stock S, ψ_t units of cash account B_t and assuming a self-financing strategy with ϕ_t and ψ_t being positive or negative corresponding to the investor's long or short position in the underlying asset. Over a short time interval, due to the self-financing properties, discussed in Section 3.1, the value in the portfolio thus becomes

$$\delta\Pi = \phi_t \delta S + \psi_t r B_t \delta_t \qquad (27)$$

If $\delta B_t \approx r B_t \delta_t$, where r is the rate of interest, then the difference in value between the two portfolios can be represented as;

$$\delta(V - \Pi) = (V_t - \psi_t r B_t)\delta_t + (V_s - \varphi_t)\delta_s + 1/2 V_{ss}(V_{ss}(\delta S)^2 + \ldots \qquad (28)$$

Equation 28 above depends on the unknown change δS, but the first order dependence on S can be eliminated by taking $\varphi_t = V_s$. This determines φ_t and simultaneously removes the ``randomness" from the equation (transforming a Brownian motion with drift, to a standard Brownian motion). Alternatively, if the investor is able to compute the function V_s, then he can compute its derivative with respects to S and artificially implement a trading strategy that at first order tracks the same risks.

Since the difference portfolio is now *non-risky*, it must grow in value at exactly the same rate as any risk-free bank account, because of the assumption of no arbitrage (lack of possibility to make a profit without risk). In the absence of the no arbitrage assumption then;

$$\delta(V - \Pi) = r(V - \Pi)\delta_t \qquad (29)$$

If $\delta(V - \Pi) > r(V - \Pi)\delta_t$, then an investor could borrow money at rate r to acquire the portfolio $(V - \Pi)$, holding the portfolio for a time δ_t, and then selling, with the growth in the difference portfolio more than enough to cover the interest costs on the loan.

Conversely, if $\delta(V - \Pi) < r(V - \Pi)\delta_t$, then sell the option in the marketplace for V, cover the risk by purchasing φ_t shares of stock and loan the rest of the money out at rate r.

Recalling that:

$$r(V - \Pi)\delta_t = (V_t - \Psi_t r B_t \delta_t + 1/2Vss(\delta_t)^2 \qquad (30)$$

and given that quadratic variation of the geometric Brownian motion is deterministic, and can be depicted as;

$$(\delta S)^2 = \sigma^2 S_t^2 \delta_t \quad (31)$$

and where if δ_t is small, the stochastic process S_t becomes a Brownian motion or wiener process. Therefore substituting in equation 30 gives;

$$r(V - \Pi)\delta_t = (V_t - \Psi_t r B_t \delta_t + 1/2\sigma^2 S^2 V_{ss}\delta_t \quad (32)$$

Canceling the δ_t terms, and recalling that; $V - \Pi = V - \varphi_t S - \Psi_t r B_t$, and $\varphi_t = V_s$, so that on the left $r(V - \Pi) = rV - rV_s S - r\Psi_t B_t$. The terms $- \Psi_t r B_t$ on left and right cancel, leaving the Black-Scholes equation:

$$V_t + 1/2\sigma^2 S^2 V_{ss} + rSV_s - rV = 0 \quad (33)$$

Note that the drift coefficient ***"a"*** has disappeared, hence does not affect the value of the option. The partial differential equation depends only on the volatility σ and the risk-free interest rate r. This partial differential equation (PDE) must be satisfied by the value of any derivative security depending on the asset S. Option prices can also be calculated and the Black-Scholes equation derived by probabilistic methods. In this equivalent formulation, the discounted price process $e^{-rt}S_t$ is shifted into a ``risk-free" measure using the Cameron-Martin-Girsanov (CMG) Theorem, so that it becomes a martingale. The option price $V(S_t)$ is then the discounted expected value of the payoff $\Lambda(S)$ in this measure, and the PDE is obtained as the backward evolution equation for the expectation. The derivation above follows the classical derivation of Black and Scholes, but the probabilistic view is more modern and can be more easily extended to general market models.

Appendix B

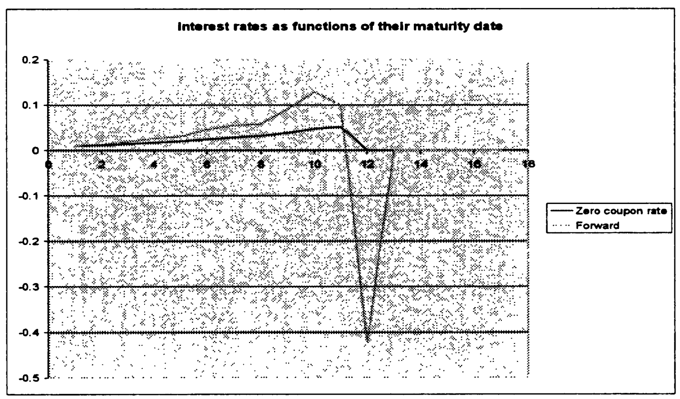
The Forward Rates Model (Adapted)

Data

	1	2	3	4	5	6	7	8	9
Name	US ZERO	US ZERO	US ZERO	US ZERO	US ZERO	US ZERO	US ZERO	US ZERO	US ZERO C
Code	US01Y00	US02Y00	US03Y00	US04 Y00	US05Y00	US06Y00	US07Y00	US08Y00	US09Y00
1/4/2003	0 92	1.1	1 356	1.654	1.924	2.354	2 789	3.153	3 7921
Zero coupon rates	0 0092	0 011	0.01356	0.01654	0 01924	0.02354	0.02789	0.03153	0.037921
Forward rates	0 0092	0.012803	0.018699	0.025533	0.030112	0.045314	0.054381	0.057373	0.0904953

	10	11	12	13	14	15	16	17
Name	US ZERO	US ZERO	US ZERO	US ZERO	US ZERO	US ZERO	US ZERO	US ZERO CURVE 17Y - ZERO YIELD
Code	US10Y00	US11Y00	US12Y00	US13Y00	US14Y00	US15Y00	US16Y00	US17Y00
1/4/2003	4.657	5.124						
Zero coupon rates	0.04657	0.05124	0	0	0	0	0	0
Forward rates	0.127727	0.099102	-0 422862	0	0	0	0	0

n_1 n_2 $f_{0,1}$ $f_{1,2}$



Abstract

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An Empirical Review of US Corporate Default Swap Valuation:

The Implications of Functional Forms

Dissertation directed by Derrick Reagle, PhD

This paper first develops a reduced form three-factor model for valuing credit default premia that is used to provide implicit prices which are then compared with market prices of credit default swaps to determine if swap rates adequately reflects market risks. This model extends Jarrow (2001) two-factor model by adding three new features to enhance the effectiveness of the model and add to the growing debate on the empirical pricing of credit default swap and the effectiveness of reduce form models. Firstly, the extended model retains Jarrow's mean reverting properties but will be extended to be arbitrage free because of the use of a Cox-Ingersoll-Ross (CIR) process, thus improving the study's ability to estimate the no arbitrage value of the CDS premium. Secondly, a liquidity variable is added to the model to capture the level of liquidity in the market, which conjectively impacts CDS valuation. Thirdly, the model now makes use of an expanded dataset of 53 companies and 15 months of daily data, which should lead to more robust estimators.

The paper first develops the Jarrow (2001) two-factor mean reverting model of credit default swap valuation, with a constant recovery rate and a non-linear hazard function. Methodologies were then proposed for extending Jarrow's model to a three-factor model so as to improve the effectiveness of the model in pricing the study's short-term maturities. For

the three-factor model the study assumed that CDS prices are a function of the spot rate of interest and CDS market liquidity. The study follows the assumption that default probabilities are implicit in the default swap prices and market and credit risks are correlated across companies and dependent on the state of the macro-economy.

The study derived a closed-form expression for CDS prices, and examines its implications for pricing under both the two-product and three-product methodologies. Both models were empirically tested using daily CDS pricing data from December 31, 2002 to July 25th 2003. In both models the parameters of the hazard function were estimated using non-linear regression. Finally, empirical evidence of the model's performance is presented.

VITA

Kwamie Obutte Dunbar, son of George and Myrtle Dunbar, was born on May 10th, 1963. He graduated in 1989 from the University of the West Indies, with a Bachelors of Science degree in Agriculture, with a major in Agricultural Economics, and later entered Sacred Heart University in 1996, graduating in 1999 with a Masters degree in Business Administration and a major in Economics/Finance.

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