A MODEL OF SYSTEMIC RISK IN THE INTEREST RATE SWAP MARKET

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CHAPTER 1

INTRODUCTION

There has been explosive growth in the swap market recently. The International Swaps and Derivatives Dealers Association (ISDA) market survey estimates the outstanding notional principal, as of year-end 1997, to be $22.291 trillion. The ISDA market surveys show that there has been a 3165% growth in the swap market from 1987 to 1997. Celarier(1987) estimates that 30 to 40 % of all primary capital market transactions involve some type of swap. Rapid growth combined with the recent failures of several swap dealers, such as Drexel, Burnham and Lambert, raises the issue of systemic risk in the swap market. Systemic risk is defined in the Angell Report (see Bank for International Settlements (BIS) 1989, 1991) as:

> *Systemic Risk is the risk that the inability of one institution within a payments system, as in the financial markets generally, to meet its obligations when due will cause other participants or financial firms to be unable to meet their obligations when due.*

There are some other similar definitions of systemic risk, such as the one in the Promisel report of the Group of Ten Central Banks, which defines systemic risk as "the risk that a disruption (at a firm, in a market segment, to a settlement system etc.) causes widespread difficulties at other firms in other market segments or in the financial system as a whole". These definitions focus on the 'domino effect' or the chain reaction that could occur when a large financial institution fails. Another definition of systemic risk focuses on the cost incurred by the federal government when stepping in to avert a systemic crisis. In this dissertation we shall analyze systemic risk from the 'domino effect' point of view. Hence, the definition given above by the Angell report of the Bank of International Settlements is used in this dissertation while referring to systemic risk.

Several government officials, regulators and policy makers have expressed their concerns over systemic risk in the OTC derivatives market. The GAO report on OTC derivatives concludes that there is concern that OTC derivatives contracts pose a systemic risk to financial markets. The recent bankruptcies of swap dealers such as Drexel Burnham and Lambert, Bank of New England, and Barrings PLC had the potential for systemic repercussions and hence were closely managed by the regulators. Moreover, huge losses, such as $1 billion by Metallgesellschaft, $1.5 billion by Shell Sekiyu, $1.4 billion by Kashima Oil and $157 million by Procter and Gamble, in the OTC derivatives market have fueled concerns of possible systemic repercussions.

The systemic risk in the swap market is magnified by the size and concentration of the swap market and the linkage between the swap dealers. The International Swaps and Derivatives Dealers Association (ISDA) lists 150 firms acting as derivative dealers worldwide as of December 1992. Although there are many dealers, most dealing activity is concentrated among a few firms. A Group of Thirty, July 1993, report indicated that eight U.S. bank dealers accounted for 56% of the worldwide notional contract amount of swaps as of December 1991. Swap transactions have expanded the financial linkage among the institutions that use them and the market makers that trade them. A report published by the Bank for International Settlements in October 1992, indicated that about 40% of the notional volume of all interest rate swaps and currency swaps held by the ISDA member dealers was for contracts among themselves.

Losses in the swap market due to default have also been on the increase. Aggarwal (1991) reports a figure of $35 million in write-offs due to swap defaults as of year-end 1988. A GAO survey of fourteen major OTC derivatives dealers revealed that cumulative losses from 1990 through 1992 amounted to $400 million with $250 million occurring in 1992. Evans (1991) reports that a number of municipalities in the United Kingdom engaged in swap transactions whose volume far exceeded their outstanding debt. In February 1989 the British courts ruled that the authority of the municipalities to enter into such excessive amounts of swaps to be outside their legal capacity. This decision voided contracts between 130 government entities and 75 of the world's largest banks leading to defaults on the swaps and a loss of 500 million pounds. Derivatives related credit exposures are very high. The GAO, May 1994 study reports that the gross credit exposure from derivatives for some of the large derivatives dealers can be as high as 600% of equity. An institutional investor survey reported that roughly 80% of the CFOs responding expressed increasing concern over the credit worthiness of their swap counterparties.

To date no careful analysis of the systemic risk in the OTC derivatives market has appeared in the academic literature. As Peter Field, the Editor-in-Chief of Risk magazine recently reported, "......no one at the International Swap and Derivatives Associations July 1993 conference could cite any serious academic research in progress on the subject". Thus there is a need for academic research to better understand the systemic risk in over-the-counter derivatives markets and especially in the interest rate swap market as it makes up around 76% of the OTC derivatives market as of year-end 1997 (see ISDA Market Survey).

This dissertation contributes to the meager literature on systemic risk by developing a theoretical model of systemic risk using the stylized facts observed in the interest rate swap market. The model consists of four components: the term structure model, the firm value model, the swap dealer capital model and the recovery rate model. The model is then simulated, using the Monte Carlo simulation methodology, to measure the probability of a systemic repercussion in the interest rate swap market. To the best of my knowledge this is one of the first attempts at modeling systemic risk in the interest rate swap market.

The rest of this dissertation is organized as follows. Chapter 2 is a description of the institutional details of the swap market and the current regulatory environment. Chapter 3 presents a review of the related literature. Chapter 4 describes the model of systemic risk. Chapter 5 describes the simulation of the model. Chapter 6 presents a brief description of the software developed for conducting the simulation. Chapter 7 presents the results of the simulation and chapter 8 concludes.

CHAPTER 2

THE SWAP MARKET

This chapter presents the institutional details of the swap market and the current regulations that govern the swap market. It begins with an introduction to interest rate swaps and proceeds to outline the market structure and the regulatory environment.

Interest Rate Swaps

The most common type of interest rate swap is a "plain vanilla" swap. Plain vanilla interest rate swaps make up the majority of the interest rate swap transactions, though exotic swaps that are tailored to each customer's needs are becoming increasingly popular. Plain vanilla interest rate swaps are agreements between two parties, called counterparties, wherein one counterparty pays a fixed and the other a floating rate based on a predetermined notional principal for a predetermined maturity.

An interest rate swap can be used to transform a floating rate loan to a fixed rate loan or vice versa. For example, let us say that ABC Corp. has a borrowing of $100 million at six-month LIBOR (London InterBank Offered Rate) plus 50 basis points. ABC Corp. can now convert it's floating rate borrowing to a borrowing with a fixed rate at 5.5% by entering into a plain vanilla swap where it receives six-month LIBOR and pays 5% fixed.

A plain vanilla interest rate swap can also be used to transform an asset earning a fixed rate of interest to an asset earning a floating rate of interest or vice versa. For example, let us say that ABC Corp. owns $100 million in bonds that pay a coupon of 5%. ABC Corp. can convert this asset into an asset earning six-month LIBOR by entering into a plain vanilla interest rate swap where it pays a fixed rate of 5% and receives a floating rate of six-month LIBOR.

Most swaps are arranged and intermediated by a swap dealer. A swap dealer operates a swap book, which may contain both matched and unmatched swaps. An example of a matched pair of swaps is given below in figure 1.

Figure 1. A Matched Pair of Swaps

The dealer that pays a fixed rate and receives a floating rate is on the Bid side of the transaction and the dealer that pays a floating rate and receives a fixed rate is on the ask side. Swap dealers charge a bid-ask spread for their services.

The floating rate in a plain vanilla interest rate swap is most often the London Interbank Offer Rate (LIBOR). The fixed rate in the plain vanilla swap is normally quoted as a certain number of basis points above the U.S. Treasury note yield. Plain vanilla interest rate swaps are priced by swap dealers using the three-month Eurodollar futures strip.

Risks Borne by a Swap Dealer

The risks borne by a swap dealer are credit risk, market risk, legal risk and operations risk. Credit risk and market risk are the more significant of the risks. Credit risk arises from the possibility of default by a counterparty. Market risk arises from exposure to the possibility of financial loss resulting from unfavorable movements in interest rates. Legal risk arises from the possibility of financial loss resulting from a court or regulatory body invalidating the swap contract. Operations risk arises from the possibility of financial loss resulting from management failure, faulty controls, fraud or human error.

Credit Risk

Credit risk arises from the possibility of default by a counterparty. The credit exposure arises from the changes in the interest rate that occur after the swap contract is originated. If the interest rate falls after the swap contract is put in place, the value of the swap would rise for the floating rate payer and fall for the fixed rate payer. This happens because the floating rate payer would make payments at a lower rate while the fixed rate payer is obligated to continue paying the contracted fixed rate. Since the value of the swap falls for the fixed rate payer, there is a possibility of default by the fixed rate payer. The fixed rate payer would default if the net payment to be made on the swap exceeds the value of the firm's assets.

On the other hand if the interest rate rises above that at the time the swap was put in place, the value of the swap would fall for the floating rate payer. The floating rate payer now has to make payments at a higher rate while the fixed rate payer continues to pay the contracted fixed rate. In this situation there is a possibility of default by the floating rate payer. Default will be certain if the net payment exceeds the value of the firm's assets.

Thus, we see that the floating rate payer could possibly default when the floating rate rises and the fixed rate payer could possibly default when the floating rate falls. In other words a counterparty could default on a swap only when the value of the swap to the counterparty is positive. Thus a swap dealer has credit exposure from a swap only when the value of the swap to the dealer is positive. This situation is summarized in figure 2.

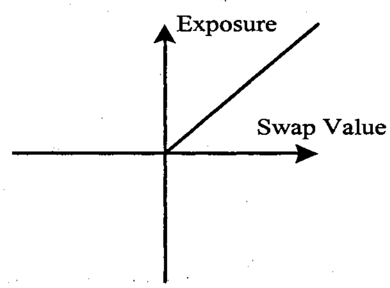

Figure 2. SwapCredit Exposure

It is also apparent that a swap dealer who enters into a matched pair of swaps with two counterparties is, at any one time, exposed to credit risk from only one of them.

The fixed rate payer or the floating rate payer would default, irrespective of whether the net payment on the swap is less than value of the firm's assets, if the firm enters into bankruptcy. This aspect of default is captured in our model by assuming that the firm enters into bankruptcy when the firm value falls below a threshold.

There are two components to the credit exposure of a swap. One is the current exposure, which is the replacement cost of the swap. This is also called the mark to market value of the swap. The other is the potential exposure, which is based on a forecast of interest rates between the present and the swap maturity date.

In the event of default by a counterparty the swap dealer would have to replace the swap at a fixed rate reflecting current market conditions. The cost incurred in replacing the swap is called the replacement cost of the swap.

For example, let us say that a counterparty has defaulted on a swap with a fixed rate of 9.3%(the dealer being the fixed rate payer) and a notional principal of $20 million with 5 years remaining till maturity. The dealer, now, has to enter into a replacement swap. The current market conditions require a 9.52% fixed rate. The differential is 22 basis points per year or 11 bps per 6 months. Since this differential will be realized at each payment date it can be examined as an annuity. The present value of the annuity over the remaining tenor is the replacement cost. The replacement cost is the measure of the actual credit exposure. The replacement cost equals the present value of this annuity for ten periods using a semiannual discount rate that is equal to the fixed rate according to the current market conditions. In this example the discount rate is 9.52%. The present value for this example is $171,875, which is the replacement cost of this swap.

This risk of default leads to systemic risk, which is the risk of multiple correlated defaults. From the above discussion we can see that credit risk and hence systemic risk is dependent on the movement in interest rates after the swap is originated. Systemic risk is also dependent on the replacement cost of the swap as this is the credit loss incurred by a swap dealer, which might cause the dealer to default on another dealer. The replacement cost, in turn, is dependent on the fixed rate on the replacement swap as determined by the forward LIBOR curve at the time of default. The forward LIBOR curve is used to price the replacement swap. Thus we can see that the term structure of interest rates is important in assessing the systemic risk in the interest rate swap market.

ISDA and Default

The ISDA Code of Standard Wording, Assumptions and Provisions for Swaps released in 1986 addresses the subject of default by a counterparty. A swap dealer typically enters into more than one swap with a counterparty and all the swaps are governed by a single master agreement. The master agreement usually provides that all swap transactions governed by the master agreement are simultaneously terminated if either party defaults on any swap transaction under the master agreement. This prevents a bankruptcy trustee from selectively enforcing those swaps that have a positive market value and discarding those with a negative market value. The ISDA 1986 code provides for seven specific events of default, but the parties may specify others if they like. The events of default are failure to pay, breach of covenant, credit support default, misrepresentation, default under specified swaps, cross default, and bankruptcy. Failure to pay refers to any failure by either party to pay an amount that is required under the swap agreement. A breach of covenant refers to a failure to comply with any covenant of the swap agreement other than the making of a required payment. Credit support default refers to any default under a credit support document that is required of the counterparty. Default under specified swaps refers to a default that results from the occurrence of a termination under another swap. A cross default refers to default on a swap occurring due to a default on some other indebtedness. The default due to bankruptcy is broadly defined to allow for variations in the bankruptcy laws of the different countries covered by the swap agreement.

Upon the occurrence of an event of default, the non-defaulting party has the right to designate an early termination date. In the case of bankruptcy, the termination is automatic. In any event other than bankruptcy, the non-defaulting party must provide notice to the defaulting party as to the early termination date. Once a notice of early termination has become effective, each party to a terminated swap is released from it's obligation to make the required payments under the swap and they must then calculate the termination payments.

Bankruptcy and Swaps

In the event of bankruptcy, swaps are considered to be unsecured claims under bankruptcy proceedings (see Hentschel and Smith(1995)). Swaps are also subordinate to debt in bankruptcy (see Cooper and Mello(1991)). Since swaps are subordinate to debt, a firm, which has debt in its capital structure, can default on the swap if the firm value is less than the sum of the debt obligations and the swap payments.

The Swap Market Structure

The International Swaps and Derivatives Association (ISDA) in its market survey reports that the notional principal of globally outstanding swaps amounted to $36.974 trillion at the close of the first half of 1998. The 1997 year-end outstanding notional principal for swaps was $22.291 trillion. Swap transactions originated in 1981 and since then there has been a phenomenal growth in the swap market. ISDA data on notional principal outstanding for interest rate swaps show that the notional principal outstanding has grown from $682.8 billion in 1987 to $22.291 trillion in 1997 (see table 1). This represents a 3165% growth from 1987 to 1997. U.S. Dollar interest rate swaps make up a major portion of the total OTC derivatives notional principal outstanding. According to ISDA data for 1997 interest rate swaps made up 76.7% of the total notional of all OTC derivatives. Approximately one third of the interest rate swap activity was in U.S. Dollars. The average notional principal for an outstanding interest rate swap was $37 million. ISDA reports that world wide there were 430,842 swap transactions of all types outstanding at the close of 1995.

In contrast, the currency swap market grew from $182.8 billion in outstanding notional principal in 1987 to $1.823 trillion in 1997. Currency swaps make up 6.28% of the total outstanding notional principal of all OTC derivatives. The average notional principal for an outstanding currency swap was $36 million.

Table 1

Outstanding Notional Principal of Swaps and OTC Derivatives (in billions)

Year	Interest Rate	Currency Swaps	OTC derivatives
1987	$682.8	$182.8	$865.6
1988	$1,010.2	$316.8	$1,654.3
1989	$1,502.6	$434.8	$2,474.7
1990	$2,311.5	$577.5	$3,450.3
1991	$3,065.1	$807.2	$4,449.5
1992	$3,850.8	$860.4	$5,345.7
1993	$6,177.3	$899.6	$8,474.5
1994	$8,815.6	$914.8	$11,303.2
1995	$12,810.7	$1,197.4	$17,712.6
1996	$19,170.9	$1,559.6	$25,453.1
1997	$22,291.3	$1,823.6	$29,035

According to the ISDA survey, as of 1994, there is greater activity in interest rate swaps with maturities up to 5 years than swaps with maturities of ten years. Figure 3 shows the maturity trend analysis as reported by ISDA.

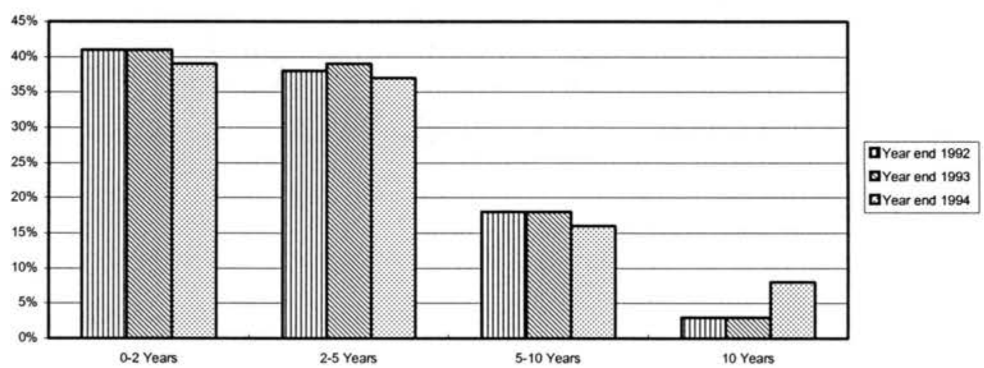

Figure 3. Maturity Trend

Thousands of institutions use derivatives but the OTC derivatives dealing activity is concentrated among a relatively few financial firms worldwide. About 150 firms were acting as derivatives dealers as of December 1992 (according to ISDA). Most dealing activity was concentrated among a small number of firms. U.S bank regulatory data indicate that eight U.S bank dealers accounted for 90% of the U.S bank derivatives activity. The May 1994 GAO study identifies fifteen major U.S OTC derivatives dealers, of which seven are banks, five are broker dealers and three are insurance company affiliates. The fifteen dealers identified by the GAO report and the notional amount of their OTC derivatives contracts outstanding as of 1992 are listed in table 2. An April 1993 report by the Group of Ten provided a possible explanation for this concentration. It stated that the need for complex information and risk management systems in conducting derivatives activities has resulted in the concentration of the activity among a few large firms. The degree of concentration of derivatives dealing activity can vary by product type. A report published by the Bank for International Settlements(BIS) in October 1992 indicated a relatively large number of dealers for high volume derivatives with low risk, such as interest rate swaps under 3 years to maturity, while there were a small number of dealers for longer term derivatives.

Table 2

Top Fifteen OTC Derivatives Dealers as of 1992

Dealer	Notional Amount (Dollars in billions)
Banks	
Chemical Banking Corporation	$1,620.819
Citicorp	$1,521.400
J.P. Morgan & Co.,Inc.	$1,251.700
Bankers Trust New York Corporation	$1,165.872
The Chase Manhattan Corporation	$886.300
BankAmerica Corporation	$787.891
FirstChicago Corporation	$391.400
Securities Firms	
The Goldman Sachs Group, L.P.	$752.041
Salomon, Inc.	$729.000
Merrill Lynch & Co., Inc.	$724.000
Morgan Stanley Group, Inc.	$424.937
Shearson Lehman Brothers, Inc.	$337.007
Insurance companies	
American International Group, Inc.	$198.200
The Prudential Insurance Company of America	$121.515
General Re Corporation	$82.729
Total	$10,994.811

OTC derivatives dealers are extensively linked to one another. The BIS(1992) report indicated that more than 40% of the notional principal of all interest rate swaps, currency swaps and interest rate options held by ISDA member dealers were for contracts among themselves. Thus the swap market is characterized by extensive inter-dealer transactions.

Most of the major non-bank derivatives dealers conduct their OTC derivatives dealing in one or more affiliates. Usually affiliates are structured and capitalized to get a AAA rating.

Current Regulatory Environment

The U.S bank swap dealers are regulated primarily by the Office of the Comptroller of Currency (OCC), the Federal reserve and the state banking authorities. The non-bank swap dealers, such as the affiliates of securities firms and insurance companies are not subject to monitoring by these authorities. The primary regulators for securities firm affiliates and insurance company affiliates are the SEC and the state insurance departments. The regulations imposed on both the bank and non-bank swap dealers are of three forms. They are reporting requirements, capital requirements and examination requirements. These regulations are discussed in detail below.

Regulation of Bank Swap Dealers

Reporting Requirements

The current reporting requirements for bank swap dealers are designed to enable bank regulators to identify the major market participants and monitor market trends.

The bank derivatives dealers are required by the Federal Reserve to report the notional contract amounts of their derivatives activities every quarter. These reports are to include separate totals for interest rate and foreign exchange derivatives and a combined total for equity and commodity derivatives. For each of these types of derivatives, banks report a combined total for futures and forwards and separate totals for options and swaps. Each quarter banks also report their total derivatives related credit exposure, aggregated for all counterparties. The credit exposure is measured by the total replacement cost for all contracts. Separate totals are reported for contracts maturing in one year or less. Regulations do not require dealers to routinely report information about large derivatives related credit exposures to individual counterparties or classes of counterparties.

The Federal Financial Institutions Examination Council (FFIEC) has issued a proposal that would require banks to provide additional details on their derivatives contracts amount by product. The FFIEC proposal requires that banks with total assets of at least $100 million begin reporting the total market value of their swap contracts with both a positive value and a negative value. The reporting would also be broken down on the basis of contracts held for dealing purposes and contracts held for hedging and other purposes. The proposal also requires that banks report their net current credit exposure across all products and counterparties after taking into account legally enforceable bilateral netting arrangements. Bilateral netting arrangements ensure that the payment flows between the parties is limited to the payment differentials. However the proposal does not require reporting of credit exposures to individual counterparties.

Current regulation requires the reporting of derivatives related earnings aggregated with the results of other trading activity. However information on the type of earnings, such as by activity (trading versus dealing) or by product (options or swaps) is not required to be reported. . The FFIEC proposal requires banks report the income from derivatives separately from other income. At the time of this writing the FFIEC proposal has not been implemented.

Specific information on credit exposure by product type and by individual counterparty will enable the regulators to better assess the risks taken by the dealer. Based on such detailed information regulators could determine whether a dealer is overly exposed to any particular counterparty, thus increasing the possibility of a systemic repercussion in the event of default by the counterparty. The aggregate nature of the information currently reported inhibits regulators from adequately assessing the risks of bank derivatives dealers.

Capital Requirements

The U.S banks are required to comply with two different types of capital requirements - a risk based capital requirement and a leverage ratio requirement. The risk-based requirement addresses the credit risk whereas the leverage ratio requirement addresses the other risks such as market risk.

The procedure for assessing capital requirements for a swap is a four-step process. The first step is to determine the notional principal of the swap. Based on this notional principal, the swap coupon and the prevailing level of interest rates, the swap is marked to market and the replacement cost of the swap is ascertained. The mark to market value is the present value of the net payment stream specified by the contract, calculated on the basis of current market interest rates, as discussed previously. To this replacement cost an additional amount is added to account for future potential increases in the credit exposure. This future potential exposure measure is calculated by multiplying the notional value by the appropriate credit conversion factor shown in table 3 (see Federal.Register, Vol. 54, No. 17).

Table 3

Credit Conversion Factors

Remaining Maturity	Interest rate contracts (percent)	Exchange rate contract (percent)
One year or less	0	1.0
Over one year	0.5	5.0

No potential exposure is calculated for single currency interest rate swaps in which payments are made based upon two floating rate indices. The result of this calculation is called the credit equivalent amount and is the second step in the process. The third step involves a risk weighting. This requires a simple multiplication of the credit risk equivalent by a fixed percentage. The percentage itself depends on the quality of the counterparty. However the maximum weight applied to the credit equivalent amount is 50%. For a summary of these risk weights see "Final Risk-Based Capital Guidelines" the Federal Register, Vol. 54, No. 17. The result of this calculation is called the risk weighted asset. The final step is to determine the capital requirement by multiplying the risk weighted asset and the capital ratio. The capital ratio is currently 8%. A diagrammatic representation of this procedure is shown in figure 4.

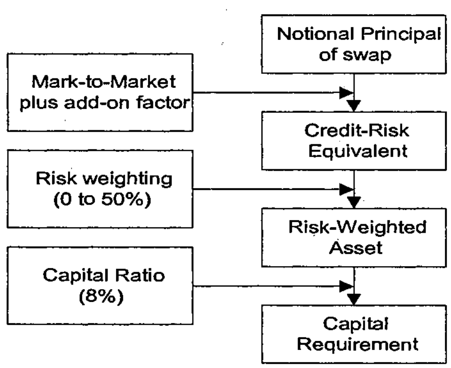

Figure 4. Procedure for Determining Capital Requirement

For the purposes of calculating the risk based capital ratio netting of swaps is recognized only when accomplished through netting by novation. Netting by novation is a written bilateral contract between two counterparties under which any obligation to each other to deliver a given currency on a given date is automatically amalgamated with all other obligations for the same currency and value date, legally substituting one single net amount for the previous gross obligations.

The bank dealers must also comply with a capital leverage ratio. The leverage ratio requires banks to hold capital as a cushion against losses arising from other risks such as operational risks etc. Beginning Mar 31, 1994 banks are required to include the value of derivatives contracts with a positive market value as part of their total assets subject to the leverage ratio capital requirement.

Current bank capital requirements do not fully address all the risks associated with derivatives. The other risks such as legal risk are difficult to quantify and hence have not been included in the regulations.

Examination Requirements

Bank Swap dealers are subject to annual examinations. Those major OTC derivative dealers regulated by the Office of the Comptroller of Currency are subject to continuous on-site examinations.

Regulation of the Non-Bank Swap dealers

Although bank Swap dealers are subject to regulation, regulatory controls are minimal or do not exist for U.S. OTC derivatives dealers that are affiliates of securities firms and insurance companies. Other than reporting requirements these dealers are subject to minimal regulations.

Reporting requirements

To allow the SEC to assess the risks posed by a broker-dealer's affiliates, the Market Reform Act of 1990 authorized the SEC to collect information from registered broker-dealers about the activities and financial conditions of their holding companies and materially associated persons. Pursuant to this act, the SEC began in Oct. 1992 to receive information which includes the total derivatives notional contract amounts, aggregate credit risk of these firm's derivatives dealers affiliates and certain concentrated exposures to individual counterparties. The SEC also instituted a reporting requirement for credit exposures to individual counterparties that exceed a certain threshold which is set at $100 million or 10% of the dealers net capital, whichever is higher. The GAO(1994) report considers this threshold to be too high to obtain sufficient information for detecting credit risk problems.

Capital Requirements

The SEC uses it's net capital rule (rule 15c3-1) to oversee the financial soundness of broker dealers. Under this rule a broker dealer must subtract from the value of it's assets various amounts called 'haircuts' depending on the assets liquidity or riskiness. For swaps, securities firms are to add to their net worth the value of any contracts with unrealized positive value and subtract from their net worth the value of any contracts with a negative market value. However they are also required to deduct from their net worth any swap payments due them as unsecured receivables.

These capital standards imposed by the SEC apply only to regulated broker-dealers and not to OTC derivatives dealers that are affiliates of securities firms. Also, the SEC has no authority to examine the activities of these affiliates.

The GAO(1994) study reports that derivatives dealer affiliates of insurance companies are subject to minimal reporting requirements and no capital requirements. They are also not examined. State insurance departments and not federal regulators are responsible for monitoring insurance companies and they do not directly oversee the financial condition of affiliates of insurance companies that are OTC derivatives dealers. Insurance regulators receive audited consolidated financial statements for the parent or holding company of the insurance company. These statements contain information on the holding companies derivatives notional amounts and aggregate credit exposure. The affiliate is not required to provide any other financial information to the regulators.

Other than these regulations which are mandatory there are also guidelines suggested by the group of thirty and the bank regulators. These guidelines deal with managing credit risk and market risk.

The guidelines for managing credit risk suggested by the group of thirty are:

1. Firms need to fully measure their derivatives related credit risk and establish limits on the amount of exposure by counterparty.

2. Firms need to establish a separate, independent credit management function for overseeing customer credit analysis, developing credit limits, and monitoring compliance with these limits.

3. Firms need to use bilateral netting arrangements to reduce their credit exposures with individual counterparties.

The guidelines for managing market risk suggested by the group of thirty are:

1. Systems should be able to measure and limit exposure to market risk losses. Banks should mark to market their derivatives portfolio at least daily. The Board of Directors should set approved limits on such exposures to loss.

2. Systems should stress test, or simulate, the impact that various changes in market prices and rates would have on the value of the firm's derivatives portfolio.

CHAPTER 3

LITERATURE REVIEW

This chapter reviews the literature relevant to this study. There are four strands of literature that are related to this study. The first is the literature on systemic risk, second is the literature on the use of simulation techniques in evaluating the credit exposure of swaps, the third is the literature on term structure modeling, and the fourth is the literature on modeling default. A review of the literature on each one of these topics follows.

Systemic Risk

The literature on systemic risk is scant at best. At the time of this writing there are no published academic papers on systemic risk models for the OTC derivatives market. However, there are two working papers that attempt to model systemic risk. There have been few discussions (without any formal modeling) on systemic risk in OTC derivatives markets. Scholes(1996) presents one such discussion wherein he cites four causes of systemic risk:

i. behavioral (causing bank runs)

ii. structural failure

iii. innovation risk. This is the risk that innovations could be too numerous and the volume of transactions too large for the financial infrastructure to handle.

iv. Unanticipated changes in regulatory, legislative, legal and other rules.

Scholes concludes that the fear of systemic risk is unwarranted on the basis that there is no empirical evidence that supports the premise that OTC derivatives can lead to systemic risk. Scholes also emphasizes the need for modeling and pricing credit risk in mitigating systemic risk. Scholes, other market participants and researchers agree that there is a possibility of systemic risk, however small it might be. The lack of empirical evidence on systemic risk makes it all the more important to assess the systemic risk in the OTC derivatives market by means of a model.

The United States General Accounting Office conducted a study of the OTC derivatives market in 1994 and concluded that there were several factors in this market that could lead to a systemic failure. The GAO report found that the OTC derivatives activity is concentrated among 15 major OTC dealers that are extensively linked to one another. It also found that the regulation of OTC derivatives dealers was inadequate. The GAO report found that there were no capital requirements and examination requirements for securities firms affiliates and insurance firm affiliates which have been growing rapidly, accounting for about 30% of the U.S. OTC derivatives dealer's volume as of year-end 1992. Thus the GAO report concludes that the combination of explosive growth, concentration, linkages and regulatory gaps in the OTC derivatives market could pose a risk to the financial system as a whole.

Two studies model systemic risk. Wall, Tallman and Abken(1996) model the impact of a dealer's failure on OTC derivatives market liquidity during volatile periods. They point out that though concerns about systemic risk have been alleviated by the failures of several OTC derivatives dealers, such as Barings PLC, without disastrous consequences, these dealers had small OTC market shares. They argue that these factors have been too small to induce systemic failure. They model the systemic implications of increased contracting costs due to the temporary information loss when a dealer fails in a period of market uncertainty. Their model consists of three dealers and *N* firms with a set of initial conditions and two subsequent periods in which developments occur. Every firm is exposed to a random symmetric shock with realized value S^+ or S^-. Solvent firms that receive an adverse shock S^- are assumed to become financially distressed. Shocks may be hedged with a forward contract with one of three OTC dealers.

In the first/initial period the firms establish hedges with one of the dealers and some firms become insolvent. In the second period insolvent firms unwind their existing hedges and seek to speculate, while solvent firms maintain their forward contracts at the optimal hedge size. Both solvent and insolvent firms may seek to enter into new forward contracts in this period. In the third period a shock to the exogenous risk factor is realized. Solvent hedged firms are not affected by the shock, while solvent unhedged firms enter into financial distress if the shock is unfavorable. All insolvent firms fail if the shock is adverse.

Based on this three period setting Wall, Tallman and Abken consider two cases, the first being where no dealer fails and the second where one dealer fails. In the case where no dealer fails there is no market breakdown. In the case where one dealer fails there is a market breakdown if the minimum spreads that the dealers require exceed the maximum that the good firms will pay. Based on their model they assume a shock that would result in a 10% loss in face value of the 30-year treasury bond and calculate the minimum spread the dealer must charge to break even and the maximum spread that good firms will pay so that their cost of hedging does not exceed the gains from hedging. Based on these calculations they conclude that a systemic failure is unlikely but not completely impossible.

The Wall, Tallman and Abken(1996) model focuses exclusively on the market breakdown resulting from an information loss when a dealer fails and ignores other equally important (if not more important) problems such as the credit loss arising from the failure of a dealer. The analysis also assumes that the recovery rate in the event of failure is zero. Moreover the analysis is conducted with respect to the forward market and thus ignores other OTC derivatives such as swaps that make up a large portion of the OTC derivatives market. The study also does not attempt to measure the probability of a market breakdown, which would be a valuable piece of information to policy makers. The present study focuses on the credit losses occurring due to the failure of a dealer and incorporates recovery rates in measuring the probability of a systemic repercussion in the interest rate swap market.

Schneck(1994) adapts the swap market intermediation model of Campbell and Kracaw(1991) to study the systemic risk in the OTC derivatives market. Schneck's model consists of n counterparties and l intermediaries who offer market making services for tailored swaps. Schneck assumes that all the swap contracts are fully tailored to hedge the risk exposure of the counterparty and that all end-users wish to convert a floating cashflow to a fixed one. He also assumes that each counterparty deals exclusively with one market maker. Default within the context of his model occurs when the cashflow from a swap at time t is greater than the capital of the firm at time t. Two risk factors are considered in the model, one is a factor shock and the other is an idiosyncratic shock. Schneck assumes a gamma distribution for the capital of the market maker and arrives at a conditional probability of a second market maker going bankrupt given that another has gone bankrupt, to measure systemic risk. Based on simulations of the model he concludes that the systemic risk in OTC derivatives markets is negligibly small.

Our study is somewhat similar to Schneck's study in that we also attempt to measure systemic risk as the conditional probability of a dealer defaulting due to the default of another dealer. Schneck does not employ a term structure model to determine the cashflows from a swap, instead he assumes that the casflows are random. In contrast we employ a term structure model to determine the cashflows from a swap. Schneck does not consider causes of default other than non payment on the swap. We include causes of default other than non payment on the swap by modeling default to occur when the firm value falls below a threshold value. Also Schneck does not consider recovery rates in the event of default, which is taken into account in our model.

There have been some studies that attempt to model systemic risk in the electronic fund transfer networks. They are briefly reviewed here for the sake of completeness. Cohen and Roberds(1993) attempt to measure the systemic risk in electronic fund transfer networks using network theory. They calculate upper bounds on systemic risk under varying assumptions about both the networks' settlement rules and the extent of the guarantor's obligation to the network. Eisenberg(1995) also performs a similar network analysis of financial market shutdown. He derives analytic results of the statistical properties of payments mechanisms using Boolean graphs.

Thus, in summary, we note, from the above literature review, that systemic risk is definitely a possibility (however small it may be) which has received considerable attention from policy makers, albeit without the benefit of a formal model. The lack of historical experience and the lack of empirical evidence make formal modeling of systemic risk all the more important. As evidenced by the above literature review, currently there is no model of systemic risk in the interest rate swap market, which makes up a lion's share of the OTC derivatives market. The only two existing models of systemic risk in the OTC derivatives market are work in progress and have several shortcomings as discussed above. Hence, there is an indisputable need for modeling work in this area of finance.

Credit Risk in Interest Rate Swaps

The Simulation Approach

One of the approaches to measuring credit risk in interest rate swaps is to measure the potential credit exposure using simulations of future interest rate scenarios. Several studies have used Monte Carlo simulation to determine the distribution of potential exposure for interest rate swaps. A partial list includes Arak , Goodman and Rones(1986), Muffet(1987), Bank of England and Federal Reserve Board Staff(1987), Feron and Handjinicolaou(1987), Neal and Simmons(1988), Simmons(1989), Hendricks and Barker(1992), Gilberti, Mentini and Scabellone(1993), Bond, Murphy and Robinson(1994), and Duffee(1996). The standard approach followed by all the above mentioned papers is the following.

A particular parametrization of the underlying financial variable (e.g. the Cox, Ingersoll and Ross(1985) interest rate model in the case of interest rate swaps) is chosen and its parameters are calibrated using historical data. The resulting model is used to generate, randomly, a hypothetical time path of the relevant financial variables. The replacement values of an instrument or a portfolio of instruments are calculated at each point along each time path. This exercise is repeated thousands of times and the resulting distributions of replacement costs are used to calculate expectations and confidence bounds for exposures.

The Bank of England and Federal Reserve Board(1987) study is the basis for calculating the potential exposure on fixed for floating interest rate swaps in the risk based capital guidelines described in the previous chapter. This study calculates the average replacement cost over the life of a matched pair of swaps using a Monte Carlo simulation. Fixed rates on the swap are randomly generated every semiannual period from a lognormal distribution. These fixed rates were used to calculate the replacement cost of the swap at every semiannual period thus determining the distribution of replacement costs. The volatility of the interest rates (the standard deviation of the lognormal distribution) were estimated as the 90% quantile of observed annual volatilities in long term bond rates for the period 1981-86. Based on the distribution of potential credit exposure calculated by this study the Federal Reserve issued a proposal for the calculation of credit exposure for interest rate swaps and currency swaps. After public comment and debate the final guidelines as described in the previous chapter were agreed upon.

Simmons (1989) uses Monte Carlo simulation to value the credit exposure. Thousands of possible interest rate scenarios are generated and market values for the swaps are calculated for each scenario and averaged. The interest rate simulations are based on a lognormal distribution and a matched pair of swaps is used to carry out the analysis. The credit exposure is calculated as a percentage of the notional principal of the swap. Since these credit exposures are predicted to occur at a future date they are discounted to the present at the fixed interest rate prevailing when the swaps were booked. The expected lifetime exposure is the average of the expected exposures in each settlement period. Simmons found that the calculated credit exposures are much greater than the estimate of credit exposure produced by the risk based capital requirements. Simmons's findings could be due to the difference in volatility of interest rates used in her study and the Federal Reserve study. The Federal Reserve used the 90% quantile of observed annual volatilities for the five year interval ending 1981-86 while Simmons's study used the mean volatility of interest rates between 1979-87.

Ferron and Handjinicolaou(1987) also use Monte Carlo simulations to calculate average expected exposure. They use a lognormal distribution with a volatility of 20% and a starting rate of 9% to generate the interest rate paths. Average expected exposures were calculated using the interest rate paths generated. Based on the calculated average expected exposures the authors arrive at a rule of thumb for calculating credit risk in interest rate swaps:

— 0.30% x (remaining years to maturity) x (notional amount)

— If the mark to market value exceeds the above formula then credit risk is equal to current mark to market value.

— If the mark to market value is negative or less than the above formula, then credit risk is equal to the formula.

Again the volatility assumed in this study is different from that used by the Federal Reserve.

While the previously described studies measured the credit exposure of single swaps, Wall & Fung(1987), examine the effect of interest rate changes on the credit exposure of an interest rate swap portfolio. They demonstrate that the credit exposure of an interest rate swap portfolio depends on the mix of fixed rates in the portfolio and on whether the matched pairs have the same fixed rates. The analysis considers two portfolios, one where all matched pairs of swaps have one fixed rate and the other where matched pairs have the same fixed rates but the various matched pairs have different fixed rates. Their results show that the credit exposure of the diversified portfolio is less volatile. They also show that if the two portfolios are identical in every respect except diversification of fixed rates then the first portfolio never has more credit exposure than the second. Thus Wall and Fung conclude that the analysis of credit exposure based on a single matched pair may be misleading.

Belton(1987) analyzes the credit risk in interest rate swaps. The cashflows from the swap are made independent of the floating rate index (e.g. LIBOR) by making use of the fact that a counterparty may unwind it's position in the swap at period t by entering into an opposite position. For example, suppose that an n period swap contract is signed at time 0 with a fixed rate of $R_{n,0}$ then, at period t, the fixed rate payer may unwind his position by entering into an n-t period swap at the current market rate of $R_{n-t,t}$. This combined position will yield cashflows equal to $(R_{n-t,t} - R_{n,0})P$. Since these cashflows are not dependent on the floating rate index their present value is calculated as

$$RPL_{n,t} = \sum_{i=t+1}^{n} (R_{n-t,t} - R_{n,0}) PB_{ti} \tag{3.1}$$

Where B_{ti} is the period t price of a discount bond that promises to pay $1 in the i^{th} period and P is the notional principal amount. The above method is an effective way of calculating the replacement cost of the swap as it captures the loss that the swap dealer would actually incur due to default by a counterparty. Belton goes on to simulate his model in the second part of his study. He does not use a term structure model but characterizes the yield curve by a simple vector autoregressive process. He finds that the credit exposure of a matched pair of swaps tends to initially increase and then decrease during the life of the swap. He does not find support for allegations that the market is systematically underpricing credit risk.

The shortcomings of Belton's study are that he does not consider portfolios of swaps with different fixed rates and tenors (maturities), in evaluating the credit exposure. Also, a more rigorous model of the term structure could change his results.

The Contingent -Claims Approach

Another approach to pricing the credit risk of interest rate swaps uses option pricing theory. In this approach, each counterparty is considered to be short an option that the other party will default.

Sorenson and Bollier (1994) initially assume a one way default exposure. They consider a counterparty 'X' that is receiving fixed from a counterparty 'Y' and paying floating. Party X's credit exposure can be viewed as a series of European swap options for the right to receive fixed which 'X' has written to 'Y', to replace the cashflows that are lost after default. The net option value to party X is the value of a standard European swap option times the probability of default for that date. This value of credit risk is analyzed over the remaining life of the swaps to produce an adjustment to the mid market swap level at which X will be willing to transact with Y.

The value of the option that X is effectively exposed to Y's credit can be written as follows:

$$CR_X = P_y \, RV_X \tag{3.2}$$

Where CR_X – Credit risk adjustment allocated to Y's risk of default

P_y – The probability that Y will default on the single default date

RV_X – Value of the option for X to replace the swap

In the case of bilateral default risk the equation becomes, from X's point of view,

$$CR_X = P_yRV_X - P_XRV_y \tag{3.3}$$

$$CR_X = -CR_y \tag{3.4}$$

The model developed by Sorensen and Bollier is strictly a compound option model, but one possible date for default has been assumed in order to simplify the analysis.

Abken(1991) analyzes the credit exposure by viewing the swap as a combination of a cap and a floor, having the same strike rate, equal to the fixed swap rate. Abken uses the Longstaff(1990) model of the short term interest rates which is a reparametrization of the Cox, Ingersoll and Ross(1985) term structure model. He also uses the geometric brownian motion for the value of the firm with the drift term adjusted to reflect the cash flows from the swap. The stochastic processes for the term structure and the firm value are correlated with one another. The cap and floor are valued using the Longstaff(1990) yield option model. In order to implement the model Abken uses Monte Carlo simulation by risk neutralizing the stochastic processes, generating sample realizations for them and computing payoffs. Abken finds that for a fixed rate payer on a swap with a maturity of two years the credit spreads are much narrower than those that have been actually observed. The floating payer has a greater default rate than the fixed rate payer because the term structure considered is upward sloping. The default rates are also high when there is a high correlation between the term structure and the firm value stochastic processes. Abken also finds that swap credit spreads widen dramatically for five and ten year swaps.

Abken's study has a few shortcomings. He has assumed the CIR model for the term structure, but two recent studies, Chan, Karolyi, Longstaff and Sanders(1992) and Pearson and Sun(1994) have rejected the CIR model and have concluded that the model fails to provide a good description of the short term interest rates. Moreover the CIR model is not consistent with the initial term structure and hence will not provide a correct pricing of a credit risky swap. The CIR model also induces serial correlation in bond prices thus restricting the shape of the term structure. Term structure movements are critical in assessing credit risk, as it is precisely the movements in the term structure and the short rate that increases or decreases credit risk. Another important factor that significantly magnifies the credit risk is jumps in the interest rate. The CIR model does not take into account any jumps in the interest rate. Moreover, Abken does not consider a swap portfolio while evaluating the credit exposure. A swap dealer typically will have a book or a portfolio of swaps and analyzing the credit exposure from the perspective of a portfolio of swaps will yield different results than analyzing a single swap. All the criticisms leveled at Abken's study are rectified in our model as we perform the analysis on a portfolio of swaps and model the term structure with jumps in the interest rate and impose no restrictions on the shape of the term structure.

Whittaker (1987) unlike Sorenson and Bollier viewed the swap as the right to buy and sell a bond and a floating rate note (FRN) at the prices prevailing when the swap was arranged. They take the swap to be equivalent to a call and a put rolled into one package. These options are excersized by the default of the end-user, which will occur only if the swap is in the money. A swap is in the money for a fixed rate receiver when interest rates rise and for a fixed rate payer when interest rates fall. The default of an end-user in a swap is tantamount to the joint exercise of a call option and a put option on a bond and a FRN. A modified Cox-Ross-Rubenstein arbitrage-pricing approach is developed for swaps which shows that credit exposure of a swap dealer and therefore the pricing of swaps varies directly with expected interest rate volatility and swap maturity. Interest rates were assumed to be lognormally distributed. Whittaker concluded that the swap market did not adequately account for the varying swap payment structures, end-users credit quality or swap maturity in pricing credit risk and also that the present regulations do not account for certain swap complexities such as payment frequency mismatches. Whittaker considers the swap to be a call on bonds and a put on FRNs, but he fails to consider the fact that these options themselves are default risky and have to be valued as such. The model also requires the required rate of return on the swap, which is subjective and varies from dealer to dealer. Thus Whittaker's model introduces many complexities thereby abstracting from reality and a practical solution to the issue.

Hull(1989) considers default to occur only when the counterparty is bankrupt and the value of the off balance sheet contract is negative. The loss to the bank arising from a counterparty defaulting is $max(u, 0)$ where u is the value of the contract to the bank. This loss is regarded as a payoff from a contingent claim and again the Cox-Ross-Rubenstein arbitrage pricing method is used to value the default option.

Hull also considers the credit weighting schemes under the present regulation and notes that certain key assumptions such as, the exposure on any given contract is independent of the probability of bankruptcy, are necessary to justify these schemes. He concludes that the appropriate risk weight for an off-balance sheet contract depends on the size of the bank, the other contracts in the bank portfolio and the objectives of the counterparty when it entered into the contract.

Cooper and Mello(1991) model credit risk in a continuos time framework. They assume a mean reverting process for the interest rates and a geometric brownian motion adjusted for the dollar payout of the firm, for the firm value. A numerical solution is derived using standard risk neutral valuation methods taking the local expectation hypothesis to be true.

Unlike the other studies Rendelman(1992) takes a binomial modeling approach to pricing swaps which have a potential for default on both sides of the contract. Binary variables are used to indicate "up" and "down" outcomes for the interest rate and for the cashflow capacities of the counterparties. The study does not model credit risk but demonstrates that if debt has priority over swaps in a bankruptcy, then the stockholders of the high-risk party in a swap gain at the expense of the low risk party's stockholders.

Term Structure Models

The movement in the short rate and the term structure of interest rates have a significant impact on the possibility of default (credit risk) and hence on systemic risk. Thus the term structure is a significant component of our model of systemic risk and hence the literature on term structure modeling is reviewed here.

Term structure modeling has been an area of research that has received considerable attention from researchers. Due to the abundance of literature in this area I will review only the dynamic term structure models below. Dynamic term structure models are the class of models containing a stochastic component that produces inter temporal uncertainty.

Term structure models can roughly be classified into three categories. The models in the first category are premised on a short term rate stochastic process and derive closed form solutions, where possible, for bond prices. These models are typically derived under general equilibrium considerations and hence are also referred to as equilibrium models. Examples of term structure models that fall into this category include Merton(1973), Vasicek(1977), Dothan(1978), Brennan and Schwartz(1977, 1979, 1980, 1982), Cox, Ingersoll and Ross(1980,1985), and Rendelman and Bartter(1980) and Longstaff and Schwartz(1992). The Cox, Ingersoll and Ross (CIR) model is probably the most popular and oft cited model of the lot and hence we will review it in some detail.

Cox, Ingersoll and Ross assume the short rate to follow a mean reverting process as shown below.

$$dr = k(\theta - r)dt + \sigma\sqrt{r}dz \tag{3.5}$$

Where k, θ, and σ are constants. In this model the short rate reverts to a long-term value θ, and the speed of reversion is given by k. This short rate model has the following properties.

i. Negative interest rates are precluded.

ii. If the short rate reaches zero it can subsequently reach a positive value.

iii. As the short rate increases its standard deviation increases.

iv. There is a steady state distribution for the short rate.

A closed form solution for bond prices is obtained as

$$P(r,t,T) = A(t,T)e^{-B(t,T)r} \tag{3.6}$$

Where $$A(t,T) \equiv \left[\frac{2\gamma e^{[(k+\lambda+\gamma)(T-t)]/2}}{(\gamma+k+\lambda)(e^{\gamma(T-t)}-1)+2\gamma}\right]^{2k\theta/\sigma^2}$$

$$B(t,T) \equiv \left[\frac{2(e^{\gamma(T-t)}-1)}{(\gamma+k+\lambda)(e^{\gamma(T-t)}-1)+2\gamma}\right]$$

$$\gamma \equiv ((k+\lambda)^2 + 2\sigma^2)^{1/2}$$

All the other equilibrium models assume that the short rate follows a form of stochastic process. Some allow for mean reversion, such as Vasicek(1977), and others do not allow for mean reversion, such as Dothan(1978). A summary of the different stochastic processes used in the equilibrium models is given in table 4.

Table 4

Equilibrium Models of the Short Term Interest Rate

Model	Short rate process
Merton(1973)	$dr(t) = \alpha dt + \sigma dz$
Vasicek(1977)	$dr(t) = (\alpha + \beta r(t))dt + \sigma dz$
Cox, Ingersoll and Ross(1985)	$dr(t) = (\alpha + \beta r(t))dt + \sigma r^{1/2}dz$
Dothan(1978)	$dr(t) = \sigma r(t)dz$
Rendleman and Bartter(1980)	$dr(t) = \beta r(t)dt + \sigma r(t)dz$
Brennan and Schwartz(1980)	$dr(t) = (\alpha + \beta r(t))dt + \sigma r(t)dz$
Cox, ingersoll and Ross(1980)	$dr(t) = \sigma r^{3/2}dz$
Constant Elasticity of variance	$dr(t) = \beta r(t)dt + \sigma r^{\gamma}(t)dz$

The above mentioned equilibrium models produce the initial term structure as an output of the model and hence are not necessarily consistent with the initial term structure observed in the market. Moreover these models depend on the risk preferences of decision-makers. Another disadvantage of this class of models is that they produce a serial correlation in bond prices. The shape of the term structure is restricted to parallel shifts.

Chan, Karolyi, Longstaff and Sanders(1992) estimated and compared the models in table 4 using the generalized method of moments. They show that the most commonly used models such as Vasicek(1977) and Cox, Ingersoll and Ross(1985) perform poorly relative to the less well known models such as Dothan(1978). Another study by Pearson and Sun(1994) use an empirical method that utilizes the conditional density of the state variables to estimate and test the term structure models using data on both discount and coupon bonds. They reject the CIR model using a Likelihood ratio test and conclude that the CIR model fails to provide a good description of the short-term interest rates.

The second class of models take the initial term structure as an input and develop the term structure model in an arbitrage free framework. These models are hence called no-arbitrage models. Ho and Lee(1986) pioneered this approach and Heath, Jarrow and Morton(1992) generalized the Ho and Lee model. Since these models take the initial term structure as an input to the model, they are always consistent with the initial term structure observed in the market. Ho and Lee(1986) started with the initial prices of bonds and built an arbitrage free binomial tree for the subsequent movement of bond prices. Ho and Lee assume a constant volatility and their model is in discrete time. Heath, Jarrow and Morton(1992) significantly generalized the Ho and Lee model by extending it to a continuous time framework and by placing no restrictions on volatility. As I use the Heath, Jarrow and Morton(HJM) model in my model of systemic risk, I shall review it in detail below.

Heath, Jarrow and Morton(1992) take as given the initial forward rate curve and impose a fairly general stochastic structure on it. They use the insight of Harrison and Kreps(1979) to arrive at the condition that the forward rate curve must satisfy in order for the model to be arbitrage free. This condition is equivalent to the existence of a martingale measure under which the relative price movement of any security in the economy is a martingale. In the HJM model markets are assumed to be perfect. The uncertainity in the economy is characterized by the probability space $\{\Omega, F, P\}$, where Ω is the state space,

F a σ algebra representing all events in the economy and P is a probability measure. The economic forces that determine the prices of securities and their dynamics are represented by n independent Brownian motions $\{W_1(t), W_2(t), \ldots, W_n(t)\}$. The dynamics of the forward rate in the HJM model is given by

$$df(t,T) = \mu(t,T,w)dt + \sum_{i=1}^{n} \sigma_i(t,T,w)dW_i(t) \tag{3.7}$$

Where $\mu(t,T,w)$ is the drift term of the forward rate curve and the $\sigma_i(t,T,w)$ are the stochastic volatility functions of the forward rate curve. $f(0,T)$ is the initial forward rate curve which is taken as given. A restriction is placed on the family of drift processes in order to guarantee the existence of a unique equivalent martingale probability measure. This restriction is called the forward rate drift restriction by HJM and is given by

$$\mu(t,T) = -\sum_{i=1}^{n} \sigma_i(t,T)(\phi_i(t) - \int_t^T \sigma_i(t,v)dv) \tag{3.8}$$

Where $\phi_i(t)$ is the market price for risk associated with the random factors $W_i(t)$.

The criticisms and disadvantageous of the first class of models cited above are largely not applicable to the HJM model. The HJM model is consistent with the initial term structure as it takes the initial term structure as an input. The HJM model is a completely general model with no restrictions or assumptions being placed on the volatility functions. Thus the HJM model does not place any restrictions on the shape of the term structure. Moreover the HJM model does not produce a serial correlation in bond prices as it models the forward curve and each forward rate in the curve evolves with an innovation that is independent of the other. Hence the HJM model probably comes closest to describing the actual term structure movements observed in the market.

Although the theoretical literature on the HJM term structure model is quite large, there is very little empirical work testing the model. HJM models can be estimated using either historical volatility methods or implied volatility methods. Historical volatility techniques estimate the volatility specification by using past observations of forward rates or zero coupon bond prices. Implied volatility models use prices of options on the term structure to estimate the volatility of the forward rate process. One disadvantage of the implied volatility approach is that options on interest rates are available only for short maturities, thus limiting the portion of the term structure to be estimated.

Amin and Morton(1994) tested six different volatility specifications for the HJM model using implied volatility techniques on eurodollar futures options data. The authors find that the number of parameters in the volatility specification is a more important determinant of the models behavior than the specification of the volatility function itself. Further the authors conclude that the constant volatility model is preferred as it has the most stable parameter estimates. Abken(1993) tested four simple specifications of the one factor HJM model using the Generalized Method of Moments (GMM) methodology with monthly data on forward rates derived from treasury bills from July 1964 to December 1991. Abken finds that the GMM goodness-of-fit statistic was rejected for all the models and hence concludes that more complicated path dependent models may be necessary. Smith(1997) follows Abken's methodology but uses forward rate data derived from LIBOR data and interest rate swap quotes, in estimating the HJM model. Smith uses this estimation of the HJM model in pricing swap default risk.

The third class of models blends the first and second category of models in certain ways. Examples of models in this category are Hull and White(1990,1993), Black, Derman and Toy(1990) and Black and Karasinski(1991). These models start with the short rate process but are different from the models in the first category in that the parameters of the process are allowed to be time dependent. The functional form of these parameters is determined by matching it to the initial term structure. One disadvantage of these models is that it is not clear what the parameters, except the volatility parameter, represent in the market.

The fourth and final category of term structure models incorporate jumps in the interest rate. Examples of this category of models include Ahn and Thompson(1988), Das and Foresi(1996), Baz and Das(1996), Das(1997), Burnetas and Ritchken(1997) and Shirakawa(1991). Stylized facts observed in the bond market are strongly suggestive of jump behavior in interest rates (see Das(1997)). Jumps in interest rates are caused by exogenous interventions in the markets by the Federal Reserve, monetary shocks, supply shocks, demand shocks, policy changes and economic news announcements. Moreover changes in interest rates exhibit considerable skewness and kurtosis (see Das(1998)). The addition of a poisson jump process to the diffusion process is one way to capture the excess skewness and kurtosis. Most of these studies use a jump diffusion process or a poisson gaussian process of the form

$$dr = k(\theta - r)dt + \sigma dz + Jd\pi(\lambda) \tag{3.9}$$

The interest rate evolves with a mean reverting drift and two random terms, one a diffusion and the other a poisson process with jump size J and jump arrival intensity λ.

Ahn and Thompson(1988) use a jump diffusion process to model the short rate assuming a Cox, Ingersoll and Ross economy. Baz and Das(1996) assume a jump augmented Vasicek model for interest rates and derive a closed form approximation for bond prices using a linearization technique. Das(1997, 1998) extend the HJM model to jumps. They operate in a discrete time environment and build a tree based approach to pricing contingent claims using the jump extended HJM model. The forward rate process is given by

$$f(t+h,T) = f(t,T) + \alpha(T)h + \sigma(T)\sqrt{h}X_1 + J[\mu(T),\gamma^2(T)]N(\lambda) \qquad (3.10)$$

Where J is the jump size with mean μ and variance γ^2 and λ is the jump arrival rate. Das exploits the fact that the diffusion process and the poisson jump process are independent of each other to develop two separate trees for the diffusion and the jump and combining them to form a hexanomial tree. Contingent claims are then priced using the hexanomial tree.

The term structure is a critical component in modeling swap default risk and hence systemic risk. It is the movement in the short rate (usually LIBOR) that drives default by a counterparty. In the event of default the swaps replacement cost is found by repricing the swap using the forward rate curve at the time of default. This replacement cost provides a measure of the credit loss suffered by the dealer and in turn affects the possibility of a systemic repercussion. In the context of systemic risk jumps in the interest rate become important, as they would significantly increase the probability of serial defaults. Thus, in order to correctly model systemic risk the following features of the term structure are a necessity.

i. The term structure model should allow for jumps in the interest rate

ii. The term structure model should not place any restriction on the shape of the term structure.

The other two features that are desirable in any model of the term structure are

i. Consistency with the initial term structure.

ii. Lack of arbitrage opportunities.

The only model that has all the above desirable features is the HJM model extended to jumps (the HJMJ model) as specified in Das(1997) and Das(1998).

Default Modeling

Systemic risk in the interest rate swap market is caused by the default of a swap dealer leading to the default of another swap dealer. Thus modeling default is another critical component of our systemic risk model and hence a review of the literature on default modeling is presented here.

Default has been modeled in two different ways in the literature. One category is called the "structural" approach and the other is called the "reduced form" approach.

The structural approach considers default to occur when the firm value, V, reaches a threshold, K. The firm value dynamics take on stochastic processes of various forms. Proponents of this category of models are Merton(1974), Nielsen, Saá-Requejo and Santa-Clara(1993), Shimko, Tejima and Van Deventer(1993) and Longstaff and Schwartz(1995). The lower bound could be a constant as in Longstaff and Schwartz(1995) or could be stochastic as in Nielsen, Saá-Requejo and Santa-Clara(1993). This model is consistent with both the case where the firm is insolvent because assets with value of $V \leq K$ do not generate sufficient cashflow to meet the current obligations of the firm (flow based insolvency), as well as the case where assets with value of $V \leq K$ imply a violation of minimum net worth or working capital requirements (stock based insolvency).

The structural approach is firmly rooted in theory but has the disadvantage that the firm value process is difficult to estimate empirically. Moreover the continuity of the sample paths of the firm value and threshold imply that the time of default is predictable.

The reduced form approach assumes that default can be exogenously triggered by a random event, on which firm value may have no impact. Examples of this approach include Duffie and Singleton(1998), Duffie, Schroder and Skiadas(1994), Lando(1994) and Jarrow, Lando and Turnbull(1993). In these models default arrives at a rate, called the hazard rate, and hence is unpredictable. The disadvantage of these models is the lack of economic meaning to the assumption: the default rate is a one-dimensional random variable that synthesizes all determinants of default. Moreover, not considering firm value disregards crucial information whose impact is probably the most important in the analysis of default.

So far, there has been little effort in bridging these two types of models. Hübner(1998) attempts to capture the advantages of both the approaches by choosing a state variable that is the ratio of the value of the firm and, what the author calls, an economically comparable counterpart. This economically comparable counterpart is open to interpretation and can be interpreted as the threshold for default, a measure of earnings or a measure of book value to name a few.

In the context of systemic risk, how default is modeled is critical, as it is default that causes systemic risk. Default in the swap market is certain to occur when the payment on the swap exceeds the value of the firm's assets. Hence, in modeling default we need to take the structural form approach, where the firm value is modeled with a threshold to capture default.

CHAPTER 4

THE MODEL

In order to effectively model systemic risk we need to start by identifying the determinants of systemic risk in the swap market. Systemic risk in the swap market occurs when the default of one swap dealer causes the default of another swap dealer. Hence, the driving force behind a systemic repercussion is the default by a swap dealer. A dealer would default due to its swap dealing activities when either one of the following two conditions are satisfied:

i. If the credit loss the dealer incurs on its swap portfolio is greater than its capital.

ii. If the dealer does not have enough liquid assets to make its swap coupon payments.

Thus default is determined by the swap coupon payments, the value of liquid assets, the capital and the credit loss. The swap coupons are determined by the floating rate of interest. The credit loss is determined by the replacement cost of the defaulted swaps and the recovery rate. The replacement cost, in turn, depends on the fixed rate on a replacement swap calculated using the forward rate curve on the default date. Hence, the following factors should be considered while modeling systemic risk in the interest rate swap market.

i. the floating rate of interest (the short rate)

ii. the forward rate curve

iii. the value of the firm's assets

iv. the recovery rate

v. the event of default

vi. the capital of the swap dealer

Thus, the theoretical model of systemic risk developed in this dissertation consists of the following components.

i. The term structure model

ii. The counterparty firm value model

iii. The recovery rate model

iv. The swap dealer capital model

Each of these components is described in detail below.

The Term Structure Model

In order to capture fully the systemic risk in the interest rate swap market, the model we choose for the term structure of interest rates should provide the most realistic description of the term structure movements. The term structure model choosen for examining systemic risk in the interest rate swap market should allow for the following interest rate dynamics:

i. Jumps in the interest rate.

The probability of default and hence the probability of a systemic repercussion is significantly affected by jumps in the interest rate.

ii. No restrictions on the shape of the term structure.

The term structure movements should not be constrained to only parallel shifts. This is critical as term structure movements drive defaults and determine credit losses incurred by swap dealers.

In addition, we require that the term structure model

i. be consistent with the current term structure.

ii. be arbitrage free.

Based on the discussion in chapter 3 (the literature review) the only model that satisfies all the above requirements is the Heath, Jarrow and Morton model extended to jumps (the HJMJ model) as in Das(1997) and Das(1998) and hence is chosen as the model for the term structure component of our systemic risk model. A detailed description of the Heath, Jarrrow and Morton model extended to jumps (HJMJ model) is given below.

The Heath, Jarrow and Morton Model Extended to Jumps

The HJM model imposes a stochastic structure directly on the evolution of the forward rate curve. It takes as input the initial term structure of forward rates and the volatility term structure of the forward rates. The forward rates follow a stochastic process of the form

$$df(t,T) = \alpha(t,T,f(t,T))dt + \sigma(t,T,f(t,T))dw_1(t) + J_1(t,T)d\pi(\lambda_1) \qquad (4.1)$$

Where $f(t,T)$ is the instantaneous forward rate at time t for a contract with expiration at time T

$\alpha(t,T,f(t,T))$ is the drift of the forward rate process

$\sigma(t,T,f(t,T))$ is the volatility of the forward rate process

$dw_1(t)$ is a standard brownian motion

$J_1(t,T)$ is the jump size

$d\pi(\lambda_1)$ is a poisson process with an arrival rate λ_1 per unit time

In this stochastic process n independent brownian motions determine the evolution of the forward rate curve starting from a fixed initial curve taken as the input to the model. The volatility function $\sigma(t,T,f(t,T))$ represents the instantaneous standard deviation as of time t for the forward rate of maturity T. The volatility structure determines how shocks are distributed throughout the yield curve. The volatility function can take on many possible forms. The volatility functions are left unspecified in the HJM model. The constant volatility structure is chosen when we simulate this model and is discussed in greater detail in the next chapter (chapter 5). The jump size $J_1(t,T)$ is completely general and can be a constant or drawn from a probability distribution. The jump size is assumed to be normally distributed, N(0,1) in our simulation of the model. Jumps arrive at a rate λ_1 per unit time through the poisson process π. The jump size and arrival are independent of the diffusion process.

The term structure of forward rates (the forward curve) generated by the HJMJ model is used to calculate the cashflows of the swaps in the dealer's portfolio at various points in time and also calculate the fixed rate on a replacement swap when default occurs. As swaps are priced using the 3-month LIBOR forward rate curve, the HJMJ model will be used to model the 3-month LIBOR forward rate curve in our systemic risk model. The procedure for calculating the fixed rate on a swap with the term structure generated by the HJMJ model is given below.

The pricing algorithm explained below is from the book "Understanding Swaps" by John F. Marshall and Kenneth R. Kapner. The key to setting the midrate (fixed rate) of a swap is to equate the present values of the fixed-rate leg and the floating-rate leg of the swap. The fixed rate that equates the present value of the fixed leg with the present value of the floating leg based on the LIBOR term structure generated by the HJMJ model is the dealer's midrate. The procedure by which the dealer would calculate the midrates involves the five steps below.

Step 1: Calculate the future value of one dollar at the end of each quarter, till the tenor (maturity) of the swap, n, based on repeated reinvestments at LIBOR forward rates generated by the HJMJ model.

$$TV_\tau = \left(1+\frac{L_1 \times D_1}{360}\right)\left(1+\frac{L_2 \times D_2}{360}\right)\cdots\left(1+\frac{L_m \times D_m}{360}\right) \tag{4.2}$$

Where τ – time subscript measured in years such that $\tau = 0.25, 0.5, \ldots, n$ and $m = 4\tau$

D_i – actual number of days spanned by the i^{th} Eurodollar futures contract

L_i – LIBOR generated by the HJMJ model

Step 2: Calculate zero coupon swap rates on an annual bond basis at quarterly intervals up to the tenor of the swap. That is, calculate $y_{a,\tau}$ using equation 4.3 for $\tau = 0.25, 0.5, \ldots, n$.

$$y_{a,\tau} = TV_\tau^{1/\tau} - 1 \tag{4.3}$$

Step 3: Restate the effective annual zero rates on a quarterly bond basis using equation 4.4.

$$y_{q,\tau} = \left[(1 + y_{a,\tau})^{1/4} - 1\right] \times 4 \tag{4.4}$$

Step 4: The annual swap midrate per \$100 notional principal stated on a quarterly bond basis is the value of $M_{q,\tau}$ satisfying equation 4.5.

$$100 = 1/4 M_{q,\tau}\left[\sum_{t=1}^{T}(1 + y_{q,\tau}/4)^{-t}\right] + 100(1 + y_{q,\tau}/4)^{-T} \tag{4.5}$$

Where $T=4n$, the number of quarters in the tenor of the swap.

This midrate from equation 4.5 is given by

$$M_{q,\tau} = \frac{100 - 100(1 + y_{q,\tau}/4)^{-T}}{\sum_{t=1}^{T}(1 + y_{q,\tau}/4)^{-t}} \times 4 \tag{4.6}$$

Step 5: The midrate needs to be restated on the appropriate payment frequency of the swap. The simplest way to do this is to restate the midrate on an annual basis and then restate the annual rate on the appropriate frequency of the swap. The annual midrate $M_{a,\tau}$ is obtained using equation 4.7.

$$M_{a,\tau} = (1 + M_{q,\tau}/4)^4 - 1 \tag{4.7}$$

The midrate can now be restated on a semiannual basis using equation 4.8.

$$M_{s,\tau} = \left[(1 + M_{a,\tau})^{1/2} - 1\right] \times 2 \tag{4.8}$$

The Firm Value Model

The firm value (value of the firm's assets) is modeled along the lines of Abken(1991) using a bounded geometric brownian motion with the drift term adjusted for the cashflows and credit losses arising from the swap portfolio. A lower bound, K, is placed on the geometric brownian motion. The firm enters into financial distress when the firm value reaches this lower bound, i.e. when $V=K$.

The dynamics of the firm value is assumed to take on a geometric brownian motion as shown below.

$$dV = \left[\mu_v V - \sum_i CF_i \delta(t - t_i) \right] dt + \sigma_v V dw_2 \tag{4.9}$$

Where μ_v is the instantaneous expected rate of return on the assets of the firm

σ_v is the volatility of the firm value

$dw_2(t)$ is a standard brownian motion

The summation term $\sum_i CF_i$ represents the discrete cashflows and credit losses arising from the swap portfolio. The dirac delta function $\delta(t - t_i)$ is used to formalize the discrete cashflows and credit losses within the continuous-time setting of the model[1]. Thus, in other words, the firm value jumps by discrete amounts equal to the cashflows and credit losses arising from the swap portfolio at each payment date.

The firm value is allowed to take on arbitrary correlations with the spot interest rate through the instantaneous correlation coefficient,ρ_1, i.e. $dw_1 dw_2 = \rho_1 dt$

The value of the current assets of the firm are assumed to be a constant proportion of the value of the total assets of the firm. This constant proportion is denoted by CA.

The Recovery Rate Model

The recovery rate is the percentage of the defaulted amount that is recovered. The literature on modeling credit sensitive debt has largely taken the recovery rate to be a constant but, recent literature such as Das and Tufano(1996) have shown that stochastic recovery rates generate credit spreads that are closer

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[1] The property of the dirac delta function used here is $\int_0^{\tau} \sum_i CF_i \delta(t - t_i) dt = \sum_i CF_i$

in magnitude and variability to the spreads observed in the market. Hence we have modeled the recovery rates to be stochastic.

The recovery rate is assumed to follow the continuous time stochastic process, as in Das(1996), shown below.

$$d\beta = \left(\frac{\beta}{\beta + (1 - \beta) e^{\sigma_\beta dw_3}} \right) - \beta \tag{4.10}$$

Where σ_β is the volatility of the recovery rate

dw_3 is a standard brownian motion

This stochastic process has the property that if $\beta(0) \in [0,1]$ then $\beta(t) \in [0,1]$, $\forall\, t$.

The recovery rate is allowed to take on arbitrary correlations with the spot interest rate, i.e.,

$$dw_1 dw_3 = \rho_2 dt$$

The Swap Dealer Capital Model

Capital according to the risk-based capital guidelines consists of:

i. Tier 1 or core capital, defined as common stockholder equity plus noncumulative preferred stock plus minority interest in the equity accounts of consolidated subsidiaries minus goodwill and other intangibles.

ii. Supplementary or tier 2 capital is defined as allowance for losses on loans and leases, cumulative preferred stock, and perpetual debt.

Swap dealers are required by the risk-based guidelines of the federal reserve to have a minimum amount of capital equal to 8% of the risk-weighted assets[2]. This capital requirement is primarily for the purpose of absorbing credit losses incurred by the swap dealer. The actual capital ratio of a swap dealer (the ratio of the capital to the value of the assets) of the swap dealer would vary over time, but due to the regulatory requirement the capital ratio has to revert back to 8%. Moreover, a swap dealer whose capital ratio is below 2% is considered critically under-capitalized and is closely monitored by the federal reserve. Hence we model the capital ratio of the firm using a mean reverting process with the drift term adjusted to reflect the change in the capital ratio due to credit losses, as given below.

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[2] The calculation of capital according to the risk based capital guidelines is discussed in detail in chapter 2.

$$dc = \left[g(\theta - c) - CR\delta(t - t_i)\right]dt + \sigma_c c dw_4 \qquad (4.11)$$

Where θ – the long run mean to which the capital ratio reverts back

g – the speed of reversion to the mean

σ_c – the volatility of the capital ratio

The factor *CR* in the drift term represents the ratio of the credit loss to the value of the dealer's assets. As in the firm value model, the dirac delta function is used to formalize the discrete changes to the capital ratio in a continuous-time setting. The long run mean capital ratio, θ, is set by the regulators. Currently this ratio is 8%. The speed of reversion, *g*, is equal to the internal capital generation rate, which is equal to the product of the dealer's return on equity (ROE) and the retention ratio (RR), that is g = ROE X RR. By setting *g* equal to the internal capital generation rate we make the assumption that the dealer does not use external funds from the capital markets to bolster his capital. This assumption is justified, as the dealers retained earnings are usually its primary source of capital[3].

Since swap dealers are considered critically undercapitalized by the Federal Reserve if the capital ratio falls below 2%, we place a lower bound, *B*, on the mean reverting process. If the capital ratio falls below this lower bound we assume that the dealer goes into bankruptcy and defaults on its obligations. Thus, if $c<B$ the dealer enters into bankruptcy and defaults on its obligations.

The amount of capital at any time can be found by multiplying the capital ratio by the value of the firm's assets.

The Systemic Risk Model

The notation used in developing this model is described below.

$f_{d_i j}$ – Fixed rate on the j^{th} swap in the portfolio of dealer d_i

$T_{d_i j}$ – Tenor of the j^{th} swap in the portfolio of dealer d_i

$\phi_{d_i j}$ – Takes on a value –1 if the dealer d_i is a fixed rate payer on the j^{th} swap and a value of 1 if the dealer is a fixed rate receiver

$C_{d_i j}$ – Counterparty of the j^{th} swap in the portfolio of dealer d_i

$r(t)$ – Floating spot rate at time period t

[3] See Sinkey(1992) for a detailed discussion on bank capital management.

$M_{d_i j}$ – Replacement fixed rate on the j[th] swap in the portfolio of dealer d_i

N(t) – Total number of swaps in each dealers portoflio at time t

$V_{x_i}(t)$ – Value of the assets of counterparty X_i at time t

$c_{d_i}(t)$ – Capital of dealer d_i at time t

$\beta(t)$ – Recovery rate at time t

B(t) – Discount factor for time t

Let the swap market consist of n swap dealers designated by d_1, d_2, ...d_n and m external counterparties (non dealers) designated by x_1, x_2, ...x_m. Dealers enter into swaps with each other and with the external counterparties. There are N(t) swaps in each dealer's swap book at time period t indexed by j = 1....N(t). Each swap in the dealer's book is uniquely defined by its fixed rate, $f_{d_i j}$, tenor, $T_{d_i j}$, whether the fixed rate is being paid or received, $\phi_{d_i j}$, and the counterparty $C_{d_i j}$.

Determination of Default

A counterparty defaults on it's swap payments if either one of the following two conditions are satisfied:

i. Default occurs when the net payment on the counterparty's swaps is greater than the value of the current assets of the firm.

ii. Default also occurs when the firm value falls below an exogenous threshold, K, i.e., $V_{x_i}(t) \leq K$.

This approach to modeling default has been used by Longstaff and Schwartz(1995) and Neilsen, Saá-Requejo and Santa-Clara(1993). Longstaff and Schwartz(1995) take the threshold to be a constant. Other researchers such as Nielsen, Saá-Requejo and Santa-Clara(1993) have taken the threshold to be time varying by specifying a stochastic process for it. We haven chosen the threshold to be a constant. The threshold, K, can be interpreted as the level of working capital the firm needs. If the firm value falls below this level of working capital it enters into financial distress and defaults on its current obligations. This interpretation is consistent with the definition of stock based insolvency where a firm with assets that are worth less than the threshold implies a violation of minimum net worth or working capital requirements. This definition of default allows counterparty default to occur due to the other non-swap business activities of the counterparty that affects its assets. Thus this definition of counterparty default is independent of the swap activity of the counterparty.

A swap dealer defaults on its obligations if any one of the following conditions is satisfied:

i. When the credit loss incurred on a payment date is greater than the firm's capital. In other words, the swap dealer defaults when it does not have enough capital to absorb the credit loss. This definition of default for the swap dealer is consistent with the risk based capital requirements instituted by the Federal Reserve which sets a minimum capital requirement to safeguard banks from failing due to lack of capital to absorb the credit loss.

ii. When the swap payment on a payment date is larger than the value of the current assets of the firm.

iii. When the capital ratio falls below the threshold. That is when $c_{d_i}(t) < B$. B denotes the capital ratio threshold. This definition of default captures the bankruptcy and hence default that could occur due to the other non swap dealing activities of the dealer that affect capital.

iv. When the value of the firm's assets falls below the threshold. That is, when $V_{d_i}(t) \leq K$. Again this definition of default captures the bankruptcy and hence default that could occur due to the other non swap dealing activity of the dealer that affects firm value.

Thus, in order to determine default, cashflows between dealers and, between dealers and external counterparties need to be calculated. The cashflow between an external counterparty, X_i, and a dealer, d_j, is given by

$$CF_{d_j x_i}(t) = \sum_{m=1}^{N(t)} J_m \phi_{d_j x_i}(f_{d_j m} - r(t-1)) \tag{4.12}$$

Where J_m is an indicator function which takes on the value 1 whenever the counterparty of the swap is x_i i.e. when $C_{d_j m} = x_i$ and zero otherwise. Counterparty X_i owes a payment to dealer d_j when $CF_{d_j x_i}(t) > 0$ and receives a payment when $CF_{d_j x_i}(t) < 0$

The net cashflow between dealer d_j and dealer d_i at a particular point in time t is given by

$$NC_{d_j d_i}(t) = \sum_{m=1}^{N(t)} I_m \phi_{d_j m}(f_{d_j m} - r(t-1)) \tag{4.13}$$

Where I_m is an indicator function which takes on the value 1 when $C_{d_j m} = d_i$ and zero otherwise.

Dealer d_i owes a payment to dealer d_j when $NC_{d_j d_i}(t) > 0$ and receives a payment when $NC_{d_j d_i}(t) < 0$. In the interest rate swap market payments at any payment date t depend on the floating rate set in the previous time period $t-1$ and hence the floating rate in the previous period, $r(t-1)$, is employed in equations 4.12 and 4.13.

Counterparty X_i will default on dealer d_j due to non-payment of the swap coupon if it owes a payment and if payment is greater than its current assets, i.e. if condition (i) and (ii) below, together are satisfied.

i. $CF_{d_j x_i}(t) > 0$

ii. $CF_{d_j x_i}(t) > CA \times V_{x_i}(t)$

To determine whether dealer d_i defaults on dealer d_j due to non-payment of the swap coupon we proceed as follows.

We assume that all the cash inflows to dealer d_i from it's swaps with the external counterparties occur before it pays the amount it owes dealer d_j. Hence we reduce the net cashflow, $NC_{d_j d_i}(t)$, dealer d_i owes dealer d_j by the cash inflows to dealer d_i before comparing it to the value of the current assets to determine default. The reduced payment that dealer d_i owes dealer d_j is given by

$$AP_{d_j d_i}(t) = NC_{d_j d_i}(t) - \sum_{k=1}^{m} L_k CF_{d_i x_k}(t) - \beta(t) \sum_{k=1}^{m} (1 - L_k) CF_{d_i x_k}(t) \tag{4.14}$$

Where L_m is an indicator function that takes on the value one if an external counterparty, X_k, does not default on a delaer, d_i, and zero otherwise.

Dealer d_i will default on dealer d_j if d_i owes a payment to dealer d_j and if that payment is greater than its current assets. Thus both conditions (i) and (ii) need to be satisfied in order for dealer d_i to default on dealer d_j due to non-payment of the swap coupon.

i. $AP_{d_j d_i}(t) > 0$

ii. $AP_{d_j d_i}(t) > CA \times V_{d_i}(t)$

In the event of default by an external counteraprty X_i on dealer d_j at a payment date t the loss to dealer d_j at time t is the sum of the payment at time t less any recovered amount and the cost of replacing all the swaps that dealer d_j had with counterparty X_i. There is a cost to replacing the swaps only if the interest rates have moved adversely from the point of view of dealer d_j. For a fixed rate payer there is a cost to replacing the swap if the fixed rate quoted on the replacement swap is higher than the fixed rate on the original swap. The opposite holds true for the fixed rate receiver.

The fixed rate of the replacement swap at time t, $M_{d_j i}$, is calculated using the term structure of forward rates at time t, as defined by the HJMJ model, as the rate that equates the present values of the fixed rate leg and the floating rate leg of the swap, as described previously. Thus the replacement cost of the swaps dealer d_j has with counterparty X_i at time t is given by

$$RP_{d_j x_i}(t) = \sum_{m=1}^{N(t)} \sum_{n=1}^{T_{d_j m}-t} J_m F_m \left(\left| M_{d_j m} - f_{d_j m} \right| \right) B(t) \tag{4.15}$$

Where F_m is an indicator function which is defined as follows.

F_m = 1 if dealer d_j is the fixed rate payer on the m^{th} swap and $N_{d_j m} > f_{d_j m}$

= 1 if dealer d_j is the fixed rate receiver on the m^{th} swap and $N_{d_j m} < f_{d_j m}$

= 0 otherwise

The credit loss of dealer d_j due to the default of counterparty X_i at time t is given by

$$L_{d_j x_i}(t) = NC_{d_j x_i}(t)(1 - \beta(t)) + RP_{d_j x_i}(t) \tag{4.16}$$

Dealer d_j defaults on dealer d_i when the total credit loss (sum of all the credit losses) it incurs at time period t is greater than its capital. Thus, dealer d_j defaults on dealer d_i when

$$\sum_{i=1}^{m} L_{d_j x_i}(t) \geq c_{d_j}(t) \times V_{d_j}(t) \tag{4.17}$$

A systemic repercussion or a domino effect would occur if dealer d_j were to default on another dealer d_k in the same time period t. Thus, the systemic risk in the swap market is measured by the probability of dealer d_i defaulting on dealer d_k in time period t conditional on dealer d_j defaulting on dealer d_i in the same time period t. The systemic risk is given by the conditional probability

$$P\left[A \mid B\right] \tag{4.18}$$

Where $A = \left(\sum_{q=1}^{m} L_{d_i x_q}(t) \geq C_{d_i}(t) \right) or \left(\left(AP_{d_j d_i} > 0 \right) \& \left(AP_{d_j d_i} > CA \times V_{d_i}(t) \right) \right)$

$$B = \left(\sum_{p=1}^{m} L_{d_j x_p}(t) \geq C_{d_j}(t) \right) or \left(\left(AP_{d_i d_j} > 0 \right) \& \left(AP_{d_i d_j} > CA \times V_{d_j}(t) \right) \right)$$

The first term in formula A and B is the condition under which the dealer defaults due to the credit loss being greater than its capital. The second term in formula A and B is the condition when the dealer would default due to the swap payments being greater than the value of the current assets of the firm.

CHAPTER 5

THE SIMULATION

This chapter describes the simulation of the model developed in the previous chapter. The primary objective of this simulation is to measure the probability of a systemic repercussion occurring in the simulated swap market and determining the sensitivity of the probability of a systemic repercussion to the various parameters of the model. The secondary objective is to address regulatory policy issues which include rules for calculating the potential credit exposure for interest rate swaps and evaluating the effect of capital requirements and swap portfolio diversification on the probability of a systemic repercussion. The various details of the implementation of the simulation follow.

The Simulated Market

The simulated interest rate swap market consists of three swap dealers (labeled 1,2, and 3) and a random number of independent external counterparties (labeled 0). The external counterparties may be thought of as the end users of swaps (i.e. non dealers). The three swap dealers and the external counterparties are interconnected as shown in figure 5 below.

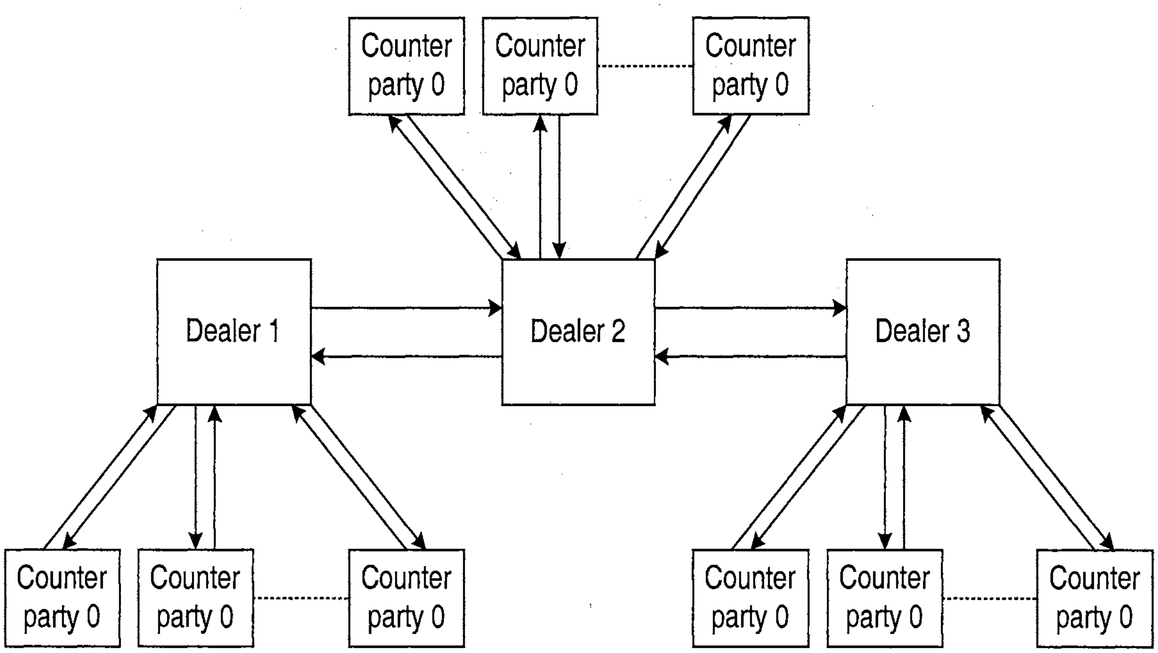

Figure 5. The Simulated Swap Market

Dealer 1 maintains a swap portfolio consisting of swaps with dealer 2 and other external counterparties. Dealer 2 maintains a swap portfolio consisting of swaps with dealer 2, dealer 3 and other external counterparties. Dealer 3's swap portfolio consists of swaps with dealer 2 and other external counterparties. Dealer 1 and Dealer 3 do not enter into swaps with each other because this would introduce a circular dependency and hence making it impossible to simulate. The external counterparties in this market are assumed to be from the manufacturing sector, the agricultural sector and the financial services sector. The rationale for the choice of the two non-financial industry sectors is provided by a survey of derivatives usage by U.S. non-financial firms conducted by Bodnar, Hayt, Marston and Smithson(1995) which finds that commodity based industries (referred to as the agricultural sector) such as agriculture, refining and mining and the manufacturing industries are the top two users of derivatives.

There would be a systemic repercussion, according to our definition of systemic risk, in this simplified market if either one of the following two events take place.

i. Dealer 1 defaults on dealer 2 in any particular time period and this causes dealer 2 to default on dealer 3 in the same time period.

ii. Dealer 3 defaults on dealer 2 in any particular time period and this causes dealer 2 to default on dealer 1 in the same time period.

A systemic repercussion, according to our definition of systemic risk, cannot be initiated by dealer 2 defaulting on dealer 1 or dealer 3, as this will not lead to a chain of defaults (domino effect) within the context of our simulated market.

The Heath, Jarrow Morton Term Structure Model Extended to Jumps

The HJMJ model is simulated using its discrete version. An Euler scheme is used to discretize the model. A brief discussion of the Euler scheme follows.

Consider a stochastic process $X = \{X(t): t_0 \leq t \leq T\}$ satisfying the following stochastic differential equation

$$dX(t) = a(t, X(t))dt + b(t, X(t))dW(t) \tag{5.1}$$

Where *a(t,X(t)), b(t,X(t))* are the drift term and the diffusion term of X, respectively. The initial condition is $X(t_0)=X_0$. For a given discretization $t_0<t_1<t_2<\dots\dots<t_N=T$ of the time interval $[t_0,T]$, the Euler scheme is a stochastic process $\widetilde{X} = \{\widetilde{X}(t): t_0 \leq t \leq T\}$ satisfying the following set of equations

$$\widetilde{X}_{i+1} = \widetilde{X}_i + a(t_i, \widetilde{X}_i)(t_{i+1} - t_i) + b(t_i, \widetilde{X}_i)(W_{i+1} - W_i) \tag{5.2}$$

for i=0,1,....,N, with initial condition $\tilde{X}_0 = X_0$, where $\tilde{X}_i$ is the value of the approximation at the time t_i. Let us define $\Delta t_i = t_{i+1} - t_i$ and $\Delta t = \text{Max } \Delta t_i$, the maximum time step. Since we are using equal time steps in our simulation we can set Δt_i to Δt. In the equidistant discretization $W_{i+1} - W_i$ are independent and identically normal with mean zero and variance Δt. Therefore for every state in the state space Ω, starting with the initial value X_0 and following the iterative scheme of equation 5.2, one can find the realization of $\tilde{X}_i$ for i = 1,2,...,N.

Thus using the Euler scheme and the basic property of a weiner process, $\Delta w = \varepsilon\sqrt{\Delta t}$, where ε is a random draw from a standard normal distribution, we can write the discrete version of the HJMJ model as

$$f(t,T) = f(t - \Delta t, T) + \alpha(T)\Delta t + \sigma(T)\sqrt{\Delta t}X_{1t} + J_1 P(\lambda_1 \Delta t), \forall T \quad (5.3)$$

Where $f(t,T)$ is the one period forward rate at time T as observed at time t. The drift coefficient is $\alpha(.)$ and the volatility is $\sigma(.)$. X_{1t} is a random shock to the process and is drawn from a standard normal distribution. The jump size J_1 is assumed to be distributed N(0,1). $P(\lambda_1 \Delta t)$ is a poisson random variable with parameter $\lambda_1 \Delta t$.

In order to simulate the HJMJ model we have to choose a volatility structure for the forward rates. As discussed previously in chapter 3 Amin and Morton(1994) tested six different volatility structures for the HJM model and concluded that the constant volatility model is preferred among them. Hence we shall use the constant volatility model in our simulation. A discussion of the constant volatility model follows.

The Constant Volatility Model

In this model the volatility of the forward rates is assumed to be a constant, σ, i.e. $\sigma(t,T,f(t,T)) = \sigma$. The drift term α is obtained using the no-arbitrage drift restriction specified by Heath, Jarrow and Morton(1992), given below. The no-arbitrage restriction guarantees that forward rate movements are arbitrage free and thus also ensures that a unique equivalent martingale measure exists.

$$\alpha(t,T,f(t,T)) = -\sigma(t,T,f(t,T))\left(\phi(t) - \int_t^T \sigma(t,v,f(t,v)dv\right) \quad (5.4)$$

Where $\phi(t)$ is the market price of risk.

The market price of risk can be expressed as the excess return over the spot rate per unit of standard deviation for zero coupon bonds.

Using the above restriction the drift term for the constant volatility model is given by

$$\alpha(t,T,f(t,T)) = -\sigma\phi + \sigma^2(T-t) \tag{5.5}$$

Parameter Estimates for the HJMJ Model

The parameters for the constant volatility HJMJ model are obtained from Smith(1997). Smith estimates this model with LIBOR forward rate data using the Generalized Method of Moments technique. This estimation follows closely the method employed by Abken(1993) who uses treasury forward data. As in Abken(1993) the market price of risk is assumed to be constant over the estimation period. Smith uses a data set containing daily observations of six-month LIBOR, one year LIBOR, and bid/ask prices for interest rate swaps of 2,3,4,5,7,and 10 year maturities from March 3, 1988 to August 31, 1994. The six-month forward LIBOR rate, six months forward was obtained from six-month and twelve-month LIBOR. The six-month forward rate, eighteen months forward and twenty four months forward were bootstrapped from the average of the bid/ask prices of the two year interest rate swap assuming a linear interpolation of forward rates. This procedure was continued to determine LIBOR forward rates up to five years. The above procedure was used because forward prices are not the same as futures prices as documented by Cox, Ingersoll and Ross(1981) and Jarrow and Oldfield(1981) to name a few. The forward rates obtained by the above bootstrapping procedure were used to estimate the model. The estimates of the parameters for the constant volatility model from Smith(1997) is given in table 5.

Table 5

Parameter Estimates for the Constant Volatility Model

Parameter	Estimate	T-statistic
σ	0.056366	7.365949
ϕ	-0.33503	-3.58857

The initial term structure of three-month LIBOR forward rates for the simulation was obtained from the forward rates implied by the Eurodollar futures contracts taken from the Wall Street Journal on October 30, 1998 and is given in table 6. We take the rates implied by the eurodollar strip as an approximation of the LIBOR forward rates due to the differences in futures prices and forward prices. Jarrow(1996) explains that the forward price equals the futures price plus an adjustment term that reflects the covariance between the underlying zero coupon bond's price and the spot rate. He also proceeds to give numerical examples that illustrate this difference. From the examples cited in Jarrow(1996) we see that the difference between forward prices and futures prices is of the order 0.000004 and hence quite small. Moreover, in practice, traders price swaps off the eurodollar strip, thus using the forward rates implied by the eurodollar futures. Hence we feel that this approximation is justified.

Table 6

Initial Term Structure of forward rates

Date	Settle Price	3 month LIBOR	Date	Settle Price	3 month LIBOR
December 98	94.98	5.02	December 03	94.52	5.48
March 99	95.48	4.52	March 04	94.34	5.66
June	95.62	4.38	June	94.30	5.70
September	95.66	4.34	September	94.25	5.75
December	95.51	4.49	December	94.12	5.88
March 00	95.56	4.44	March 05	94.14	5.86
June	95.40	4.60	June	94.10	5.90
September	95.23	4.77	September	94.05	5.95
December	95.01	4.99	December	93.92	6.08
March 01	95.01	4.99	March 06	93.94	6.06
June	94.94	5.06	June	93.90	6.10
September	94.88	5.12	September	93.85	6.15
December	94.73	5.27	December	93.72	6.28
March 02	94.75	5.25	March 07	93.74	6.26
June	94.70	5.30	June	93.70	6.30
September	94.65	5.35	September	93.66	6.34
December	94.52	5.48	December	93.53	6.47
March 03	94.54	5.46	March 08	93.55	6.45
June	94.49	5.51	June	93.50	6.50
September	94.44	5.56	September	93.47	6.53

The interest rate jump rate and the maximum interest rate jump size were set as follows. Daily changes in the 3m LIBOR data for 1989 to 1996 were examined. From the daily changes in LIBOR we find that 97% of the interest rate changes were either 0.13% or below. Hence we considered an interest rate jump to be an interest rate change above 0.13%. Based on this definition of an interest rate jump we calculated the frequency of jumps for each of the years from 1989 to 1998. The interest rate jump rate for each of the years was calculated by dividing the frequency of jumps by 360 (the number of days in a year).

The jump arrival rate for the simulation was set at 0.0125 (corresponds to 9 jumps per year) which is the average of the jump rate over the time period 1989 to 1998. The maximum jump in the interest rate during this time period was found to be 0.69% and hence the maximum jump size for the base case simulation was set at 0.69%.

The Firm Value Model

The discrete version of the firm value model, using an Euler scheme, that is used in the simulation is given below.

$$\Delta V_t = \mu_v V_{t-1} \Delta t + \sigma_v V_{t-1} \sqrt{\Delta t} X_{2t} \tag{5.6}$$

The firm value process is allowed to be correlated with the interest rate process as shown below.

$$\begin{bmatrix} X_{1t} \\ X_{2t} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \rho_1 & \sqrt{1-\rho_1^2} \end{bmatrix} \begin{bmatrix} u_{1t} \\ u_{2t} \end{bmatrix} \tag{5.7}$$

Where u_{1t} and u_{2t} are standard normal variates and ρ_1 is the coefficient of correlation between the firm value and the spot LIBOR rates.

The firm value is bounded by a lower bound *K*. As explained previously, the firm enters into financial distress and defaults on it's obligations when $V=K$. There are four separate firm value processes with different parameter estimates used in this simulation; one for the swap dealers, another for the manufacturing firm, a third for the agricultural firm and a fourth for the financial service firm.

The firm value is adjusted by the cashflows and the credit losses arising from the swap portfolio while transitioning from one time period to the next.

Parameter Estimates for the Firm Value Model

The parameter estimates of the firm value model for swap dealers, manufacturing firms, agricultural firms and financial services firms are given in table 7, 8, 9, and 10 respectively. The parameter μ_v, which is the instantaneous rate of return on the firm's assets, was set at 6.2% for the simulation. This estimate was obtained from the Robert Morris Associates (RMA) annual statement studies as the average return on assets for the industry category 'securities brokers and dealers' for the financial year ending 1997. The ROA was defined as the profit before taxes divided by the total assets. Similarly, the ROA for the manufacturing sector, the agricultural sector and the financial services sector were obtained from the RMA annual statement studies as 7.86%, 5.18% and 3.64% respectively. Hence, the estimates of μ_v for the manufacturing firms, the agricultural firms and the financial services firms were set at 7.86%, 5.18% and 3.64% respectively. The volatility of the value of the firm's assets, σ_v, was calculated as follows.

Total assets data (annual) was collected for the top fifteen OTC derivatives dealers mentioned in the GAO(1994) report 'Financial Derivatives: Actions needed to protect the financial system' for the period 1989 to 1996. The volatility of the percentage change in total assets was calculated for each of these fifteen dealers and averaged to arrive at a volatility of 19.47% per year. Thus σ_v was set at 19.47% for the simulation. The initial value of the firm was normalized to one for the simulation. The correlation between the firm value and the spot 3-month LIBOR rate was calculated to be –0.6667. Thus ρ_1 was set at –0.6667 for the simulation. This high correlation is reasonable as the swap dealers are mostly banking firms whose asset values are highly dependent on changes in interest rates.

Similarly, a random sample of fifteen firms from each of the three industry sectors (manufacturing, agriculture and financial services) with assets over $250 million were used to estimate σ_v for the manufacturing firms, agricultural firms and financial services firms. Firms with assets over $250 million were chosen because the Bodnar, Hayt, Marston and Smithson(1995) survey showed that 65% of large firms (with market value over $250 million) used derivatives contracts while only 13% of small firms (with market value below $50 million) used derivative contracts.

The threshold, *K*, for each of the four processes was set at the natural boundary for the firm value process, which is zero. A sensitivity analysis examining the change in the probability of a systemic repercussion due to a change in the default threshold is presented in the results section (chapter 7).

Current assets and total assets data (annual) for the time period 1989 to 1996 were collected for each of our samples (i.e. swap dealers, manufacturing firms, agricultural firms and financial services firms). The ratio of current assets to total assets was calculated and averaged over the time period to arrive at the proportion of current assets to total assets.

Table 7

Parameter Estimates of the Firm Value Model for Swap Dealers

Parameter	Estimate
μ_v	6.2%
σ_v	19.47%
ρ_1	-0.6667
Current Assets / Total Assets	0.8434

Table 8

Parameter Estimates of the Firm Value Model for Manufacturing Firms

Parameter	Estimate
μ_v	7.86%
σ_v	10.55%
ρ_1	0.3925
Current Assets / Total Assets	0.4164

Table 9

Parameter Estimates of the Firm Value Model for Agricultural Firms

Parameter	Estimate
μ_v	5.18%
σ_v	11.39%
ρ_1	0.1551
Current Assets / Total Assets	0.2031

Table 10

Parameter Estimates of the Firm Value Model for Financial Services Firms

Parameter	Estimate
μ_v	3.64%
σ_v	14.62%
ρ_1	-0.0723
Current Assets / Total Assets	0.8072

The Recovery Rate model

The discrete version of the recovery rate model, using an Euler scheme, which is used in the simulation is shown below

$$\beta(t)=\left(1+\frac{1-\beta(t-\Delta t)}{\beta(t-\Delta t)}\exp(\sigma_\beta X_{3t}\sqrt{\Delta t})\right)^{-1} \tag{5.8}$$

Where σ_β is the volatility of the recovery rate

Δt is the discrete time interval

The recovery rate process is also allowed to be correlated with the interest rate process with a correlation coefficient of ρ_2 as follows.

$$\begin{bmatrix} X_{1t} \\ X_{3t} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \rho_2 & \sqrt{1-\rho_2^2} \end{bmatrix} \begin{bmatrix} w_{1t} \\ w_{2t} \end{bmatrix} \tag{5.9}$$

Where w_{1t} and w_{2t} are standard normal deviates.

Parameter Estimates for the Recovery Rate Model

The parameter estimates for the recovery rate model are given in table 11 below. The only parameter of the recovery rate process is, σ_β, the volatility of the recovery rates. The recovery rates for subordinated debt are used as a proxy for recovery rates in the swap market, as recovery rate data for the swap market is unavailable. The recovery rates for subordinated debt for the period 1985 to 1991 were obtained from Altman(1992). The volatility of the recovery rates was calculated to be 9.56% per year. Thus σ_β, was set at 9.56% for the simulation. The correlation between the recovery rates and the spot 3-month LIBOR rates was calculated to be 0.03722 and hence ρ_2 was set at 0.03722 for the simulation. The initial recovery rate was set at 30.14%, which was the average recovery rate for subordinated debt over the period 1985 to 1991.

Table 11

Parameter Estimates for the Recovery Rate Model

Parameter	Estimate
σ_β	9.56%
ρ_2	0.03722
Initial Recovery Rate	30.14%

The Swap Dealer Capital Model

The discrete version of the swap dealer capital model, which is used in the simulation, is shown below.

$$\Delta c = g(\theta - c)\Delta t + \sigma_c \sqrt{\Delta t} X_{4t} \tag{5.10}$$

Where g is the speed of reversion and θ is the long run mean.

When transitioning from one period to the next during the simulation the capital ratio is adjusted by the ratio of the credit loss to the firm value. When the capital ratio falls below 2% the Federal Reserve considers the bank to be severely undercapitalized and hence steps in to take corrective action. Hence the capital ratio process has a lower bound of 2%. When the capital ratio falls below 2% the swap dealer is considered to enter into bankruptcy.

Parameter Estimates for the Swap Dealer Capital Model

The parameter estimates for the capital model are given in table 12. Data on dividends, net income and shareholder's equity for the time period 1989 to 1996 were collected for the top fifteen swap dealers (enumerated in table 2, chapter 2) specified by the GAO(1994) report. The return on equity and the retention ratio were calculated from the data and multiplied together to arrive at the value of the internal capital generation rate, g, for each swap dealer. The values of g were then averaged to arrive at the parameter estimate of g. The volatility parameter σ_c was estimated by estimating the volatility of the shareholder's equity. Volatility of the percentage change in shareholder's equity was calculated for each swap dealer and averaged to arrive at the parameter estimate for σ_c. The long run mean capital ratio, θ, and the initial capital ratio were set at the current regulatory requirement of 8%.

Table 12

Parameter Estimates for the Swap Dealer Capital Model

Parameter	Estimate
g	0.0963
σ_c	18.64%
θ	8%
Initial capital ratio	8%

The Simulation Time Frame

The time period of the simulation is ten years, which is the maximum possible tenor of the swaps in each dealers swap portfolio. The simulation proceeds in six-month time steps as semiannual payments are assumed on the swaps.

Random Variate Generators

Random variates are generated from a uniform distribution, a normal distribution and a poisson distribution during the simulation run. The routine, ran1, from Press, Teukolsky, Vetterling and Flannery(1996) was used to generate the random variates from an uniform distribution. Press, Teukolsky, Vetterling and Flannery(1996) state that the routine 'ran1' has no known flaws and passes all relevant statistical tests and hence recommend its use for generating random numbers from a uniform distribution. The 'gasdev' transformation given in Press, Teukolsky, Vetterling and Flannery(1996) was used to generate the random variates from the normal distribution. The 'poidev' transformation specified in Press, Teukolsky, Vetterling and Flannery(1996) was used to generate random variates from a poisson distribution.

Implementation Details of the Simulation

An overview of how the simulation is implemented is given in figure 6. The various broad steps that take place during the simulation are explained below. Each of the steps in the simulation is depicted in detailed flowcharts shown in figures 6 through 13. As a picture speaks a thousand words, I will not attempt to restate the flowcharts in words as I proceed with the explanation below. The reader is urged to study the flowcharts to understand the specifics of how the simulation was conducted.

Step 1: Generate portfolios for the three dealers

Random portfolios are generated for the three dealers based on certain minimum and maximum constraints (specified later) that are an input to the software. These portfolios are used by steps 2 and 4 to calculate credit exposures and systemic risk. The procedure for generating portfolios is discussed later in the chapter and is also shown in figure 7.

Step 2: Generate the evolution of the forward curve according to the HJMJ model

The forward curve evolution is generated for the 10 years of the simulation. The HJMJ model is simulated daily over the ten years. A year is assumed to have 360 days. This daily evolution is then sampled every 180 days to obtain the term structure of forward rates at the semiannual payment dates.

Step 3: Calculate Credit exposures

Using the forward rate curve evolution simulated in the previous step, credit exposures are calculated for the three portfolios. The procedure for calculating credit exposures is discussed later in the chapter and is also shown in figure 8.

Step 4: Generate recovery rates

Recovery rates are generated every semiannual period for the ten years of the simulation. These recovery rates are used in calculating the credit loss suffered by a dealer in the event of default.

Step 5: Determine whether there is a systemic repercussion

This step determines the occurrence of either one of the two systemic events explained earlier. The flowchart in figure 9 shows how the measurement of systemic risk is implemented.

Steps 2 through 5 are repeated for n iterations during the simulation to calculate the probability of a systemic repercussion for a particular portfolio. Steps 1 through 5 are repeated for N iterations in order to generate a distribution of systemic risk. The number of iterations is an input to the simulation software and can be changed by the user. In our simulation run n was set at 100 and N was set at 50 for a total of 5000 iterations.

Generation of the Swap Portfolios

The procedure for generating the swap portfolios for the three dealers is shown in the flowchart in figure 7. A swap is uniquely identified by the fixed rate, tenor, counterparty and whether the fixed rate is paid or received. The number of swaps in the portfolio is the same for all three dealers and was set at 100 for this simulation. The minimum and maximum tenors were set at 2 years and 10 years respectively. The minimum fixed rate was set at 5.53% and the maximum fixed rate was set at 7.35%. These values were determined from actual swap quotes for plain vanilla interest rate swaps ranging in tenor from 2 years to 10 years for the period January 13, 1997 to August 14, 1998 obtained from DRI. Based on these minimum and maximum constraints fixed rates and tenors were randomly generated. While generating the portfolios, care is taken to implement the interdependencies correctly, i.e. we make sure that if the first swap in dealer 1's portfolio is with dealer 2 then the first swap in dealer 2's portfolio is also with dealer 1 and the parameters are consistent.

Calculation of Potential Credit Exposure

The future credit exposures are calculated from distributions of exposures at each semiannual point over the life of the portfolio. For each of these distributions the mean exposure is calculated. Thus there will be a maximum of twenty (as the maximum tenor is set at 10 years) such mean exposures for each swap in the portfolio. The mean exposures are then discounted to the present using the fixed rate on the swap. These discounted mean exposures are then averaged over the life of the swap to obtain a single exposure for each swap.

For example let us consider a two-year pay fixed swap at a fixed rate of 6% with semiannual payments. At the first semiannual period the replacement cost of the swap is calculated using the forward rate curve generated by the HJMJ model. Let us assume that the fixed rate on a replacement swap calculated with the forward rate curve generated by the HJMJ model is 7%. Since the dealer is paying fixed and the fixed rate on the replacement swap is greater than the original fixed rate there is a cost to replacing this swap. We calculate the replacement cost based on the forward rate curve generated by the HJMJ model. Let us assume that the replacement cost calculated thus is 2% of notional. We move on to the next time period and repeat the same calculations. Thus we will have three replacement costs at the three time periods of the swap (let us say 2%, 0% and 4%). We now move on to the next iteration. In this iteration there will be a new forward rate curve generated based on the HJMJ model. Using this new forward rate curve all the above mentioned calculations are performed. Let us assume that the three replacement costs in this iteration are (1%, 3% and 5%). Let us just consider two iterations for this example. Thus after 2 iterations we arrive at a distribution of replacement costs at each time period of the swap. We now take the mean of the distribution at each time period of the swap (1.5%, 1.5%, and 4.5%). The mean replacement cost is discounted to the present using the fixed rate on the swap. The discounted replacement costs are 1.449%, 1.4% and 4.059%. The discounted replacement costs are averaged to arrive at a single value for the potential credit exposure of the swap. In our example the potential credit exposure of the swap is 2.303%.

Each swap's exposure is summed together to obtain the total exposure for the portfolio. The total exposure is divided by the notional principal to express the exposure in terms of percentage of notional principal. In the simulation, since the notional principal is set at one dollar, we will divide by the number of swaps to arrive at the percentage credit exposure. The potential credit exposure calculated as explained above represents the potential credit exposure for a particular random generation of portfolios for dealers 1, 2 and 3. A distribution of potential credit exposures is constructed by repeating this procedure for *N* different random generation of portfolios for dealers 1, 2 and 3. The mean and the 95% confidence interval for the distribution of potential credit exposure are then calculated. The exact mechanics as to how the credit exposure is calculated is shown in figure 8.

Measuring Systemic Risk

The objective here is to measure the probability of either of the following two events occurring in the same time period.

i. dealer 1 defaulting on dealer 2 which causes dealer 2 to default on dealer 3

ii. dealer 3 defaulting on dealer 2 which causes dealer 2 to default on dealer 1

In every iteration of the simulation we check for each of the above-mentioned events happening. The probability of a systemic repercussion is calculated as the sum of the systemic repercussions that occurred over the *n* iterations, divided by the number of iterations. This probability represents the systemic risk for a particular random generation of portfolios for dealers 1, 2 and 3. A distribution of systemic risk is calculated by repeating this procedure for *N* different random portfolios for dealers 1, 2 and 3. The final measure of systemic risk is the mean of the distribution of the probability of a systemic repercussion. The flowchart in figure 9 shows the details of the implementation.

Procedure for Checking if One Dealer Defaults on Another

The procedure for checking whether one dealer defaults on another involves the six steps detailed below:

Step 1: Net all cashflows owed to the same counterparty to arrive at one cashflow for each counterparty.

Step 2: Check if the dealer's firm value is less than the threshold. If the firm value is less than threshold then the dealer defaults.

Step 3: Check if the dealer's capital ratio is below the threshold of 2%. If the capital ratio is less than 2% then the dealer defaults.

Step 4: Check whether the dealer owes a payment. If it does, then reduce the payment by the cash inflows that the dealer gets. While calculating the cash inflows we have to check whether any of the external counterparties default on their payments to the dealer. If an external counterparty defaults then the replacement cost is calculated and the fixed rate field of the swap is changed to reflect the replacement rate. Thus, the assumption here is that the dealer replaces the defaulted swap with a new swap for the remaining tenor of the original swap. The procedure for calculating the replacement cost is shown in figure 12.

Step 5: Check whether this net payment is greater than the dealer's firm value. If it is then the dealer defaults.

Step 6: Check if the credit loss incurred by the dealer is greater than the capital of the dealer. If the credit loss is greater than the capital the dealer defaults.

The details of the implementation are presented in the flowcharts shown in figures 10 and 11. Figure 10 shows the steps involved in determining whether dealer 1 defaults on dealer 2. The procedure is exactly the same for determining whether dealer 3 defaults on dealer 2. Figure 11 shows the steps involved in determining whether dealer 2 defaults on dealer 1. The procedure is exactly the same for determining whether dealer 2 defaults on dealer 3.

Procedure for Moving to the Next Time Step of the Simulation

The next period's firm value depends on the current period's firm value adjusted for all the cashflows from the swaps in the dealer's portfolio. Thus when we move forward to the next time step the current period's firm value is adjusted by all the cashflows (both inflow and outflow) arising from the swaps in the dealer's portfolio. The firm value is also reduced by the cost of replacement in case of default by any of the external counterparties.

The current period's capital ratio is also adjusted by the ratio of the credit loss to the firm value before proceeding to the next time step. The flowchart in figure 13 shows in detail the steps taken when transitioning from one time step to the next.

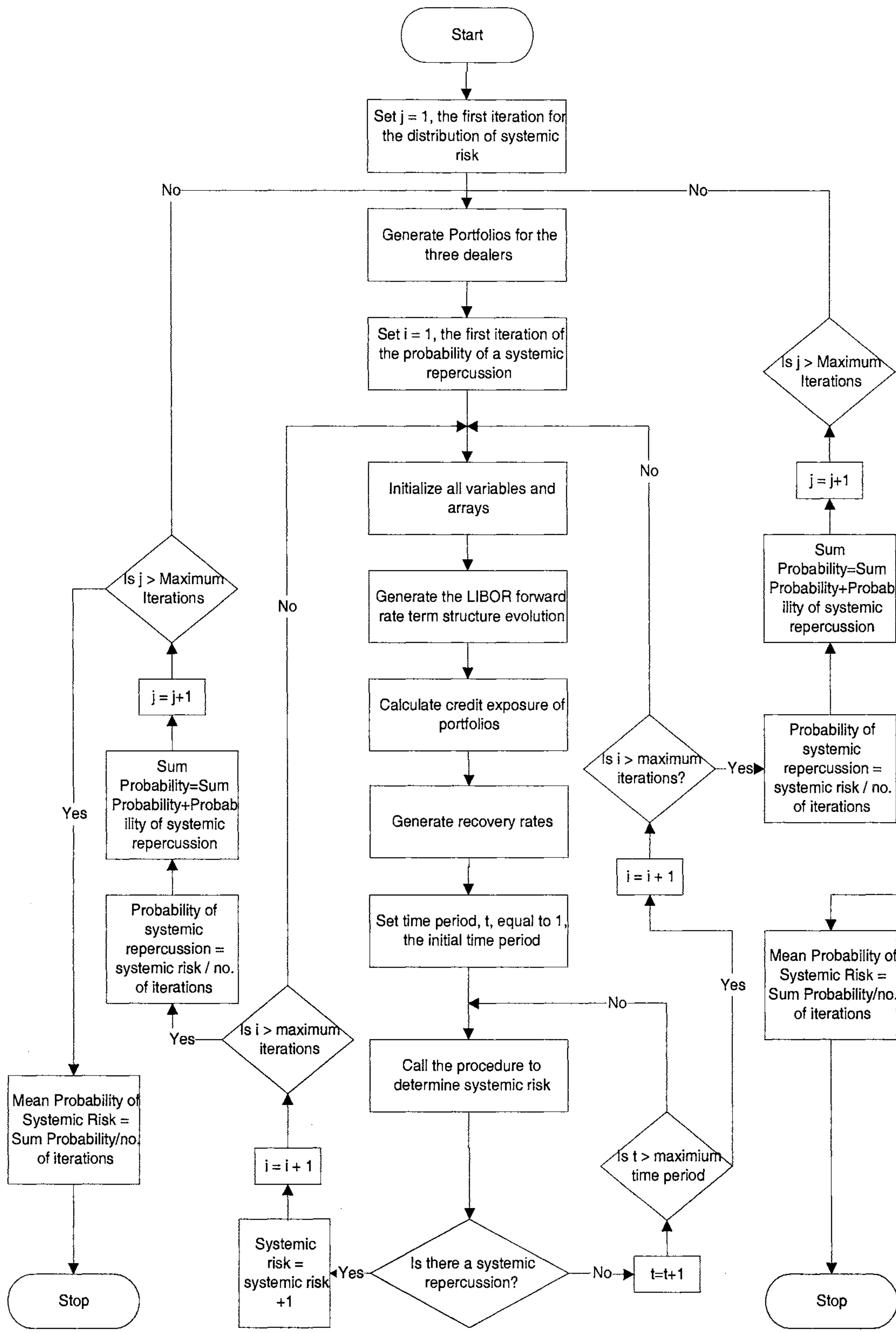

Figure 6. Overall Implementation of the Simulation

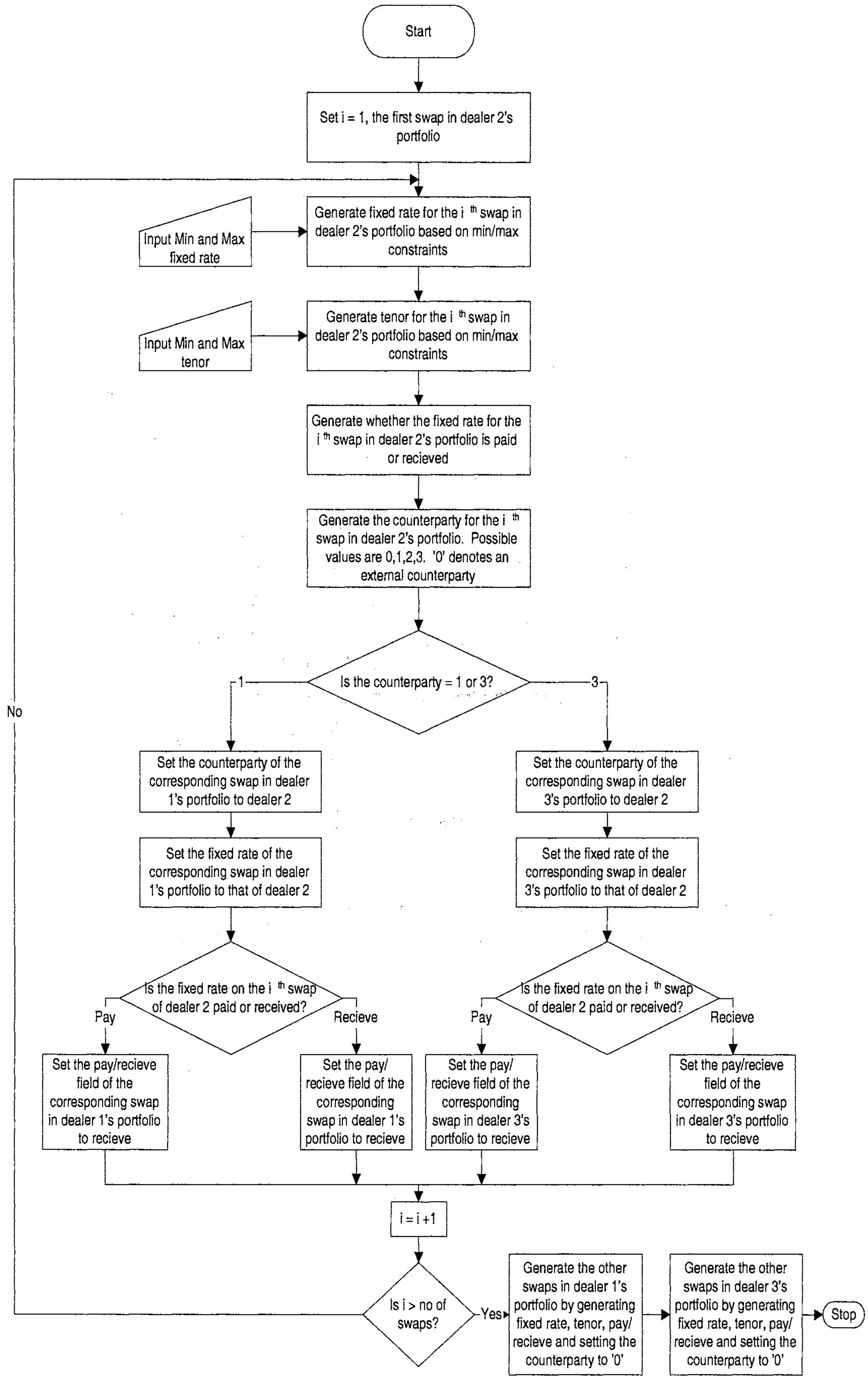

Figure 7. Procedure for Generating the Portfolios

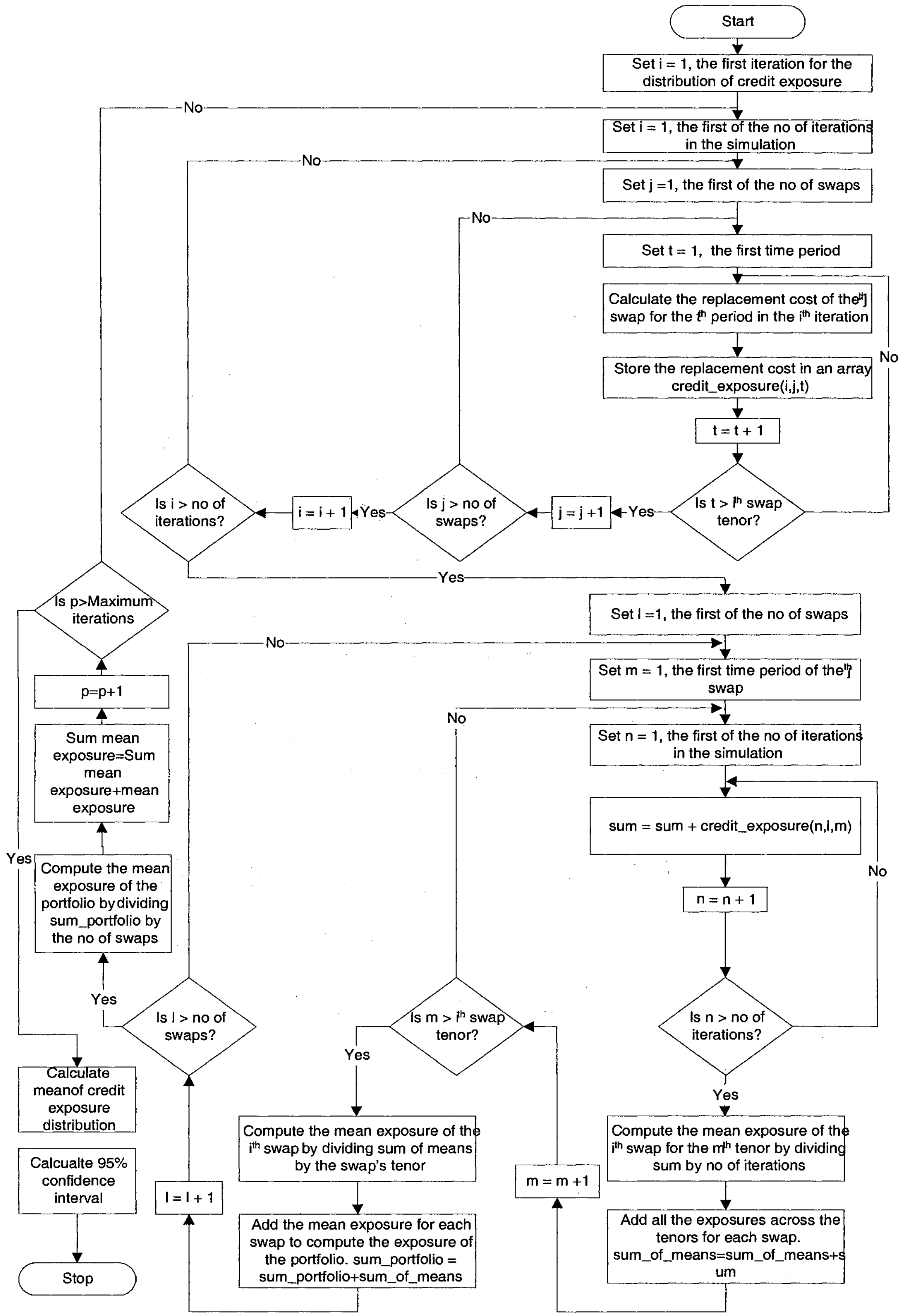

Figure 8. Procedure for Calculating Credit Exposures

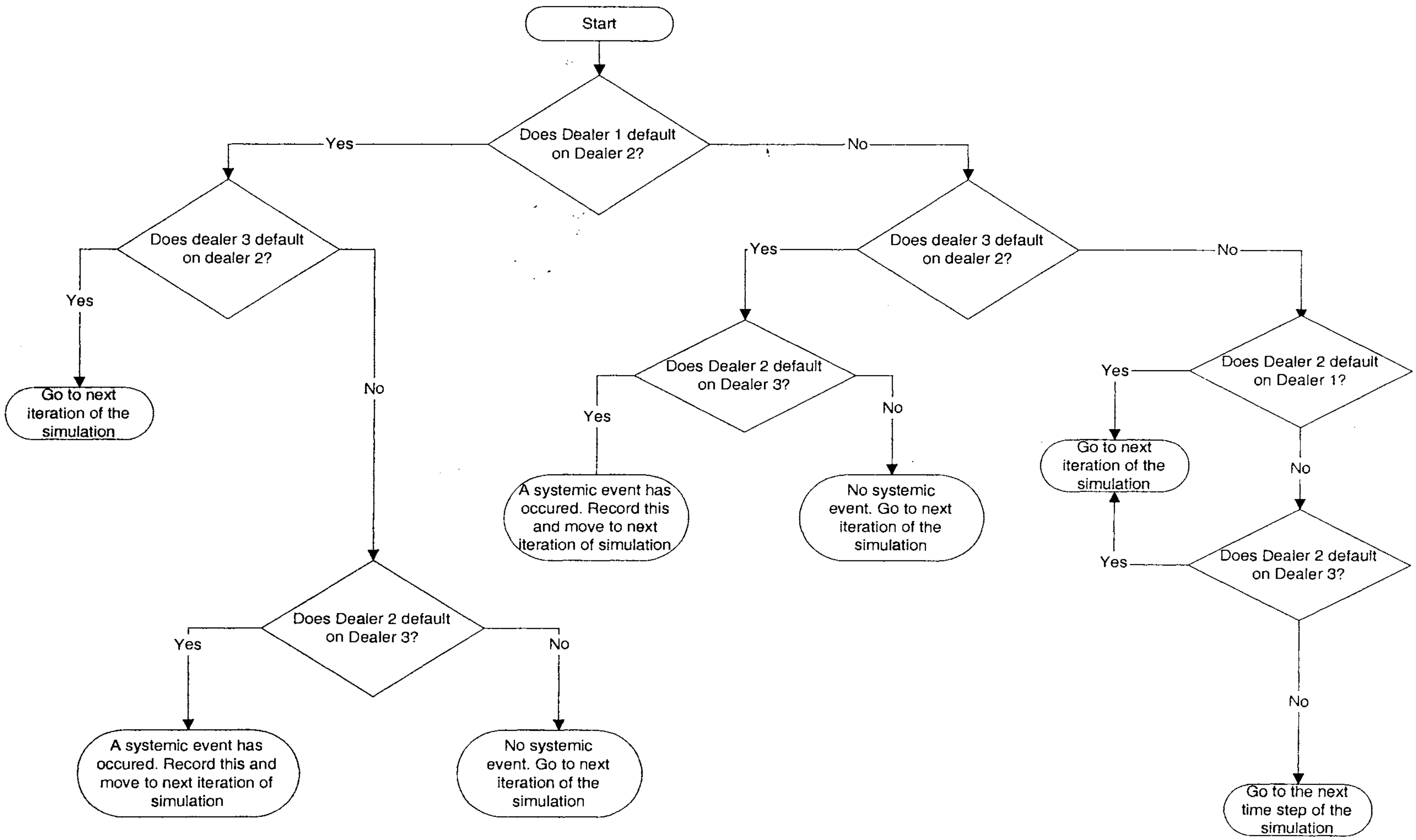

Figure 9. Procedure for Measuring Systemic Risk

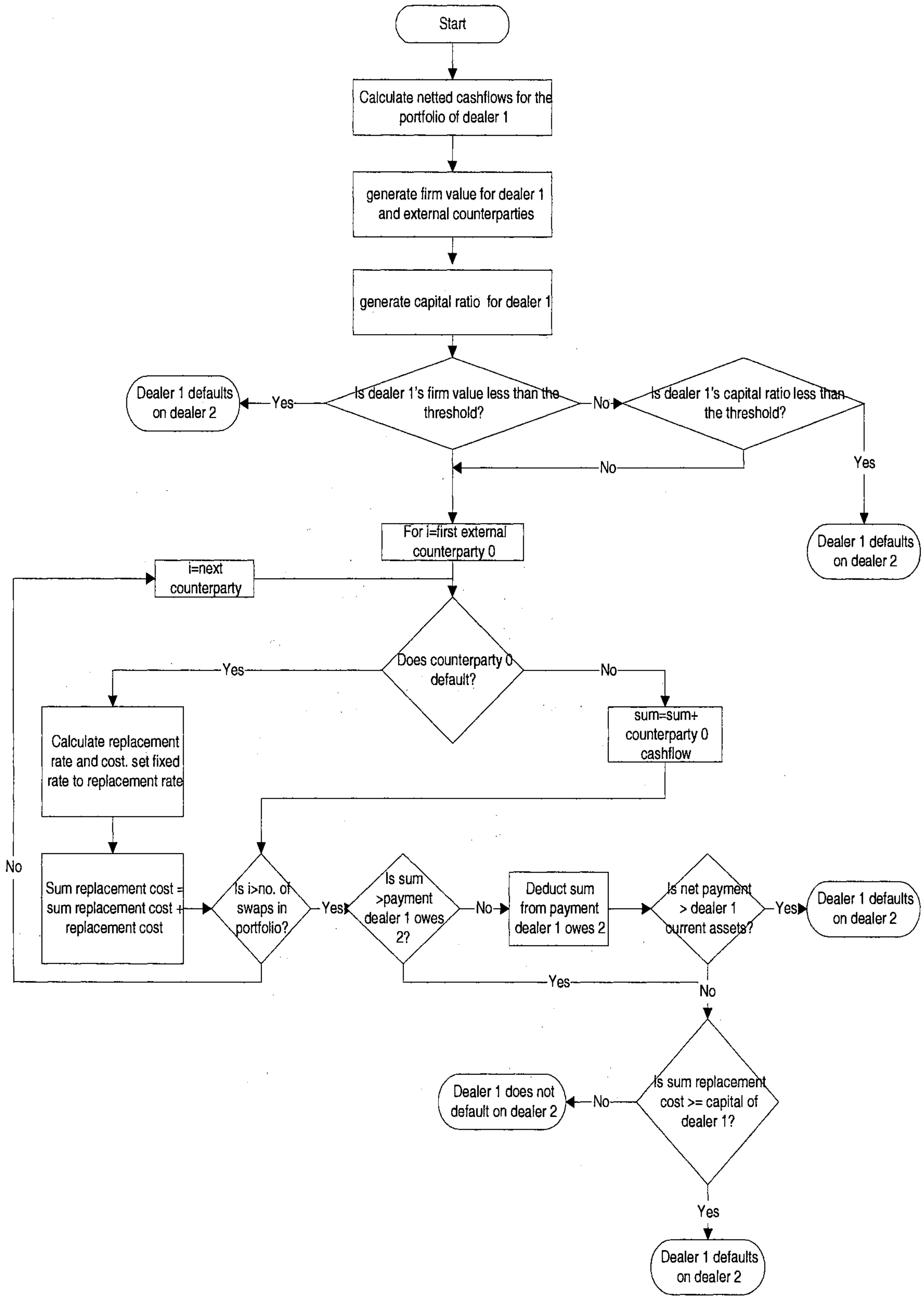

Figure 10. Procedure for Determining Whether Dealer 1 Defaults on Dealer 2

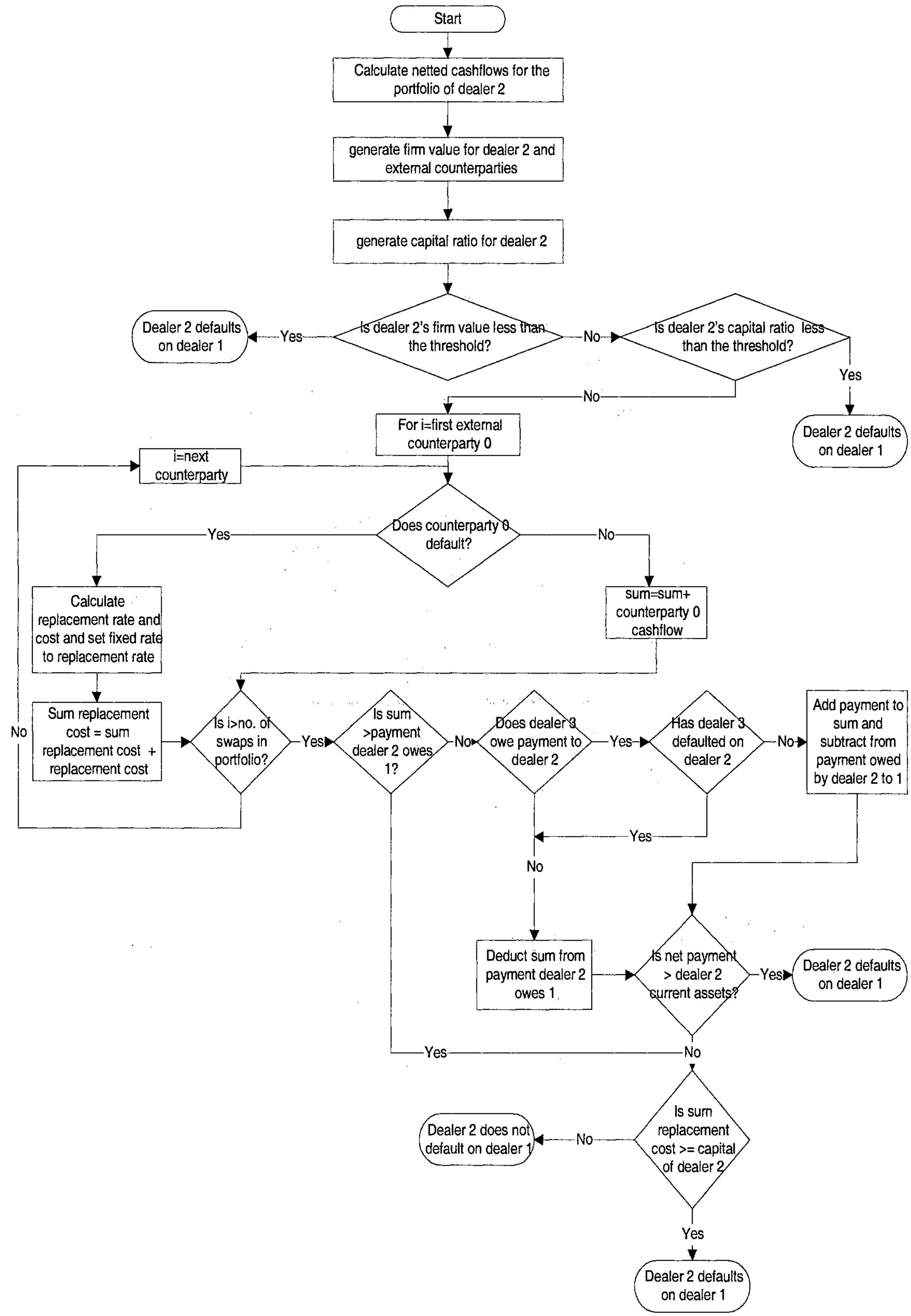

Figure 11. Procedure for Determining Whether Dealer 2 defaults on Dealer 1

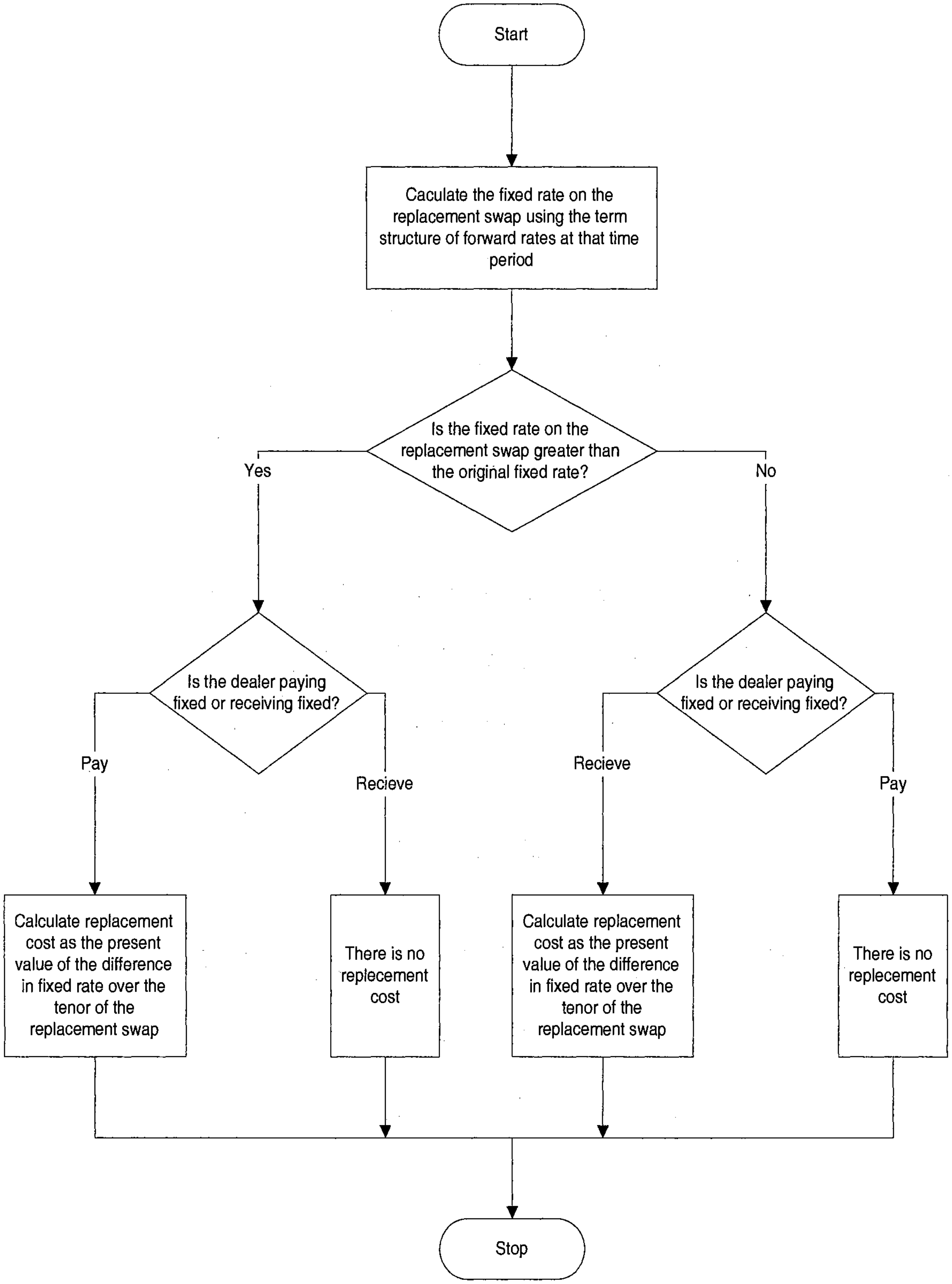

Figure 12. Procedure for Calculating the Replacement Cost

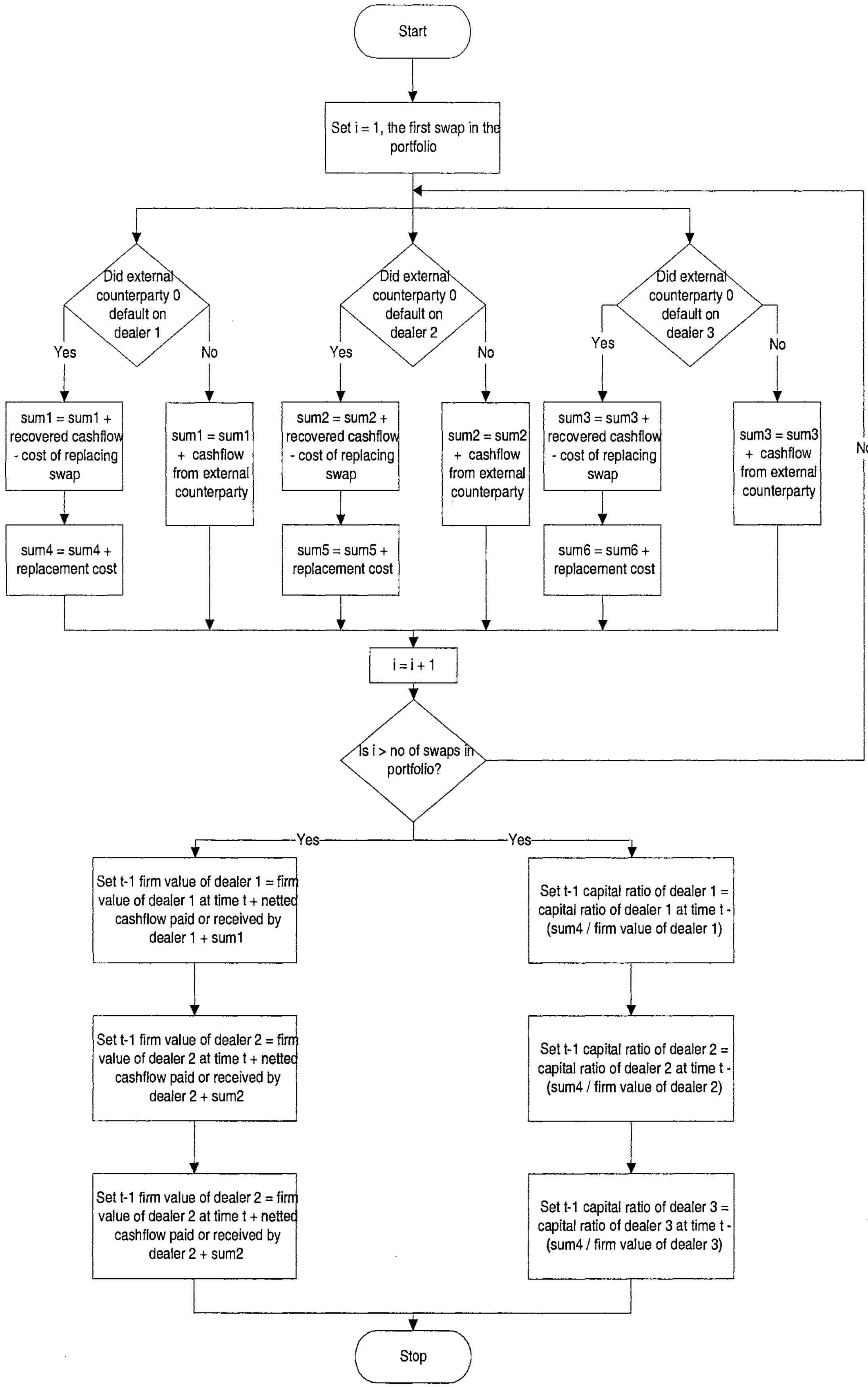

Figure 13. Procedure for Transitioning From One Time Period to the Next

CHAPTER 6

THE SIMULATION SOFTWARE

This chapter provides a brief description of the software developed for conducting the simulation. This chapter can be considered a brief and simple user guide to the software that was developed for the simulation.

Software Platform and Design

The software was developed using Microsoft Visual Basic 5.0. The software will work only on 32-bit windows operating systems such as Windows 95, Windows 98 and Windows NT. The memory requirement will vary with the number of iterations in the simulation and the number of swaps in the portfolio. The minimum suggested memory is 32MB.

The software was developed using a simple object oriented design where the swap is considered as a class with the tenor, fixed rate, counterparty, replacement rate and pay/receive (indicates whether the fixed rate is paid or received) as its members. Portfolios of swaps are constructed as arrays of the swap class.

The Main Screen

The main screen of the software is shown in figure 14. The user first clicks the 'Market Data' button to enter the initial term structure of forward rates (the forward rate curve) to be used in the simulation. The user would then click the 'Simulation Set Up' button to enter the parameters of the simulation such as the number of swaps in the portfolio etc. The user then clicks the 'Run Simulation' button to start the simulation. A status bar shows the progress of the simulation and when the simulation is complete the user clicks the 'View Results' button to view the probability of systemic risk, the credit exposure etc. The 'Exit' button exits out of the software. The functions performed by the four buttons can also be accessed through the menu bar. For example, File>Setup simulation takes the user to the simulation setup screen, where all the parameters of the simulation are input. There are also shortcut keys associated with each of the menu items, for example, pressing the function key 'F9' runs the simulation.

The Market Data screen

The market data screen is shown in figure 15. It consists of a spreadsheet where the user enters the initial term structure to be used in the simulation. The user enters the three-month Eurodollar futures prices from the Wall Street Journal in the spread sheet. The software automatically calculates the implied three-month LIBOR rates from the futures prices and uses them to simulate the term structure evolution. The number of Eurodollar prices that need to be entered depends on the maximum tenor of the swaps in the portfolio (entered through the simulation setup screen). The number of prices should be equal to four times the maximum tenor of the swaps in the portfolio of the swap dealer, as the Eurodollar futures contracts trade on a quarterly cycle. If the user fails to enter a price then that price will be taken as zero and hence will lead to unrealistic interest rate evolutions.

The Simulation Setup Screen

The simulation setup screen is the screen where the user enters all the parameters for the simulation and is shown in figure 16. Relevant fields on the setup screen are grouped under various categories in order to facilitate easy entry of parameters. The user can choose the model he/she wants to use for the term structure, the firm value and the recovery rates by pulling down the relevant list box. Once the model is chosen the user clicks the 'Enter Parameters' button to enter the parameters for the model chosen. All entries on this screen are persistent, which means that the user will not have to reenter the parameters the next time he/she launches the application unless he/she wants to change them. All inputs to the simulation software are stored in various files. If the user unchecks the 'Calculate Credit Exposures' checkbox then the software will ignore the credit exposure calculations and only perform the systemic risk part of the simulation. If the user's main objective is to measure systemic risk then he/she should uncheck the 'Calculate Credit Exposures' check box as this will reduce the time taken by the simulation and the memory needed by the simulation.

The View Results Screen

The results of the simulation are shown in the view results screen shown in figure 17. The probability of systemic repercussion and the credit exposures are shown in this screen. The user can also plot several graphs by choosing the X and Y axis from the appropriate list boxes and then pressing the graph button. The graph and the data for the graph can be copied to the clipboard and pasted into software such as Microsoft Excel and Word by clicking on the graph and then right clicking the mouse.

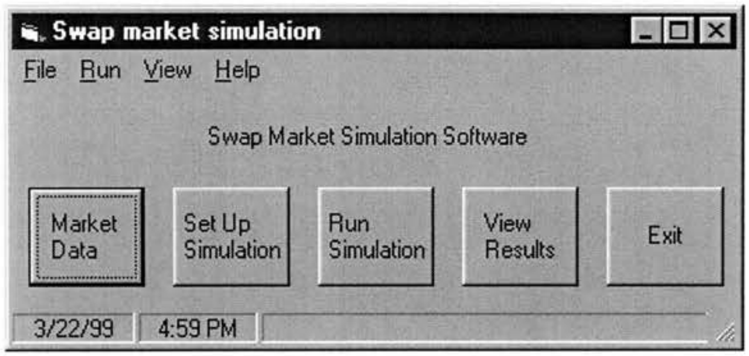

Figure 14. The Main Screen

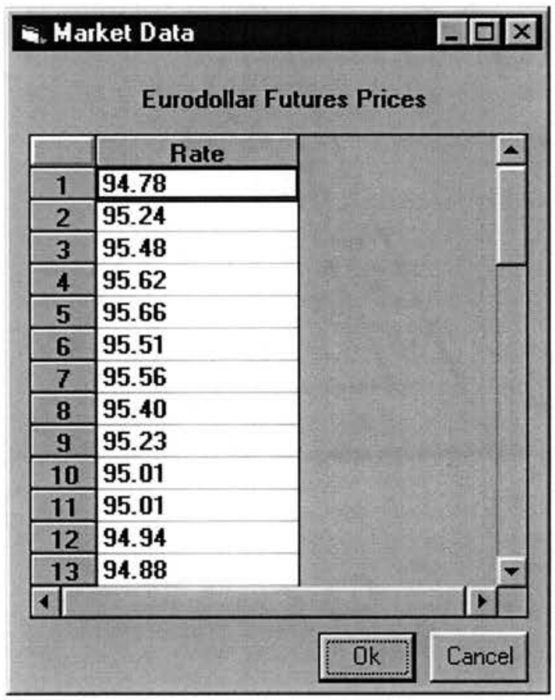

Figure 15. The Market Data Screen

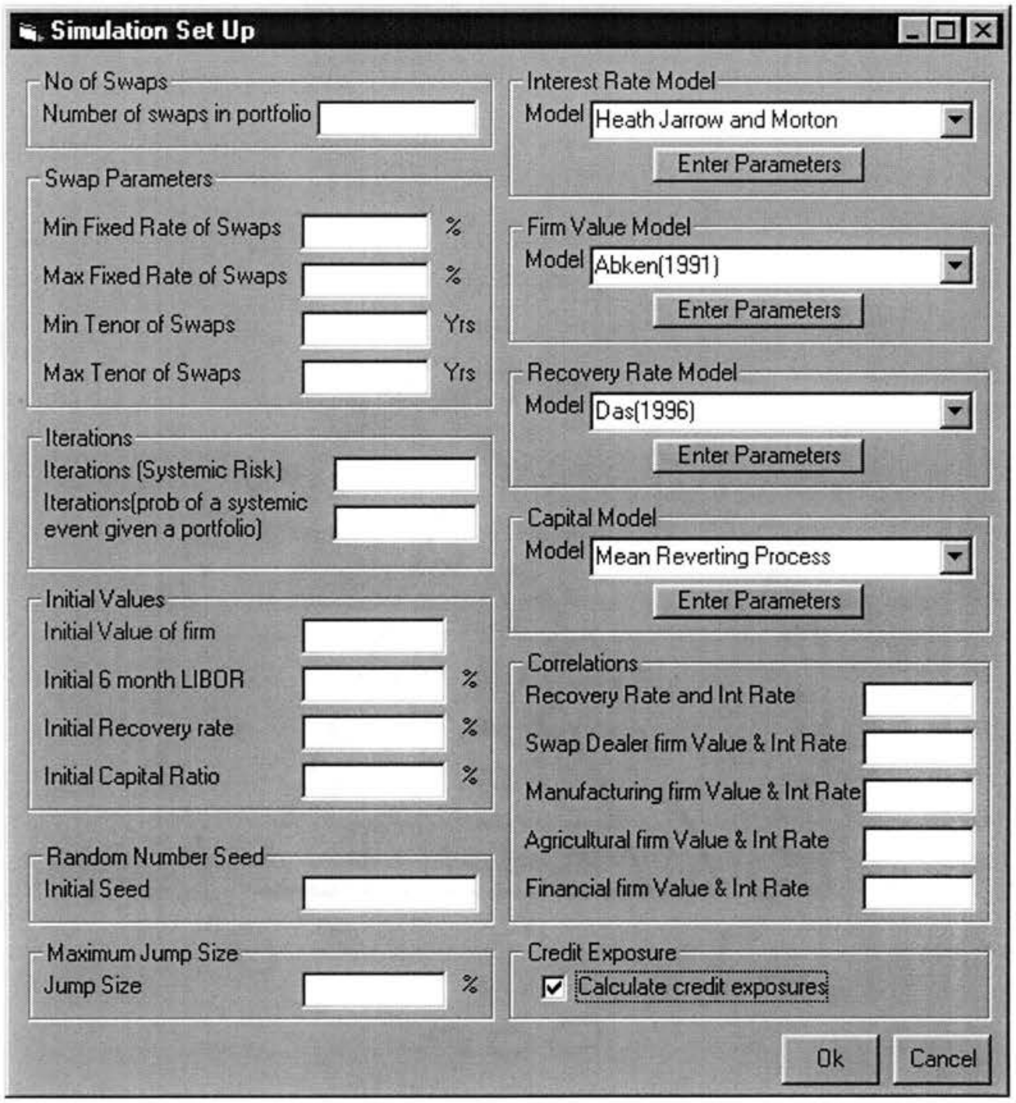

Figure 16. The Simulation Set Up Screen

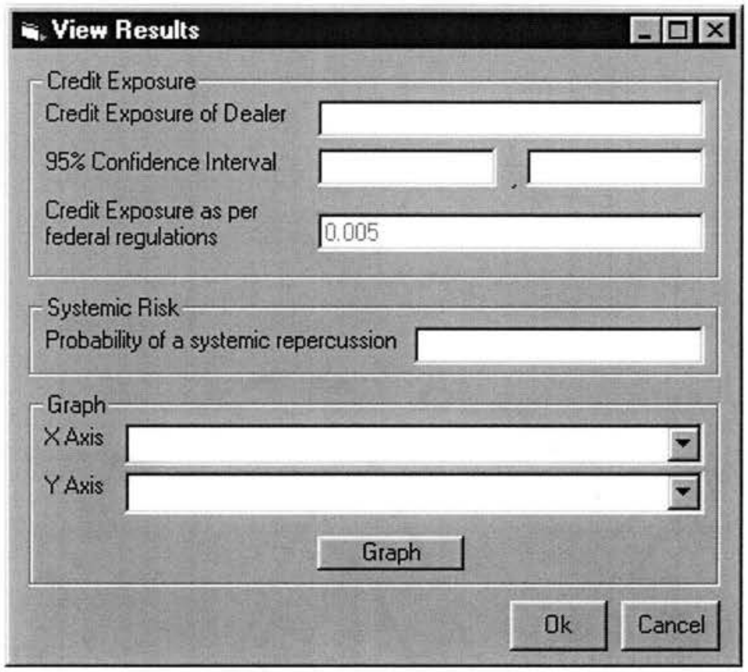

Figure 17. The View Results Screen

CHAPTER 7

THE RESULTS

This chapter presents the results of the simulation of the systemic risk model. The results discussed here can be divided into two groups. The first group consists of measuring the systemic risk in the interest rate swap market and evaluating the sensitivity of systemic risk to the various factors that determine it. The second group has a regulatory focus and addresses, what regulators and policy makers can do to mitigate systemic risk. A discussion of the two groups of results is presented below.

Systemic Risk

Table 13 shows the characteristics of the distribution of systemic risk based on MonteCarlo simulations of our model of systemic risk. The simulation was run with 50 iterations for calculating the distribution of systemic risk and 100 iterations for calculating the probability of systemic risk for a particular portfolio, for a total of 5,000 iterations. The characteristics of the 50 initial portfolio settings are shown in figures 18 to 20. The distribution of systemic risk is shown in figure 21. The distribution is restricted between 0 and 1 as it is a distribution of probabilities and is skewed towards zero. The expected probability of a systemic repercussion occurring during the ten year time frame of the simulation is 0.72%. The maximum and minimum probability of a systemic repercussion is 3% and 0% respectively. Thus the systemic risk in the interest rate swap market is quite small. This result is in line with the other two studies, Schneck(1996) and Wall, Tallman and Abken(1996), who also conclude that the systemic risk in the OTC derivatives market is small.

The interest rate environment during the occurrence of the systemic events is given in figure 22. The figure shows the distribution of systemic events with respect to the change in the interest rate. We see from the distribution that the majority of the systemic events occurred when there were large changes in the interest rate. This analysis shows that systemic events are more probable in an interest rate environment characterized by large changes in interest rates.

The maximum probability of a systemic repercussion was 3%, which means that for one particular set of portfolios a systemic event occurred three times out of the one hundred iterations. It would be of interest to investigate the composition of the portfolios that caused this maximum case. For the maximum case dealer 1's portfolio consisted of 64% of swaps with tenor five years and above, dealer 2's portfolio consisted of 73% of swaps with tenor five years or more and dealer 3's portfolio consisted of 68% of swaps with tenor five years or more. The number of swaps on the pay side and the number of swaps on the receive side were quite evenly distributed (46%, 48% and 48%). Hence, one possible reason for this maximum case could be due to the fact that the portfolios have a greater number of long-term swaps thus increasing the probability of default.

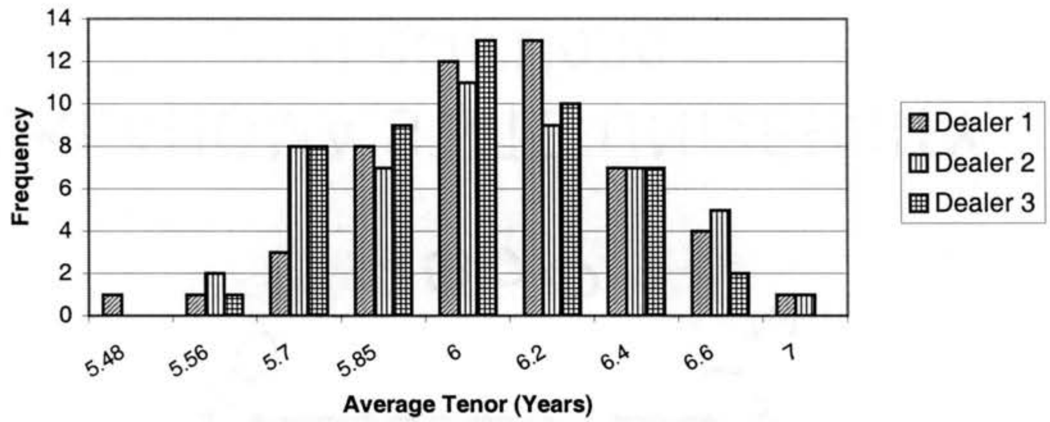

Figure 18: Distribution of Average Tenor in the fifty initial portfolios

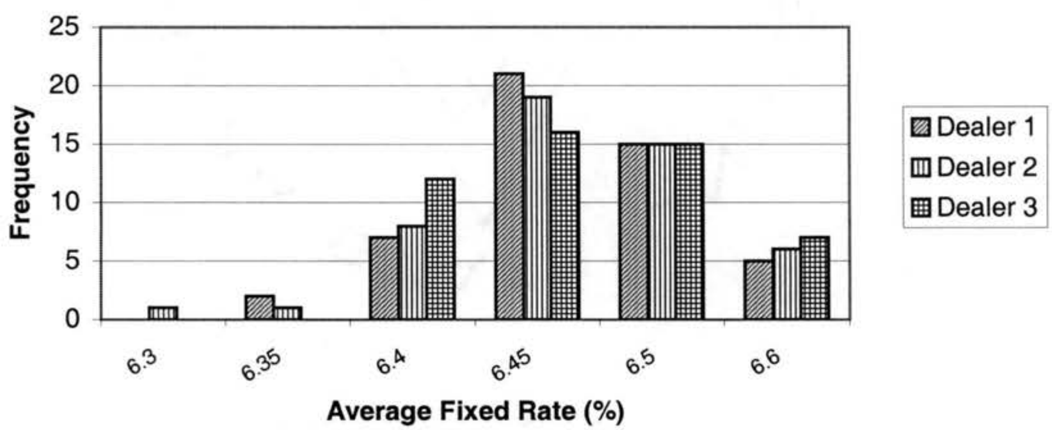

Figure 19: Distribution of Average Fixed Rate in the Fifty Initial Portfolios

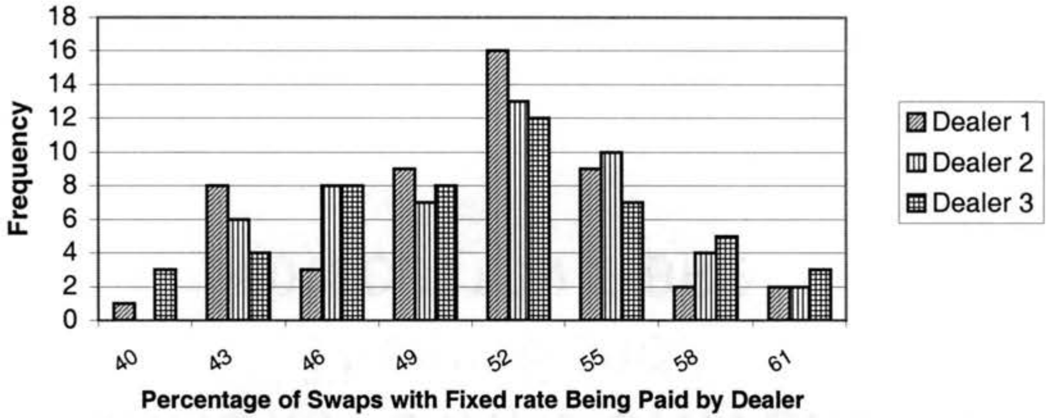

Figure 20: Percentage of Swaps with Fixed Rate Being Paid by the Dealer for the Fifty Initial Portfolios

Table 13

Characteristics of the Distribution of Systemic Risk

Characteristic	Systemic Risk
Mean	0.0072
Maximum	0.03
Minimum	0
Standard Deviation	0.008091

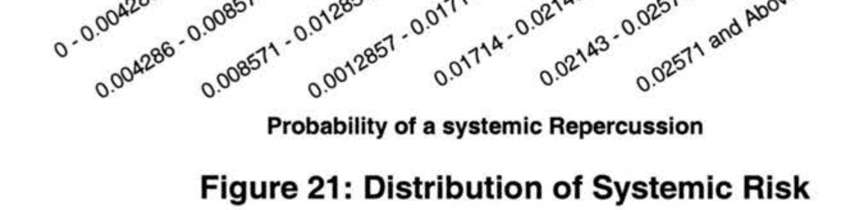

Figure 21: Distribution of Systemic Risk

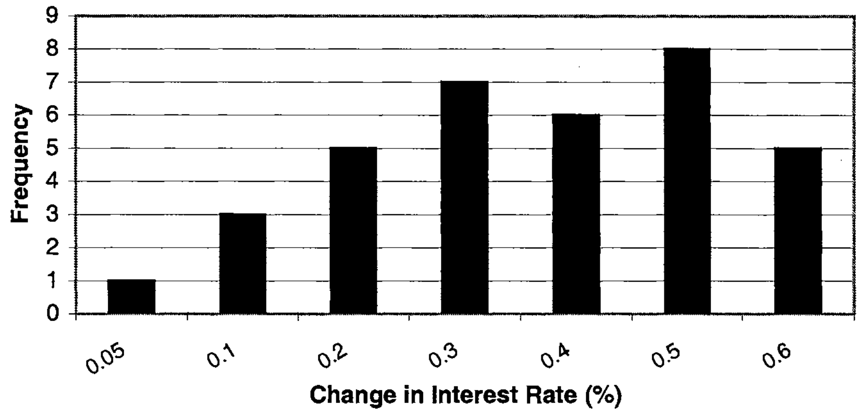

Figure 22: Distribution of Systemic Events With Respect to Interest Rate Changes

Sensitivity Analysis

Systemic Risk and Interest rate Jump Size

The maximum interest rate jump size for the base case was set at 0.69%. The maximum jump size was varied from 0.35% to 1.05%, which is a 50% interval around the base case jump size. Figure 23 shows the sensitivity of the probability of a systemic repercussion to the jump size. The figure shows that the probability of a systemic repercussion increases with interest rate jump size. As the size of interest rate jumps increase, the payments to be made or received by a swap dealer becomes larger, hence increasing the probability of default. This increased probability of default leads to greater systemic risk.

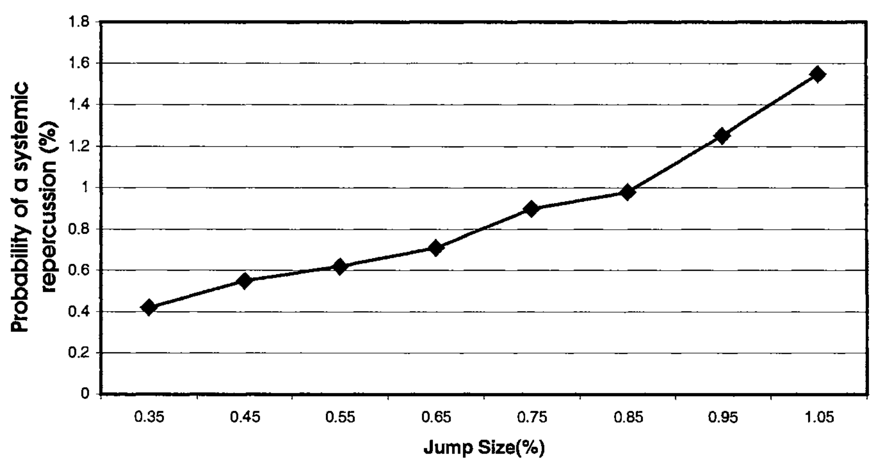

Figure 23: Systemic Risk Vs Interest Rate Jump Size

Systemic Risk and Interest Rate Jump Arrival Rate

The interest rate jump arrival rate for the base case was set at 0.0125 (corresponds to 9 jumps in a year). The jump arrival rate was varied between 0.00694 and 0.0194, which is a 50% interval around the base arrival rate to observe its effect on the probability of a systemic repercussion. Figure 24 shows the change in the probability of a systemic repercussion due to a change in the jump arrival rate. The figure shows that the probability of a systemic repercussion is high when the jump arrival rate is high. This is as expected because when there are more jumps in the interest rate there is a greater probability of default and hence a greater probability of a systemic repercussion.

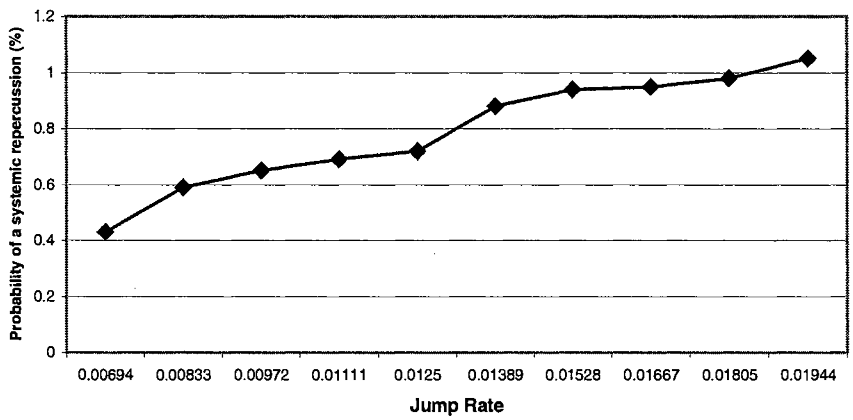

Figure 24: Systemic Risk Vs Interest Rate Jump Rate

Systemic Risk and Default Threshold

The default threshold for the base case was set at the natural lower bound for firm value which is zero. The default threshold for the firm value was varied from zero to 0.5. Figure 25 shows the sensitivity of the probability of a systemic repercussion to the default threshold. The plot shows that the probability of a systemic repercussion is highly sensitive to the change in the default threshold. The default threshold determines when the firm enters into bankruptcy. Higher the default threshold the greater the probability of default by the counterparties and hence greater the probability of a systemic repercussion.

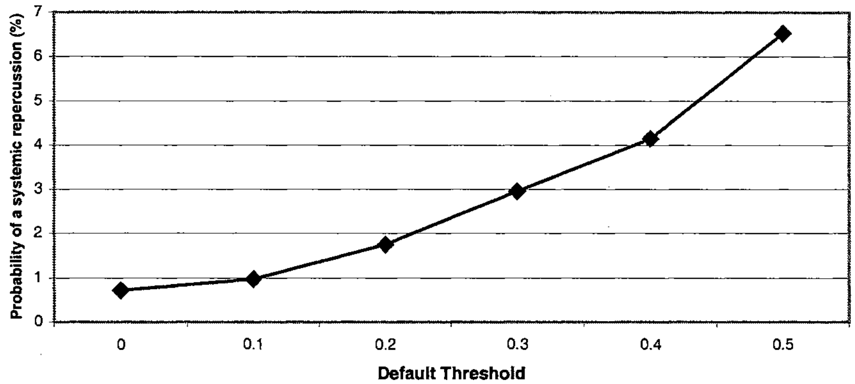

Figure 25: Systemic Risk Vs Default Threshold

Systemic Risk and Recovery Rate

The relationship between recovery rates and systemic risk is examined by varying the recovery rate from 0% to 60% in our simulation of the model of systemic risk. The lower bound of the range is the worst case and the upper bound is the highest recovery rate among any type of debt reported by Altman(1992). Figure 26 shows the change in the probability of a systemic repercussion with changes in the recovery rate. We see, from figure 26 that the probability of a systemic repercussion decreases with an increase in recovery rate. As the recovery rate increases the credit loss of the dealer decreases and hence the probability of a systemic repercussion decreases.

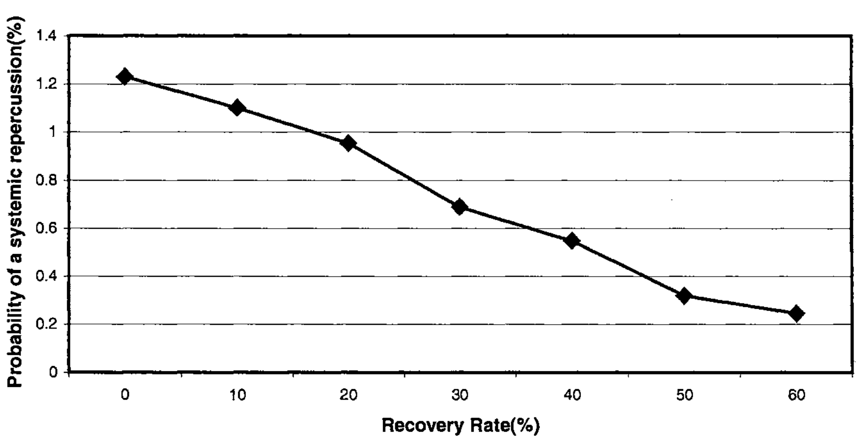

Figure 26: Systemic Risk Vs Recovery Rate

Systemic Risk and the Volatility of Interest Rates

The base case volatility of the forward rates was set at 0.05636. The volatility was varied from 0.02818 to 0.08454, which represent a 50% interval around the base case value. From figure 27 we see that the systemic risk increases rapidly with an increase in the volatility of the forward rates. Higher volatility implies greater swings in the interest rate leading to more defaults and hence greater systemic risk.

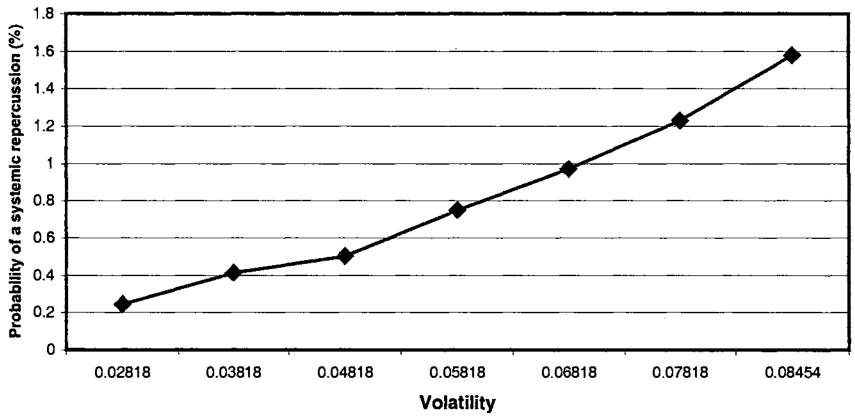

Figure 27: Systemic Risk Vs Volatility of Interest Rates

Comparison of the Sensitivities of the Various Parameters

Figure 28 presents all the sensitivity plots in one plot with the same scale for comparison purposes. We see, from figure 28, that the probability of a systemic repercussion is most sensitive to the default threshold. This is because increasing the default threshold sharply increases the probability of default. We also see that the probability of a systemic repercussion is more sensitive to the jump size than to the jump rate. This is because an interest rate jump of a large magnitude has a high probability of causing a systemic repercussion, while a high jump rate indicates more jumps but with a smaller magnitude, which may or may not cause a systemic repercussion. The probability of a systemic repercussion is also slightly more sensitive to the interest rate volatility than the jump size, as increasing the interest rate volatility causes larger changes in interest rates during every time period though the changes are not as big as the jumps (which do not affect every time period). From figure 28 we also see that the probability of a systemic repercussion is more sensitive to the recovery rate than the interest rate jump size, rate and volatility as the negative slope of this plot is higher than the others. Higher recovery rates imply smaller credit losses and hence a lesser probability of a systemic repercussion.

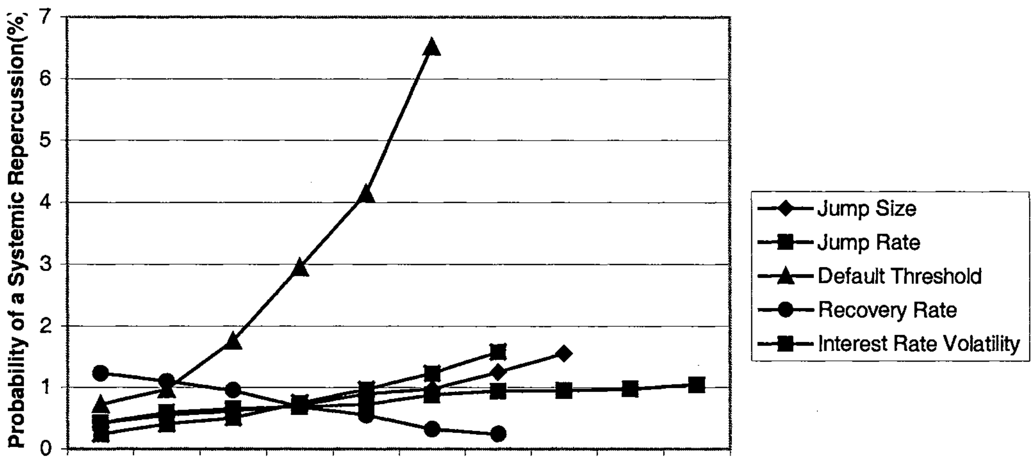

Figure 28: Comparison of Sensitivities to Different Parameters

Systemic Risk and Regulatory Issues

This section is motivated by the question, "What can regulators do to mitigate systemic risk?" In order to address this question we first need to identify the factors that regulators have control over. The following factors can be controlled by regulators (this is a list of factors that in theory can be controlled by regulators, whether they can do so in practice is open to question).

i. Calculation of potential credit exposure

ii. Capital requirement

iii. The swap portfolio weights

Other than the above three factors there are other factors such as operational issues, accounting and disclosure and legal uncertainties which the Federal Reserve has control over, but, these factors cannot be analyzed within the context of our model, as they require modeling of decision making. Thus we shall examine the above listed factors, within the context of our model, and make regulatory recommendations to mitigate systemic risk. The cost of imposing the recommended regulation has not been taken into account while making regulatory recommendations below.

Calculation of Potential Credit Exposure

Table 14 shows the characteristics of the distribution of the potential credit exposure of a portfolio of swaps calculated within the context of our model. Figure 29 shows a plot of the distribution of credit exposures. The results show that the potential credit exposure (4.8948% of notional principal) calculated under our model is larger than the potential credit exposure (0.5% of notional principal) prescribed by the Federal Reserve guidelines. The possible reasons for this result are:

1. The method followed by the Federal Reserve uses a lognormal distribution for the interest rates. The Federal Reserve's simulation was conducted by generating random values from the lognormal distribution for interest rates. Unlike the method employed by the Federal Reserve we rigorously model the term structure of interest rates using the Heath, Jarrow and Morton model. The entire term structure is then simulated using an Euler scheme.
2. The method employed by the Federal Reserve considers a single par swap while we consider a portfolio of par and non-par swaps.

Table 14

Characteristics of the Distribution of Potential Credit Exposures

Characteristic	Credit Exposure
Mean	4.8948%
Standard Deviation	0.5407%
Maximum	6.1730%
Minimum	3.9127%
95% confidence interval Upper Bound	5.0447%
95% confidence interval Lower Bound	4.7450%

Based on our calculations we suggest a rule of thumb for the calculation of potential credit exposure for risk based capital requirements. This rule of thumb is given in table 15 and is akin to that suggested by the Federal Reserve, which is outlined in table 3 (chapter 2). The mean credit exposure of 4.8948% is rounded to 5% in our recommendation in table 15. This recommendation is significant due to the fact that the potential credit exposure calculated according to this recommendation is greater than the potential credit exposure calculated by the current Federal Reserve guidelines by an order of magnitude of 10. This greater potential credit exposure will effectively increase the capital requirement of the dealer thereby mitigating systemic risk.

Table 15

Credit Conversion factor Based on Systemic Risk Model

Remaining Maturity	Percentage of notional
One year or less	0%
Over One Year	5%

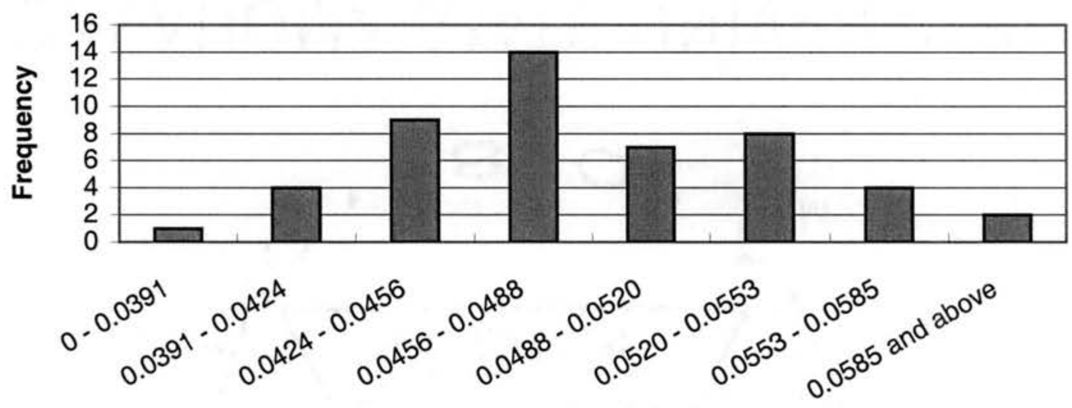

Figure 29: Distribution of Credit Exposures

Capital Requirement

Figure 30 shows the change in the probability of a systemic repercussion with changes in the capital requirement. This plot is of interest to regulators as it provides information on how sensitive the probability of a systemic repercussion is to changes in capital. The probability of a systemic repercussion decreases with an increase in the capital requirement. As the dealer holds more and more capital it can sustain higher credit losses and hence the systemic risk becomes lower. We see that the probability of a systemic repercussion decreases rapidly when the capital requirement is increased from 0% to 10% but thereafter the decrease is slower. The decrease becomes very small after 14%. Thus we suggest that the capital ratio be increased to 14% from the current requirement of 8% in order to minimize the systemic risk in the interest rate swap market.

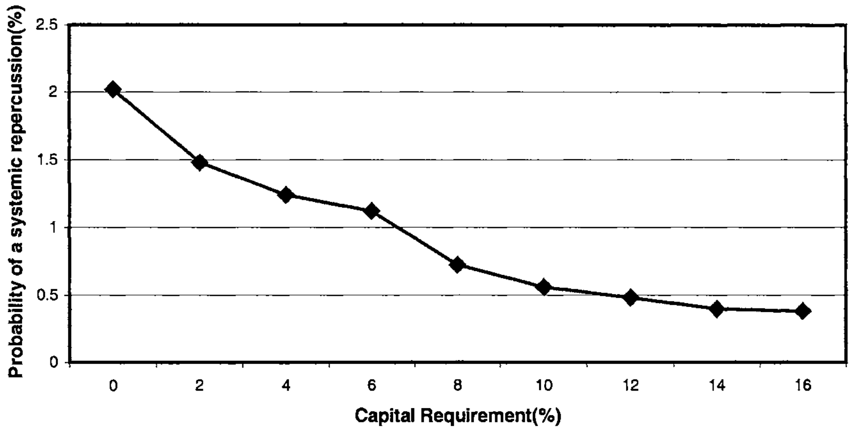

Figure 30: Systemic Risk Vs Capital Requirement

The Swap Portfolio Weights

Systemic Risk and Counterparty Diversification

The effect of counterparty diversification can be analyzed by calculating the probability of a systemic repercussion assuming that all the swaps in the portfolio are with one counterparty and repeating the same procedure assuming multiple counterparties. The number of counterparties is varied from the lower bound of no diversification, which means that all the swaps are with one counterparty, to the upper bound of full diversification, which means that every swap is with a different counterparty. When more than one counterparty is involved the assumption is that the dealer can enter into a swap with any one of these counterparties with equal probability. Figure 31 shows the plot of the probability of a systemic repercussion for various number of counterparties. This analysis sheds light on the effect of portfolio diversification, in terms of counterparties, on the probability of a systemic repercussion. We see that the probability of a systemic repercussion decreases rapidly with higher counterparty diversification. Thus this result indicates that the Federal Reserve should consider placing a restriction on the minimum number of counterparties in a swap dealer's portfolio.

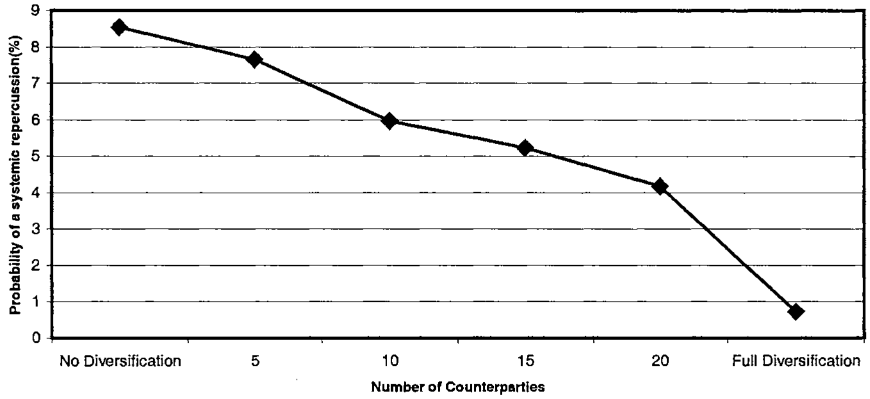

Figure 31: Systemic Risk Vs Counterparty Diversification

Counterparty Diversification in an Environment of High Probability of Counterparty Default

This analysis examines how the probability of a systemic repercussion responds to counterparty diversification in an environment characterized by a high probability of counterparty default. To create an environment of high probability of counterparty default we set the default threshold high, at the maximum value of 0.5% used in the sensitivity analysis previously. Figure 32 shows the change in the probability of a systemic repercussion with counterparty diversification. We see that the probability of a systemic repercussion is very high when there is no diversification and counterparty diversification drastically reduces the probability of a systemic repercussion. Thus we see that the probability of a systemic repercussion is is even more sensitive to counterparty diversification in an environment characterized by a high probability of counterparty default. This result strengthens our recommendation that the Federal Reserve consider placing a restriction on the minimum number of counterparties in a swap dealer's portfolio.

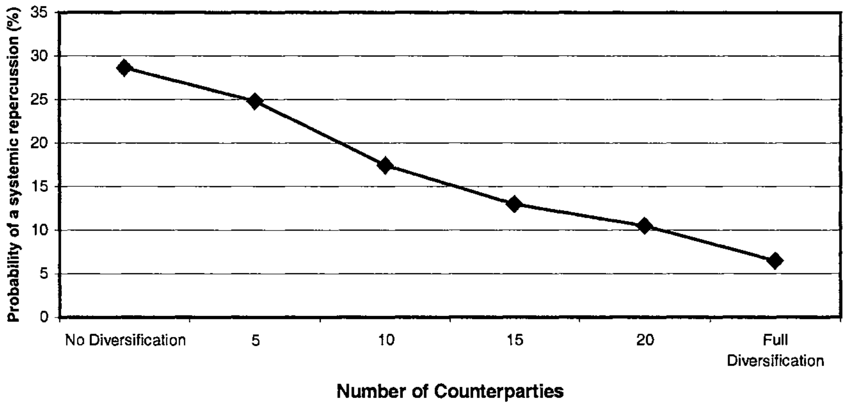

Figure 32: Systemic Risk Vs Counterparty Diversification in an environment of high probability of counterparty default

Systemic Risk and Tenor Diversification

The effect of tenor diversification can be analyzed by calculating the probability of a systemic repercussion assuming that all the swaps have the same tenor versus swaps having different tenors. The probability of a systemic repercussion was calculated by restricting all the swaps in the portfolio to one particular tenor, i.e. all the swaps in the portfolio had a tenor of either one year, 2 years, 5 years or 10 years. Figure 33 shows the result of this analysis. We see that the probability of a systemic repercussion increases for swap portfolios with longer tenors. The systemic risk is zero if all the swaps have a tenor of 1 year but increases rapidly as the tenor increases. The longer the tenor of the swap the greater the chance that default occurs and hence, greater the probability of a systemic repercussion. We can compare these values with the base case value (0.72%) which was calculated by generating a portfolio of swaps with random tenors between 1 and 10 years with equal probability. We see that a swap portfolio containing swaps all with a tenor of 10 years has a much larger probability of a systemic repercussion than a diversified portfolio containing both short term and long term swaps. This result underlines the importance of having a diversified portfolio consisting of swaps with several different tenors and indicates that the Federal Reserve should consider placing a restriction on how diversified a swap portfolio should be in terms of tenor. This could be done by placing a restriction on the average tenor of the portfolio of a swap dealer not to exceed a maximum value.

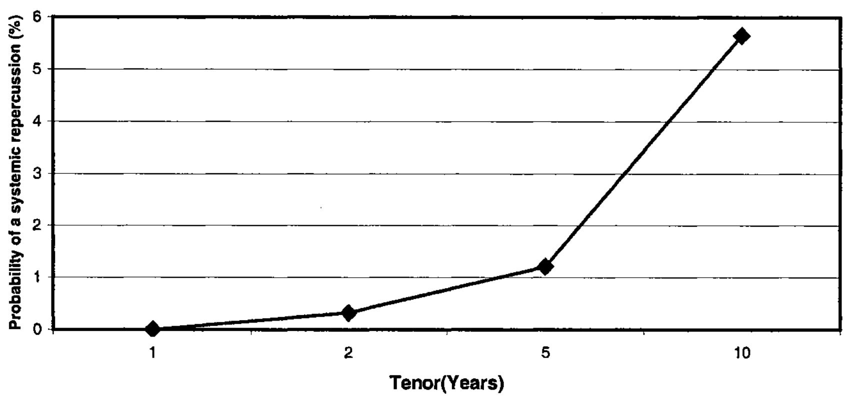

Figure 33: Systemic Risk and Tenor Diversification

Tenor diversification in an Environment of Greater Term Structure Uncertainty

This analysis examines how the probability of a systemic repercussion responds to tenor diversification in an environment characterized by a greater degree of term structure uncertainty. In order to create an environment of high term structure uncertainty we set the interest rate volatility, interest rate jump size and interest rate jump rate at their maximum values used in the sensitivity analysis previously. Thus the volatility of interest rates, the jump size and the jump rate were set at 1.05%, 0.0194 and 0.08454 respectively. Figure 34 shows the result of this analysis. From Figure 34 we see that the probability of a systemic repercussion is very high when the swap portfolio is restricted to swaps with a tenor of 10 years. This analysis shows that the probability of a systemic repercussion is more sensitive to tenor diversification when the environment is characterized by a greater degree of term structure uncertainty. This result strengthens our recommendation that the Federal Reserve consider placing a restriction on how diversified a swap portfolio should be in terms of tenor by placing a restriction on the maximum value that the average tenor of the portfolio of a swap could take.

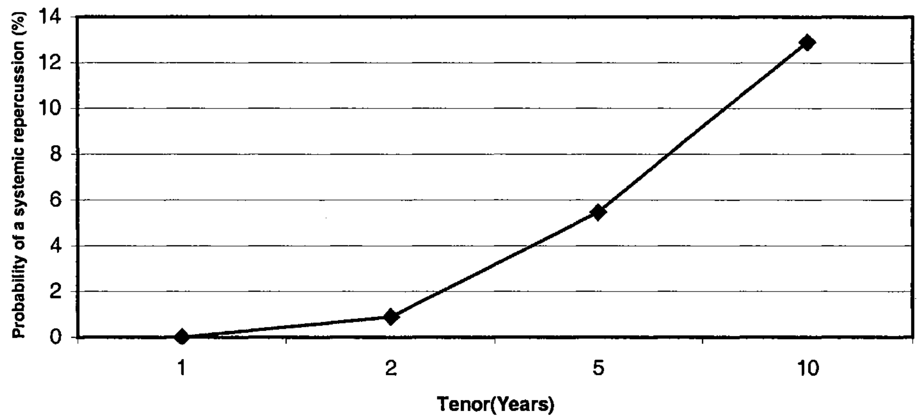

Figure 34: Systemic Risk and Tenor Diversification in an environemnt of greater term structure uncertainty

CHAPTER 8

SUMMARY AND CONCLUSIONS

The meteoric growth in the swap market in the recent past combined with the failure of several swap dealers have raised the issue of systemic risk in the swap market. There has been considerable discussion among regulators and policy makers on the issue of systemic risk in OTC derivatives markets but, there has been no serious attempt to model systemic risk by academicians nor practitioners to date. This study develops a model of systemic risk in the interest rate swap market using the stylized facts observed in this market. The model consists of four components: the term structure model, the firm value model, the swap dealer capital model and the recovery rate model. The model was simulated using the Monte Carlo simulation methodology, to evaluate the probability of a systemic repercussion in the interest rate swap market. Regulatory policy issues were addressed within the context of the model and recommendations were made for mitigating systemic risk in the interest rate swap market.

The simulation was conducted by setting the parameters of the systemic risk model to a base case value. A sensitivity analysis was then conducted on the various parameters of the model. The results of the base case simulation indicate that the probability of a systemic repercussion in the interest rate swap market is very small. The probability of a systemic repercussion over the ten year time frame of the simulation was 0.72%. This result was in line with two other previous studies Wall, Tallman and Abken(1996) and Schneck(1996).

The results of the sensitivity analysis indicate that the probability of a systemic repercussion is highly sensitive to the default threshold. The recovery rate and the volatility of interest rates have a significant effect on the probability of a systemic repercussion but not to the extent of the default threshold. The results also indicate that the interest rate jump size has a larger effect on the probability of a systemic repercussion than the interest rate jump arrival rate.

The regulatory policy issues were examined by addressing the factors that regulators have control over and can impose regulations on. Three factors were identified that regulators could impose regulations on and that could be addressed within the context of our model. The three factors were calculation of potential credit exposure, capital requirement and the diversification of the swap portfolio weights. This analysis led to the following results and recommendations. The reader should note that these recommendations are made without considering the cost of imposing the regulations.

i. The rule of thumb prescribed by the Federal Reserve for the calculation of potential credit exposure was found to grossly understate the potential credit exposure of interest rate swaps with a remaining tenor of more than one year. A rule of thumb based on our calculation of the potential credit exposure (given in table 13, chapter 7) was suggested.

ii. The effect of capital requirement on the probability of a systemic repercussion was analyzed. This analysis led to the conclusion that the changes in the probability of a systemic repercussion were very small after the capital requirement was raised to 14%. This result leads to the recommendation that the federal reserve consider raising the capital requirement from the current level of 8% to 14%.

iii. The effect of counterparty diversification on the probability of a systemic repercussion was analyzed. This analysis showed that the probability of a systemic repercussion decreased rapidly with higher counterparty diversification. This result leads to the recommendation that the federal reserve consider placing a restriction on the minimum number of counterparties that a swap dealer can deal with.

iv. The effect of tenor diversification on the probability of a systemic repercussion was analyzed. This analysis showed that swap portfolios with only long-term swaps had a high probability of causing a systemic repercussion. This analysis results in the recommendation that the federal reserve consider placing a restriction on how diversified a swap portfolio should be in terms of tenor, which could be achieved by placing a restriction on the average tenor of a swap dealer's portfolio not to exceed a certain maximum value.

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