

Advanced Financial Risk Management:

**Tools and Techniques for Integrated Credit Risk, Market Risk, Liquidity Risk
and Interest Rate Risk Management**

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Part 5: Portfolio Strategy and Risk Management

Chapter 37:

Liquidity analysis and management: examples from the credit crisis

In Chapter 36, we applied the Jarrow-Merton put option concept as a comprehensive measure of integrated interest rate, market risk, foreign exchange risk and credit risk. We listed 4 key questions and 26 supplementary questions which can be answered as a result of the risk management process that we outlined in the first 36 chapters of this book. We reviewed the observable market data on the cost of the Jarrow-Merton put option for Citigroup at various time horizons. Finally, we showed the multi-period simulation process that allows us to value the Jarrow-Merton put option, giving us an alternative measure of the dollar amount of money that would be necessary to eliminate the risk we face. We also noted in that chapter that the put option concept can be applied to risk management defined as shortfalls in net income, capital ratios or provisions for loan losses.

In this chapter, we apply the same concept to shortfalls in cash—liquidity risk—which is tightly linked with the credit risk of the institution. We take great care to avoid the single greatest mistake in liquidity risk analysis—basing the analysis solely on the cash flow history of a firm that has never had a “near death” experience from liquidity risk. Indeed, our focus in this chapter is primarily on institutions that HAVE had such near death experiences. We start with a review of the five biggest liquidity risk problems in North America during the 2007 to 2010 credit crisis.

Liquidity Risk Case Studies from the Credit Crisis

In the Introduction to this book, we discussed the six biggest fallacies in risk management. As an introduction to five case studies of liquidity short-falls, it is helpful to summarize briefly how each of the risk fallacies contributed to the 2007 to 2010 credit crisis, which in turn caused the liquidity short falls we outline in this section. The fallacies and their contribution to liquidity risk problems are summarized briefly here:

- **If it hasn't happened to me yet, it won't happen to me, even if it's happened to someone else.** Many market participants believed that home prices in the U.S. would never go down, but they did.
- **Silo risk management allows my firm to choose the "best of breed" risk model for our silo.** Risk management was so fragmented at the largest U.S. and European institutions that the pervasive impact of home price falls on a wide range of counter-party risks and security values was not modeled realistically.
- **I don't care what's wrong with the model. Everyone else is using it.** The copula approach to CDO valuation was hopelessly flawed and confined to a largely desk-top review of traded products. A macro-factor driven total balance sheet analysis of credit risk was rarely performed.
- **I don't care what's wrong with the assumptions.** Everyone else is using them. The assumption that home prices and other macro factors had returns that were independent from period to period was dramatically wrong. There is a strong persistence in trends in returns, causing macro factor swings to be much larger than what was modeled.
- **Mathematical models are superior to computer simulations.** Few banks had the systems capability to realistically model the impact of a large number of random macro factors. What analysis was done was dominated by closed form solutions that could only be obtained by making unrealistic assumptions (like the independence assumption above) about the nature of macro factor movements.
- **Big North American and European banks are more sophisticated than other banks around the world and we want to manage risk like they do.** The evidence in this section is proof positive that, sadly, their example is not one that should be followed.
- **Goldman says they do it this way and that must be right.** Michael Lewis' classic *The Big Short: Inside the Doomsday Machine* [2011] thoroughly documents how a few securities dealers were able to whipsaw smaller market participants with contrarian (and more accurate) views for an extended period of time with arbitrary mark to market positions imposed by those dealers. This aggravated the crisis, delayed recognition of its magnitude, and triggered some of the biggest flows of bail-out funds. For a less vivid but equally detailed account, see the Levin Report [2011].

We now turn to five case studies in liquidity risk during the 2007 to 2010 credit crisis.

Case Studies in Liquidity Risk: Largest Funding Shortfalls

Kamakura Corporation has posted 20 cases study in liquidity risk on its web site www.kamakuraco.com. In this section, we review the data used in the Kamakura analysis and then review each of the top five funding short-falls. For a reader interested in all 20 institutions, www.kamakuraco.com contains daily liquidity needs of Bank of America, Countrywide Financial, Merrill Lynch, a consolidation of the latter three firms, Lehman Brothers, Morgan Stanley, Citigroup, Dexia SA, Depfa Bank plc, Barclays, Goldman Sachs, the combined JPMorgan Chase, Washington Mutual, and Bear Stearns, Wachovia, State Street, BNY Mellon, HSH Nordbank AG, Societe Generale, and HBOS/Bank of Scotland.

Under the Dodd-Frank Act of 2010, the Board of Governors of the Federal Reserve was required to disclose the identities and relevant amounts for borrowers under various credit facilities during the 2007-2010 financial crisis. These credit facilities provide perhaps the best source of data about liquidity risk and funding shortfalls of the last century. We use this data to determine to what extent there was a funding shortfall at the largest institutions active in U.S. financial markets during the credit crisis.

The data used in the study consist of every transaction reported by the Federal Reserve as constituting a “primary, secondary, or other extension of credit” by the Fed. Included in this definition are normal borrowings from the Fed, the primary dealer credit facility, and the asset backed commercial paper program. Capital injections under the Troubled Asset Relief Program and purchases of commercial paper under the Commercial Paper Funding Facility are not included in this definition put forth by the Federal Reserve. We analyze borrowings under the Commercial Paper Funding Facility separately.

A summary of the Federal Reserve programs that were put into place and summary statistics are available from the Federal Reserve at this web page:

http://www.federalreserve.gov/newsevents/reform_transaction.htm

This section focuses on one set of disclosures by the Federal Reserve: primary, secondary and other extensions of credit by the Fed. This includes direct, traditional borrowings from the Federal Reserve, the primary dealer credit facilities, and the asset backed commercial paper program described at the link above. These borrowings do not include the equity stakes taken by the U.S. government under the Troubled Asset Relief Program. We separate discuss commercial paper purchased under the Commercial Paper Funding Facility.

Kamakura took the following steps to consolidate the primary, secondary and other extensions of credit:

- From www.twitter.com/zerohedge Kamakura downloaded the daily reports, in PDF format, from the Federal Reserve on primary, secondary and other extensions of credit from February 8, 2008 until March 16, 2009, approximately 250 reports in total
- Kamakura converted each report to spreadsheet form
- These spreadsheets were aggregated into a single data base giving the origination date of the borrowing, the name of the borrower, the Federal Reserve District of the borrower, the nature of the borrowing (ABCP, PDCF, or normal), the maturity date of the borrowing, and (in the case of Primary Dealer Credit Facility) the name of the institution holding the collateral.

- Consistency in naming conventions was imposed, i.e. while the Fed listed two firms as “Morgan Stanley” and “M S Co” Kamakura recognized to the maximum extent possible that they are the same institution and used a consistent name
- To the maximum extent possible, the name of the ultimate parent was used in order to best understand the consolidated extension of credit by the Fed to that firm.

For information regarding the Kamakura Credit Crisis Liquidity Risk data base, please contact info@kamakuraco.com.

Kamakura calculated the daily borrowings of a large number of prominent international financial institutions during the period covered by the Federal Reserve data. For each of these selected institutions, Kamakura calculated these statistics:

Maximum Outstanding Borrowing
Average Outstanding Borrowing
First Borrowing Date
Average Borrowing On Non-Zero Borrowing Days
Number of Borrowing Days

Figure 1 ranks these selected institutions by maximum borrowings during the period covered. AIG leads the list with a maximum borrowing of \$208 billion during this period:

Figure 1

Kamakura Corporation
Analysis of Primary, Secondary and Other Borrowings from the Federal Reserve
Ranked by Maximum Borrowing

Rank	Institution	Maximum Outstanding	Average Outstanding	First Borrowing Date	Average Of Non-Zero Borrowing Days	Number of Borrowing Days
1	AIG	208,616,483,142	72,793,773,121	20080916	161,186,211,912	182
2	Consolidated JPMorgan, Bear Stearns and WaMu	101,125,000,000	17,728,196,729	20080306	23,666,720,690	290
3	State Street	77,802,450,046	9,000,920,496	20080220	19,821,699,234	183
4	Morgan Stanley	61,292,078,000	7,223,467,296	20080317	16,172,540,667	180
5	Dexia New York Branch	50,000,000,000	12,875,000,000	20080417	15,534,805,389	334
6	Consolidated BAC, Countrywide, and Merrill Lynch	48,141,416,451	10,091,065,527	20080310	14,120,484,053	288
7	Barclays	47,942,000,000	2,452,411,911	20080317	6,177,012,500	160
8	Depfa Bank PLC New York Branch	47,800,000,000	9,716,203,474	20080930	24,022,269,939	163
9	BNY Mellon	41,588,201,426	2,495,094,570	20080922	5,880,252,114	171
10	Merrill Lynch	39,956,500,000	7,620,802,284	20080310	16,164,122,739	190
11	Wachovia Bank NA	36,000,000,000	5,962,593,052	20080416	23,791,336,634	101
12	Lehman Brothers	28,000,000,000	195,555,571	20080318	5,253,926,333	15
13	Citigroup	24,200,000,000	6,712,770,766	20080318	12,524,289,901	211
14	Goldman Sachs	24,200,000,000	2,155,973,945	20080318	11,584,766,667	75
15	Royal Bank of Scotland Group, including CP*	20,460,500,000	5,531,579,799	20080229	9,604,281,409	364
16	Bank of America	13,000,000,000	1,895,449,347	20080619	4,106,806,919	186
17	Bank of Scotland PLC New York Branch	12,000,000,000	2,363,275,434	20080917	8,140,170,940	117
18	Royal Bank of Scotland PLC New York & RBS Citizens	8,400,000,000	49,284,697	20080229	2,837,390,429	7
19	Societe Generale New York Branch	8,000,000,000	2,584,880,893	20080325	3,960,863,118	263
20	Countrywide Financial	6,295,000,000	574,813,896	20080317	2,271,078,431	102
21	HSB Nordbank AG New York Branch	5,250,000,000	1,662,622,829	20080327	3,004,650,224	223

* Average calculated through October 31, 2009

Readers should be under no illusion that this was just a temporary facility and that these institutions could have survived without government aid. Nothing could be further from the truth, as nicely summarized by the report by the Office of the Special Inspector General of the Troubled Asset Relief

Program entitled “Emergency Capital Injections Provided to Support the Viability of Bank of America, Other Major Banks, and the U.S. Financial System,” October 5, 2009. For each of the top five borrowers in Figure 1, we discuss their borrowings in detail below. Figure 2 ranks the same institutions by the average amount of borrowing on those days during the period when borrowings were outstanding:

Figure 2

Kamakura Corporation
Analysis of Primary, Secondary and Other Borrowings from the Federal Reserve
Ranked by Average of Non-Zero Borrowing Days

Rank	Institution	Maximum Outstanding	Average Outstanding	First Borrowing Date	Average Of Non-Zero Borrowing Days	Number of Borrowing Days
1	AIG	208,616,483,142	72,793,773,121	20080916	161,186,211,912	182
2	Depfa Bank PLC New York Branch	47,800,000,000	9,716,203,474	20080930	24,022,269,939	163
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4	Consolidated JPMorgan, Bear Stearns and WaMu	101,125,000,000	17,728,196,729	20080306	23,666,720,690	290
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11	Goldman Sachs	24,200,000,000	2,155,973,945	20080318	11,584,766,667	75
12	Royal Bank of Scotland Group, including CP*	20,460,500,000	5,531,579,799	20080229	9,604,281,409	364
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15	BNY Mellon	41,588,201,426	2,495,094,570	20080922	5,880,252,114	171
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21	Countrywide Financial	6,295,000,000	574,813,896	20080317	2,271,078,431	102

* Average calculated through October 31, 2009

We now turn to a name by name summary of the top five liquidity crises in North America during the period covered by the Fed data.

Case Studies in Liquidity Risk: AIG

Excellence in risk management and good corporate governance requires that financial institutions analyze their own probability of default. The proposed Basel III liquidity risk ratios are concrete symbols of the regulators’ focus on default risk. Liquidity risk is the symptom that a firm has some other severe disease, be it credit risk, market risk, interest rate risk, fraud or something else. Default becomes inevitable when it becomes apparent that an institution cannot liquidate its assets with sufficient speed or volume to meet cash needs from liabilities that have been withdrawn (in the case of deposits) or which will not be rolled over (commercial paper, bank lines, bonds, cancelled insurance policies and so on). For an institution which hasn’t failed, data from institutions that have failed or which have had “near death experiences” usually provide more insights on liquidity risk than the institution’s own history of liability amounts and costs. This section features the funding short-falls at AIG during the credit crisis for exactly that reason.

The primary, secondary, or other extensions of credit by the Federal Reserve to AIG during the period February 8, 2008 to March 16, 2009 can be summarized as follows:

Borrowing dates: Continuous from September 16, 2008

Average from

2/8/2008 to 3/16/2009	\$72.8 billion
Average when Drawn	\$161.2 billion
Maximum Drawn	\$208.6 billion

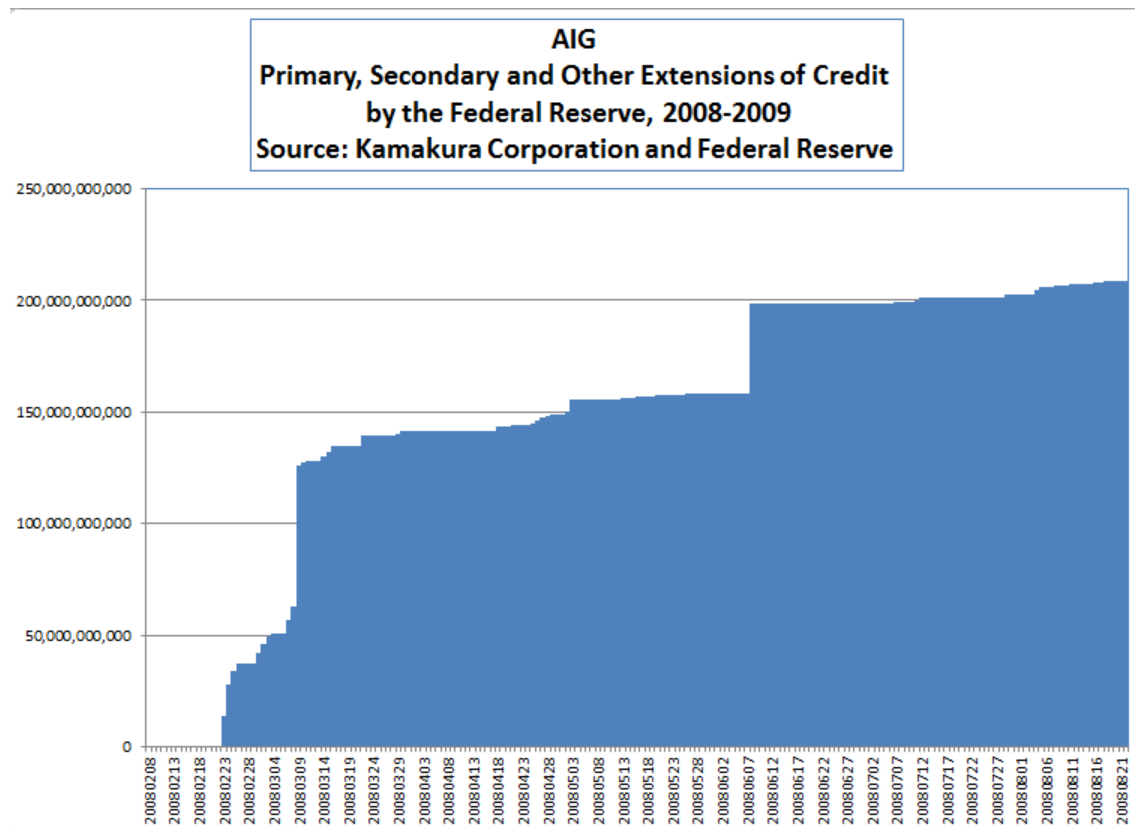
Kamakura Risk Information Services version 5.0 Jarrow-Chava default risk models showed a cumulative 5 year default probability for AIG of 65.34% on the date of its first Fed borrowing, September 16, 2008:

Figure 3



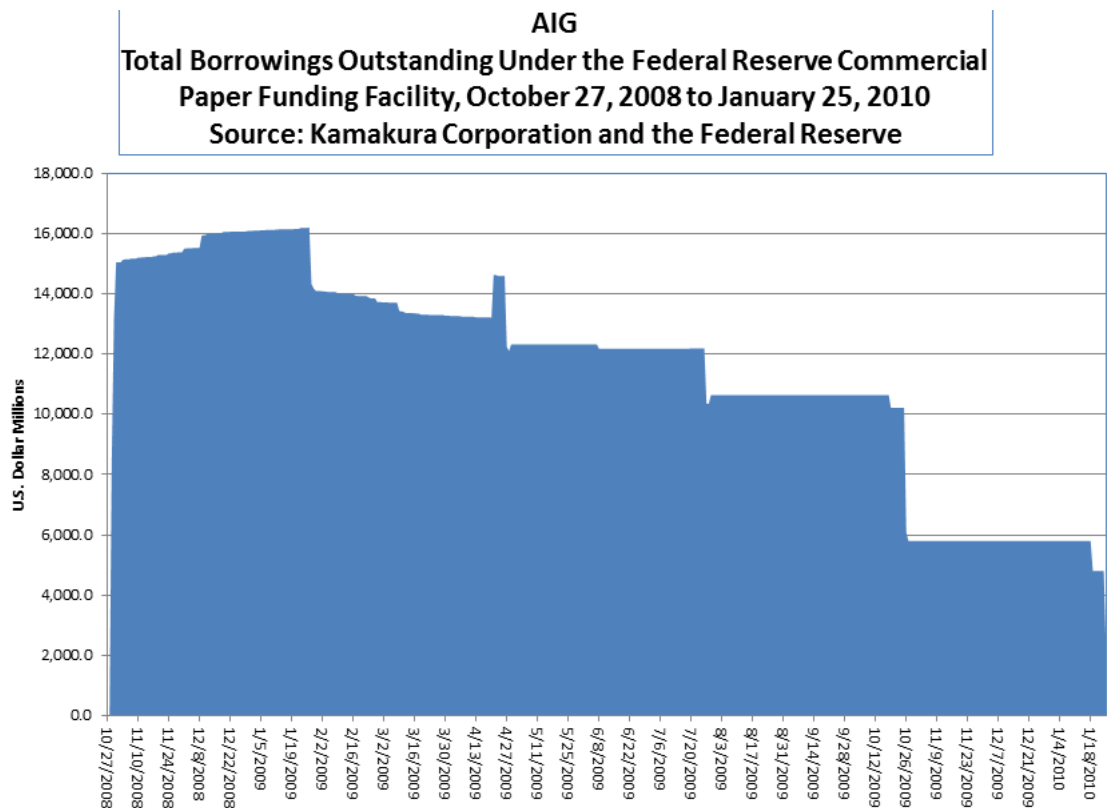
The pattern of total outstanding borrowings from the Federal Reserve shows a steady increase from the first borrowing date on September 16, 2008:

Figure 4



In addition to these borrowings (“primary, secondary or other extensions of credit” from the Federal Reserve, AIG-related entities were substantial beneficiaries of support from the Commercial Paper Funding Facility run by the Federal Reserve, as shown in Figure 5:

Figure 5



The AIG borrowings in the form of “primary, secondary, and other extensions of credit” were extraordinary in both amount and in duration. The borrowings under the Commercial Paper Funding Facility, while less dramatic, are further confirmation that the liquidity risk and funding shortfall at AIG were very large. Every careful risk manager whose institution participates in the credit markets and securitized asset markets like AIG should have no illusions about the liquidity risk that can arise when large losses are incurred on the asset side.

Case Studies in Liquidity Risk: Consolidated JPMorgan, Bear Stearns, and Washington Mutual

This section focuses on the U.S. dollar funding shortfall that took place at JPMorgan Chase, Bear Stearns and Washington Mutual during the period from February 8, 2008 to March 16, 2009. Today’s blog confirms a result that will be surprising to many: in combination with Bear Stearns and Washington Mutual, JPMorgan Chase was the most significant borrower from the Federal Reserve after AIG. JPMorgan’s peak borrowings, on a consolidated basis, were \$101.1 billion, nearly four times the \$28 billion that the Federal Reserve was willing to lend to Lehman Brothers only after Lehman declared bankruptcy on September 14, 2008.

The key dates in the chronology relevant to JPMorgan and the two firms it acquired are summarized below. We call your attention to the references to deposit run off at Washington Mutual, which total \$27 billion. Wamu’s borrowings from the Federal Reserve were only \$2 billion for 8 days, so deposit run-offs were met largely via Federal Home Loan Bank borrowings and asset sales. The Levin report referred to below is the report entitled “Wall Street and the Financial Crisis: Anatomy of a Financial Collapse,” Majority and Minority Staff Report, Permanent Committee on Investigations (Senator Carl Levin, Chairman), U.S. Senate, April 13, 2011.

September 2, 2004	Washington Mutual chief risk officer Jim Vanasek sends internal Washington Mutual memo stating “At this point in the mortgage cycle with prices having increased far beyond the rate of increase in personal incomes, there clearly comes a time when prices must slow down or perhaps even decline.” (Source: Levin report, page 66)
August, 2006	Internal Washington Mutual presentation on Option ARM credit risk reported that from 1999 to 2006 Option ARM borrowers selected the minimum payment more than 95% of the time. (Source: Levin report, page 59)
December 22, 2006	FDIC dedicated examiner at Washington Mutual Steve Funaro raises questions of senior management about unexpected increases in “early payment defaults” and demands from Wall Street firms doing securitizations to repurchase the loans. (Source: Levin report, page 82)
December 31, 2006	Washington Mutual’s high risk loans begin incurring record rates of delinquency and default (Source: Levin report, page 48).
January 31, 2007	Wamu chief risk officer Ron Cathcart identifies 5 top priority risk issues “in light of the slowdown and decline in home prices in some areas.” (Source: Levin report, page 82).
January 31, 2007	The OTS found that, as of January 31, 2007, Washington Mutual had \$62 billion in outstanding Option ARMS in its investment portfolio, of which 80% were negatively amortizing. (Source: Levin report, page 220).
February 18, 2007	Wamu chief risk officer for mortgage lending notes in a memo “There is a meltdown in the subprime market” and that “many submarkets within California actually have declining home prices...” (Source: Levin report, page 128).
February 28, 2007	David Beck, Wamu head of Wall Street securitizations, writes that securitizing second lien loans is “not a viable exit strategy” and that a Wamu May 2006 securitization had already experienced 7% foreclosures. (Source: Levin report, page 83).
June 7, 2007	Bear Stearns suspends redemption rights for hedge fund heavily invested in subprime debt market after losing 19% of value in April alone (Source: www.businessweek.com)
June 17, 2007	Two Bear Stearns subprime hedge funds collapse (Source: Levin report, page 47)
June, 2007	Washington Mutual shuts down Long Beach Mortgage Corporation as a separate entity (Source: Levin report, page 55).

August 1, 2007	Bear Stearns' two troubled funds file for bankruptcy protection and the company freezes assets in a third fund. (Source: www.investopedia.com)
September 30, 2007	Washington Mutual halts subprime lending completely. (Source: Levin report, page 55).
December 20, 2007	Bear Stearns reports its first quarterly loss in 84 years, \$854 million, after write downs of \$1.9 billion on mortgage holdings (Source: www.ft.com)
December 31, 2007	At the end of 2007, 84% of the total value of Washington Mutual Option ARMS were negatively amortizing, meaning that the borrowers were going deeper into debt rather than paying off their balances. (Source: Levin report, page 59)
January 16, 2008	JPMorgan Chase says it has cut the value of its investments in the US subprime market by \$1.3 billion (Source: http://news.bbc.co.uk)
March 13, 2008	Bear Stearns reports a \$15 billion loss in cash and cash equivalents in two days. Liquid assets also dropped \$2 billion mainly as a result of the loss of investor confidence (Source: Wall Street Journal).
March 14, 2008	Federal Reserve and JPMorgan Chase agree to provide emergency funding for Bear Stearns. Under the agreement, JPMorgan would borrow from the Federal Reserve discount window and funnel the borrowings to Bear Stearns (Source: Forbes and www.datacenterknowledge.com).
March 16, 2008	JPMorgan Chase agrees to pay \$2 per share for Bear Stearns on Sunday, March 16, a 93% discount to the closing price on Friday March 14. JPMorgan agreed to guarantee the trading liabilities of Bear Stearns, effective immediately (Source: New York Times).
March 16, 2008	Federal Reserve agrees to provide up to \$30 billion of financing to support Bear Stearns' "less liquid" assets (Source: New York Times).
March 24, 2008	JPMorgan Chase raises bid for Bear Stearns from \$2 per share to \$10 per share. JPMorgan also agreed to bear the first \$1 billion of losses on Bear Stearns assets, with the Federal Reserve bearing the next \$29 billion of losses. (Source: The Times of London).
March 24, 2008	Federal Reserve Bank of New York forms Maiden Lane I to help JPMorgan Chase acquire Bear Stearns (Source: Levin report, page 47).
April 8, 2008	Washington Mutual, the largest savings and loan association, receives a \$7 billion capital injection (Source: Reuters).

May 29, 2008	Bear Stearns shareholders approve sale and the acquisition by JPMorgan Chase is completed (Source: Levin report, page 47).
July 26, 2008	Washington Mutual borrows \$10 billion from the Federal Reserve's discount window, the Federal Home Loan Banking system, and open market operations to bolster on hand liquidity (Source: Financial Times).
July 31, 2008	Depositors withdraw \$10 billion from Washington Mutual in wake of IndyMac failure (Source: Levin report, page 57).
August 12, 2008	JPMorgan Chase reports \$1.5 billion in write downs in July, and bankers state July was the worst month for mortgage-backed securities since the start of the crisis (Source: Financial Times).
September 8, 2008	Washington Mutual ousts CEO Killinger. As a result of the credit crisis, the company's share price fell from \$40 in the summer of 2007 to \$3 in fall 2008 (Source: Financial Times).
September 15-23, 2008	Depositors withdraw \$17 billion from Washington Mutual (Source: Levin report, page 57).
September 25, 2008	Washington Mutual fails, subsidiary bank is seized by the FDIC and sold to JPMorgan Chase for \$1.9 billion. JPMorgan Chase immediately wrote off \$31 billion in losses on the Washington Mutual assets. (Source: The Guardian and Levin report, page 47).
September 26, 2008	JPMorgan issues \$8 billion in common stock in conjunction with Washington Mutual takeover (Source: The Guardian).
September 28, 2008	Washington Mutual Inc., the holding company left after banking operations were seized, files for Chapter 11 bankruptcy (Source: The Seattle Times).
October 28, 2008	U.S. uses TARP to buy \$125 billion in preferred stock at 9 banks (Source: Levin report, page 47). The 9 banks held over \$11 trillion in banking assets or roughly 75% of all assets owned by U.S. banks (Source: SIGTARP report, page 1).

We now report on "primary, secondary, or other extensions of credit" by the Federal Reserve to JPMorgan Chase, Bear Stearns, and Washington Mutual during the period February 8, 2008 to March 16, 2009. The three firms' consolidated borrowings from the Federal Reserve can be summarized as follows:

Borrowing dates:	\$175 million on March 3, 2008.
Average from	
2/8/2008 to 3/16/2009	\$17.7 billion

Average when Drawn \$23.7 billion

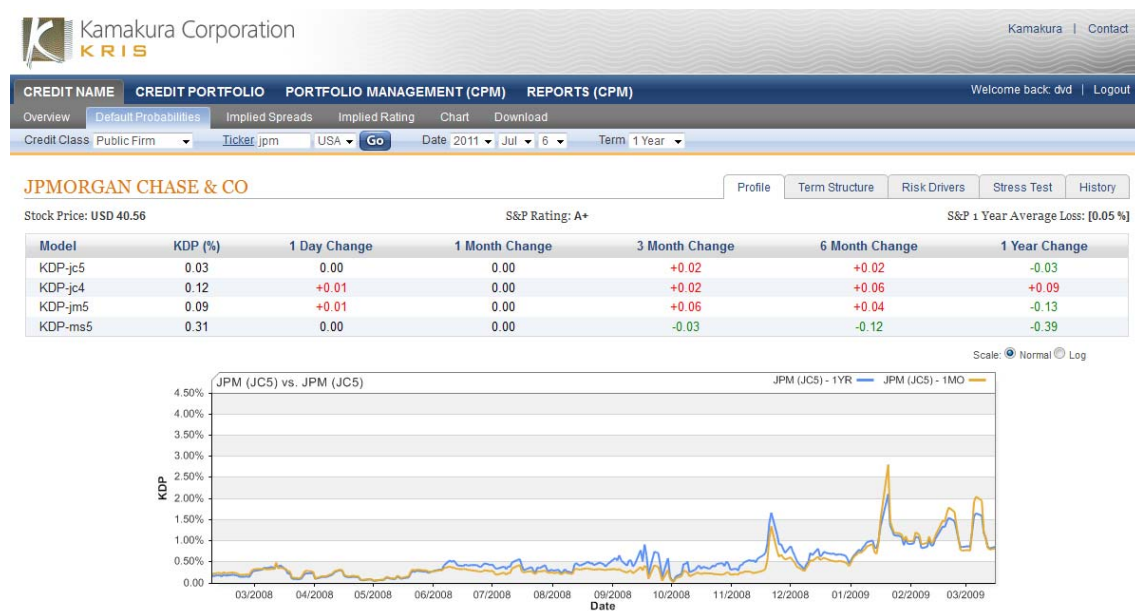
Maximum Drawn \$101.1 billion on April 3, 2008

Number of Days with

Outstanding Borrowings 290 days

Figure 6 below shows the one month and one year default probabilities for JPMorgan Chase from Kamakura Risk Information Services version 5.0 Jarrow-Chava reduced form credit model. Default probabilities began rising in an erratic pattern two months after the bankruptcy of Lehman Brothers on September 15, 2008 with the rise continuing through March 16, 2009, the last data point provided by the Federal Reserve:

Figure 6



JPMorgan's first borrowing from the Federal Reserve was \$175 million on March 3, 2008, probably a "practice run" in anticipation of the Sunday March 16 announcement that JPMorgan Chase would absorb Bear Stearns in a Fed-supported rescue. The graph below shows the dual peaks in the consolidated borrowings in the names of JPMorgan Chase, Bear Stearns and Washington Mutual. The first peak borrowing for the combined firms from the Fed was \$101.1 billion on April 3, 2008, two weeks after the rescue of Bear Stearns. The second peak was \$67.5 billion on October 15, 2008, one month after the failure of Lehman and three weeks after Washington Mutual was absorbed. Part of the means of the pay down following this second peak was a \$25 billion capital injection in late October 2008 under the Capital Purchase Program of the Troubled Asset Relief Program, according to the October 5, 2009 report of the Special Inspector General of the Troubled Asset Relief Program.

There were no borrowings from the commercial paper funding facility by JPMorgan Chase, Bear Stearns, or Washington Mutual.

JPMorgan Chase borrowed nearly four times more money, \$101.1 billion on April 3, 2008, than the \$28 billion withheld from Lehman Brothers until after Lehman declared bankruptcy. Six months later, JPMorgan borrowed a second peak of \$67.5 billion on October 15, 2008, more than double what was refused to Lehman. Both before and after Lehman, JPMorgan suffered larger funding shortfalls than Lehman. Clearly, JPMorgan was too big to fail and Lehman was not.

Case Studies in Liquidity Risk: State Street

This section focuses on the U.S. dollar funding shortfall that took place at State Street during the period from February 8, 2008 to March 16, 2009. The analysis shows that much of State Street's funding needs came from an unexpected source: losses in the firm's investment management business, which normally would be borne by the investors in the funds managed by State Street. We reach a conclusion that we have reached often in this liquidity risk series: State Street borrowed nearly three times more money from the Federal Reserve than Lehman Brothers was refused until after its bankruptcy was announced September 14, 2008.

The key dates in the credit crisis chronology relevant to State Street are summarized below.

November 1, 2007	State Street facing three lawsuits over bond fund losses (Source: USAToday)
January 3, 2008	State Street ousts head of State Street Global Advisors after losses (Source: Bloomberg).
January 4, 2008	State Street announces settlement of \$618 million on lawsuit tied to losses in pension funds managed by State Street due to declines in prices on mortgage-backed securities (Source: New York Times).
April 10, 2008	State Street hires new chief risk officer after derivatives index losses (Source: Seeking Alpha).
October 15, 2008	State Street may set aside as much as \$450 million in losses from propping up fixed income funds (Source: Bloomberg).
December 4, 2008	State Street announces plans to lay off 1800 staff (Source: Finextra.com)
January 20, 2009	State Street stock plunges 59% when firm announces fourth quarter earnings and unrealized fixed income losses of \$6.3 billion. State Street also revealed it had spent \$3 billion more to prop up stable value funds. (Source: Bloomberg).
January 21, 2009	State Street downgraded by Standard & Poor's to A+ from AA- (Source: Standard & Poor's).

State Street's borrowings from the Federal Reserve can be summarized as follows:

Borrowing dates:	First borrowing February 20, 2008 for \$605,000,000, with intermittent borrowings thereafter, followed by a \$3.3 billion borrowing on
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September 22, 2008. Borrowings were continually outstanding thereafter until the end of the Fed data series on March 16, 2009.

Average from

2/8/2008 to 3/16/2009 \$9.0 billion

Average when Drawn \$19.8 billion

Maximum Drawn \$77.8 billion on October 1, 2008

Number of Days with

Outstanding Borrowings 183 days

Figure 8 below shows the one month and one year default probabilities for the State Street from Kamakura Risk Information Services version 5.0 Jarrow-Chava reduced form credit model. Default probabilities began rising sharply after the January 20, 2009 earnings announcement that revealed \$9 billion of previously undisclosed losses:

Figure 8

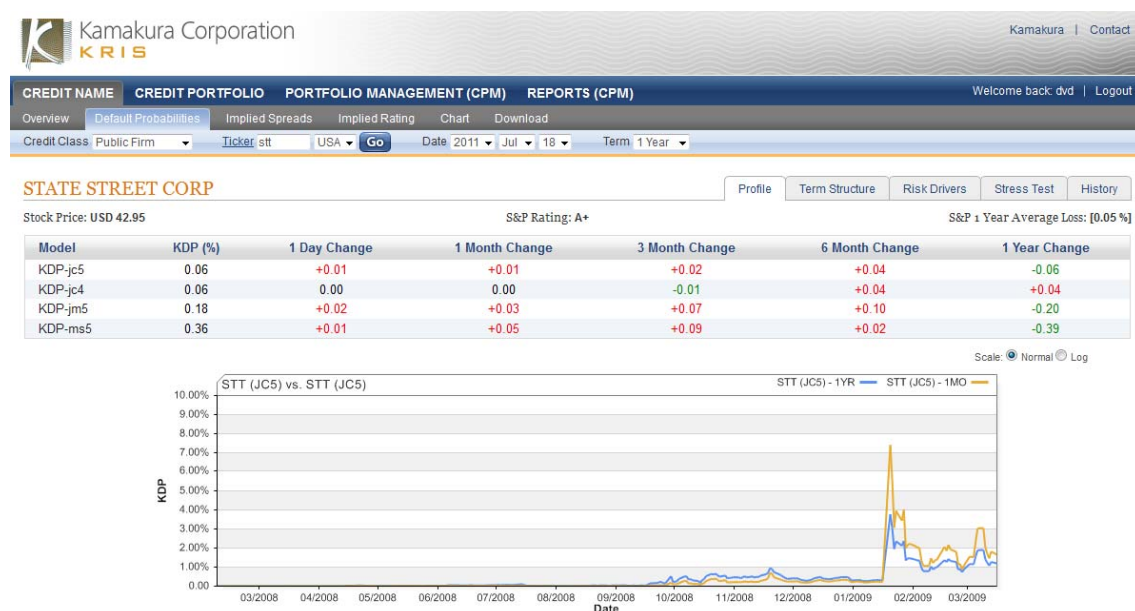
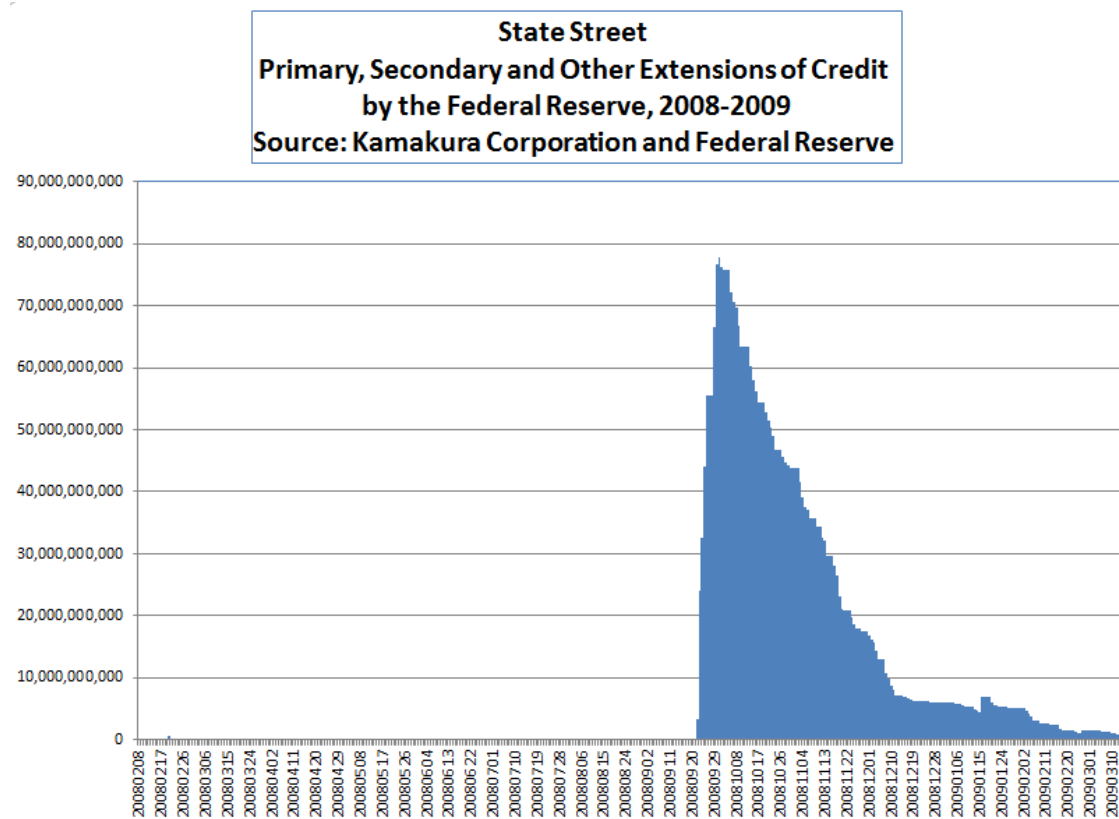


Figure 9 below shows the dramatic spike in borrowings that began on September 22, 2008 and peaked at \$77.8 billion on October 1, 2008. State Street received \$2 billion in capital under the Capital Purchase Program of the Troubled Asset Relief Program on October 28, 2008 according to the SIGTARP Report. Most important, State Street's dramatic need for funds in the wake of the failures of Lehman, Washington Mutual, Wachovia, FNMA, and FHLMC should be remembered by every serious analyst of liquidity risk at large financial institutions.

Figure 9



The Federal Reserve’s disclosure of borrowings under the Commercial Paper Funding Facility list 16 transactions in which State Street Bank & Trust is listed as “parent/sponsor at time of purchase.”

Kamakura Corporation								
Extensions of Credit by the Federal Reserve Under the Commercial Paper Funding Facility								
Trade and Settlement Date	Maturity Date	Commercial Paper Type	Amount (USD Millions)	Discount Rate (Percent)	Credit Enhancement Surcharge (Percent)	Total Discount Rate (Percent)	Issue Name	Parent/Sponsor at Time of Purchase
12/22/2008	3/23/2009	ABCP	1,500.1	3.20	0.00	3.20	GALLEON CAPITAL LLC	State Street Bank & Trust
12/23/2008	3/23/2009	ABCP	500.1	3.21	0.00	3.21	KEEL CAPITAL INC	State Street Bank & Trust
12/24/2008	3/24/2009	ABCP	1,884.5	3.22	0.00	3.22	GALLEON CAPITAL LLC	State Street Bank & Trust
12/24/2008	3/24/2009	ABCP	487.1	3.22	0.00	3.22	KEEL CAPITAL INC	State Street Bank & Trust
12/30/2008	3/30/2009	ABCP	744.0	3.18	0.00	3.18	CLIPPER RECVBLES CO LLC	State Street Bank & Trust
12/31/2008	3/31/2009	ABCP	181.5	3.18	0.00	3.18	CLIPPER RECVBLES CO LLC	State Street Bank & Trust
12/31/2008	3/31/2009	ABCP	313.5	3.18	0.00	3.18	GALLEON CAPITAL LLC	State Street Bank & Trust
12/31/2008	3/31/2009	ABCP	42.4	3.18	0.00	3.18	KEEL CAPITAL INC	State Street Bank & Trust
1/23/2009	4/23/2009	ABCP	496.0	3.23	0.00	3.23	CLIPPER RECVBLES CO LLC	State Street Bank & Trust
1/29/2009	4/29/2009	ABCP	496.0	3.22	0.00	3.22	CLIPPER RECVBLES CO LLC	State Street Bank & Trust
1/30/2009	4/30/2009	ABCP	991.9	3.23	0.00	3.23	CLIPPER RECVBLES CO LLC	State Street Bank & Trust
3/23/2009	6/22/2009	ABCP	263.4	3.23	0.00	3.23	GALLEON CAPITAL LLC	State Street Bank & Trust
3/23/2009	6/22/2009	ABCP	513.0	3.23	0.00	3.23	KEEL CAPITAL INC	State Street Bank & Trust
3/24/2009	6/22/2009	ABCP	503.4	3.23	0.00	3.23	KEEL CAPITAL INC	State Street Bank & Trust
3/31/2009	6/29/2009	ABCP	4,755.6	3.23	0.00	3.23	GALLEON CAPITAL LLC	State Street Bank & Trust
3/31/2009	6/29/2009	ABCP	461.2	3.23	0.00	3.23	KEEL CAPITAL INC	State Street Bank & Trust

We find once again, after reviewing State Street’s borrowings from the Federal Reserve, that State Street borrowed \$50 billion more, a maximum of \$77.8 billion, than the \$28 billion which was refused to Lehman Brothers until that firm declared bankruptcy. This is further confirmation that the definition of “too big to fail” was dramatically revised immediately after Lehman’s demise, since State Street’s peak

borrowing was on October 1, 2008, only 17 days after Lehman's September 14 bankruptcy announcement.

Case Studies in Liquidity Risk: Morgan Stanley

This section focuses on the funding shortfall that took place at Morgan Stanley during the period from February 8, 2008 to March 16, 2009. While the bankruptcy of Lehman Brothers and the rescue of Merrill Lynch by Bank of America are emphasized by many analysts of the credit crisis, the analysis below confirms that Morgan Stanley too was in severe financial distress. The analysis confirms that Lehman borrowed less than half as much from the Federal Reserve after its bankruptcy than Morgan Stanley did when it was at the point of highest distress.

The key dates in the credit crisis chronology relevant to Morgan Stanley are summarized below.

October 3, 2007	Morgan Stanley cuts 600 jobs (Source: www.foxnews.com)
October 17, 2007	Morgan Stanley cuts another 300 bankers in credit trading, structured products, and leveraged lending areas (Source: www.marketwatch.com)
November 7, 2007	Morgan Stanley reports \$3.7 billion in subprime losses (source: Bloomberg)
December 19, 2007	Morgan Stanley announces \$9.4 billion in write-downs from subprime losses and a capital injection of \$5 billion from a Chinese sovereign wealth fund. (Source: www.ft.com)
September 21, 2008	Goldman Sachs and Morgan Stanley convert to bank holding companies (Source: Levin report, page 47).
October 13, 2008	Morgan Stanley issued to Mitsubishi UFJ Financial Group 7,839,209 shares of Series B Non-Cumulative Non-Voting Perpetual Convertible Preferred Stock for an aggregate purchase price of \$7.8 billion plus \$1.2 billion in non-convertible preferred stock. (Source: October 16, 2008 and October 10, 2009 investor presentation by Morgan Stanley CFO Colm Kelleher)
October 28, 2008	U.S. uses TARP to buy \$125 billion in preferred stock at 9 banks (Source: Levin report, page 47).

Morgan Stanley's borrowings from the Federal Reserve can be summarized as follows:

Borrowing dates:	First borrowing \$2 billion on March 17, 2008, with borrowings continuously outstanding from September 15, 2008 to February 12, 2009.
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Average from

2/8/2008 to 3/16/2009	\$7.2 billion
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Average when Drawn	\$16.2 billion
Maximum Drawn	\$61.3 billion on September 29, 2008
Number of Days with	
Outstanding Borrowings	180

Figure 10 below shows the Morgan Stanley 1 month (yellow line) and 1 year default probabilities (blue line) for the Jarrow-Chava version 5.0 default probability models from Kamakura Risk Information Services. Note that the default probabilities for Morgan Stanley continued to rise in November and December, after the September 14, 2008 bankruptcy filing by Lehman Brothers. Ultimately the 1 month default probability for Morgan Stanley peaked at over 14%.

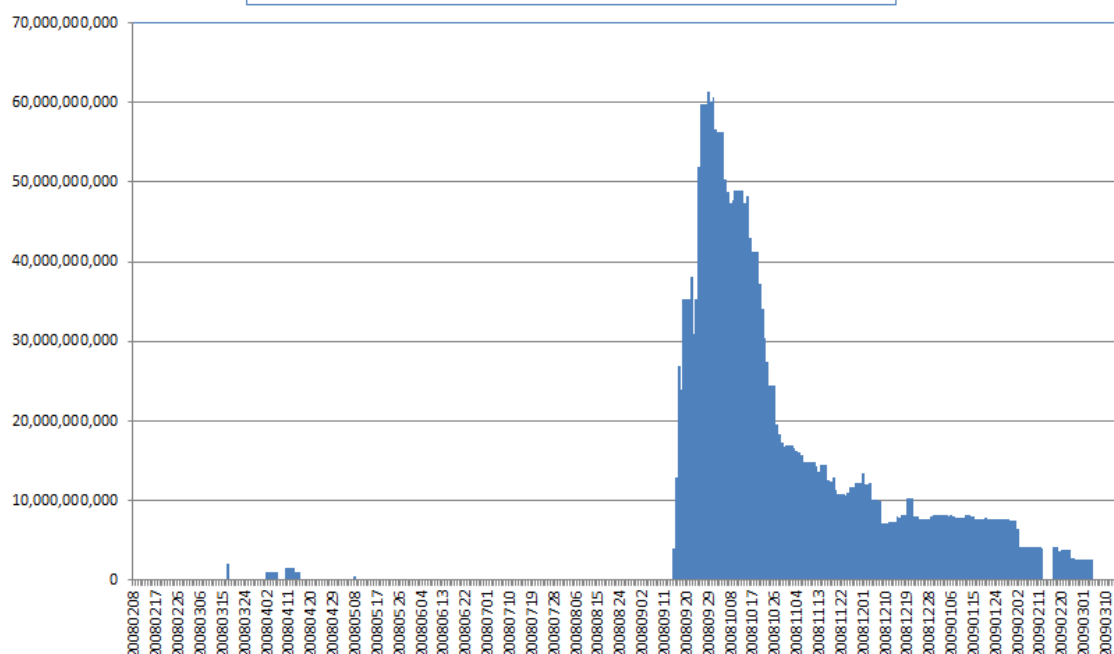
Figure 10



Morgan Stanley's first borrowing from the Federal Reserve was \$2.0 billion on March 17, 2008, which was one day earlier than Lehman's first borrowing and \$400 million more than Lehman borrowed on March 18. Lehman's peak borrowing prior to filing for bankruptcy was \$2.73 billion on March 24, 2008, but Morgan Stanley's peak borrowing was \$61.3 billion on September 29, 2008. The Federal Reserve reported that Lehman had outstanding borrowings from the Federal Reserve on only 10 days prior to its bankruptcy filing on September 14, 2008, but Morgan Stanley had borrowings outstanding for 180 days. Figure 11 below shows the dramatic spike in Morgan Stanley's borrowings from the Federal Reserve.

Figure 11

Morgan Stanley
Primary, Secondary and Other Extensions of Credit
by the Federal Reserve, 2008-2009
Source: Kamakura Corporation and Federal Reserve



After funding needs peaked at \$61.3 billion on September 29, 2008, Morgan Stanley received a capital injection of \$10 billion under the Capital Purchase Program on October 28, 2008 (Source: Office of the Special Inspector General for the Troubled Asset Relief Program, “Emergency Capital Injections Provided to Support the Viability of Bank of America, Other Major Banks, and the U.S. Financial System,” October 5, 2009, page 20-22.) Morgan Stanley began borrowing under the Commercial Paper Funding Facility in late October, as shown below. Finally, as noted in the time line above, Morgan Stanley issued \$7.8 billion in convertible preferred stock and \$1.2 billion in non-convertible preferred stock to Mitsubishi UFJ Financial Group on October 13, 2008.

Morgan Stanley began borrowing under the Commercial Paper Funding Facility on October 27, 2008 and did a total of 22 transactions which are listed here:

Extensions of Credit by the Federal Reserve Under the Commercial Paper Funding Facility								
Trade and Settlement Date	Maturity Date	Commercial Paper Type	Amount (USD Millions)	Discount Rate (Percent)	Credit Enhancement Surcharge (Percent)	Total Discount Rate (Percent)	Issue Name	Parent/Sponsor at Time of Purchase
10/27/2008	1/26/2009	CP	149.3	2.70	0.00	2.70	MORGAN STANLEY	Morgan Stanley
10/28/2008	1/26/2009	CP	139.3	2.70	0.00	2.70	MORGAN STANLEY	Morgan Stanley
11/4/2008	2/2/2009	CP	249.0	1.60	0.00	1.60	MORGAN STANLEY	Morgan Stanley
11/5/2008	2/3/2009	CP	199.2	1.55	0.00	1.55	MORGAN STANLEY	Morgan Stanley
11/6/2008	2/4/2009	CP	199.2	1.54	0.00	1.54	MORGAN STANLEY	Morgan Stanley
11/7/2008	2/5/2009	CP	199.2	1.54	0.00	1.54	MORGAN STANLEY	Morgan Stanley
11/10/2008	2/9/2009	CP	199.2	1.53	0.00	1.53	MORGAN STANLEY	Morgan Stanley
11/12/2008	2/10/2009	CP	199.3	1.47	0.00	1.47	MORGAN STANLEY	Morgan Stanley
11/13/2008	2/11/2009	CP	199.2	1.52	0.00	1.52	MORGAN STANLEY	Morgan Stanley
11/14/2008	2/12/2009	CP	219.2	1.54	0.00	1.54	MORGAN STANLEY	Morgan Stanley
11/17/2008	2/17/2009	CP	199.2	1.48	0.00	1.48	MORGAN STANLEY	Morgan Stanley
11/18/2008	2/17/2009	CP	199.3	1.48	0.00	1.48	MORGAN STANLEY	Morgan Stanley
11/19/2008	2/17/2009	CP	149.4	1.48	0.00	1.48	MORGAN STANLEY	Morgan Stanley
11/20/2008	2/18/2009	CP	149.5	1.42	0.00	1.42	MORGAN STANLEY	Morgan Stanley
11/21/2008	2/19/2009	CP	124.5	1.49	0.00	1.49	MORGAN STANLEY	Morgan Stanley
11/24/2008	2/23/2009	CP	249.1	1.49	0.00	1.49	MORGAN STANLEY	Morgan Stanley
11/25/2008	2/23/2009	CP	199.3	1.49	0.00	1.49	MORGAN STANLEY	Morgan Stanley
11/26/2008	2/24/2009	CP	199.3	1.42	0.00	1.42	MORGAN STANLEY	Morgan Stanley
11/28/2008	2/26/2009	CP	159.4	1.41	0.00	1.41	MORGAN STANLEY	Morgan Stanley
12/2/2008	3/2/2009	CP	199.3	1.39	0.00	1.39	MORGAN STANLEY	Morgan Stanley
12/3/2008	3/3/2009	CP	179.4	1.37	0.00	1.37	MORGAN STANLEY	Morgan Stanley
12/4/2008	3/4/2009	CP	368.8	1.33	0.00	1.33	MORGAN STANLEY	Morgan Stanley

Morgan Stanley's peak funding shortfall of \$61.3 billion was more than double the \$28 billion funding shortfall at Lehman Brothers on September 15, 2008, the day after Lehman Brothers filed for bankruptcy. It is clear that the U.S. government dramatically revised its decision making on which firms were too big to fail in the aftermath of the Lehman Brothers bankruptcy. If the definition of "too big to fail" that was in place on September 14, 2008 had remained unchanged, it is very likely that Morgan Stanley would have failed as well.

Case Studies in Liquidity Risk: Dexia Credit Local New York Branch

This section concentrates on a major European institution, specifically on the funding shortfall that took place at Dexia SA during the period from February 8, 2008 to March 16, 2009. The analysis confirms that Dexia, through the New York Branch of Dexia Credit Local, was one of the largest borrowers from the Federal Reserve during the credit crisis, a fact that hasn't received as much attention as it should. At its peak, Dexia was borrowing \$50 billion from the Federal Reserve, almost double the funding shortfall at Lehman Brothers on September 15, 2008, the day after its bankruptcy filing. This amount of aid is four times the Dexia "rescue" amount that was announced by the Netherlands, Belgium, and Luxembourg on September 30, 2008.

The key dates in the credit crisis chronology relevant to Dexia are summarized below.

October 31, 2007	Dexia's subsidiary FSA reports \$190 million in third quarter mark-to-market losses (Source: Reuters)
August 6, 2008	Dexia injects USD 300 million in FSA (Source: www.dexia.com)
August 7, 2008	Dexia's FSA Faux Pas (Source: www.forbes.com)
September 18, 2008	Dexia announces Lehman-related losses estimated to be around EUR 350 million (Source: www.dexia.com press release)

September 30, 2008	European governments bail out Dexia in Euro 6.4 billion rescue deal (source: www.Telegraph.co.uk)
October 1, 2008	Dexia chairman and president resign (Source: Associated Press)
November 14, 2008	Dexia sells Financial Security Assurance after Euro 1.5 billion Third Quarter Loss (Source: www.ft.com)
March 9, 2009	Dexia posts 3.3 billion Euro losses for 2008 (Source: www.neurope.de)

Dexia's losses have continued long after the September 30, 2008 bail-out by European governments. On May 27, 2011, it was announced that Dexia would make a \$5.1 billion provision for losses on accelerated asset sales (Source: www.bloomberg.com).

Dexia's borrowings from the Federal Reserve can be summarized as follows:

Borrowing dates: First borrowing \$6 billion on April 17, 2008, with borrowings continuously outstanding through March 16, 2009, even after the September 30, 2008 bail-out by three European governments.

Average from

2/8/2008 to 3/16/2009 \$12.9 billion

Average when Drawn \$15.5 billion

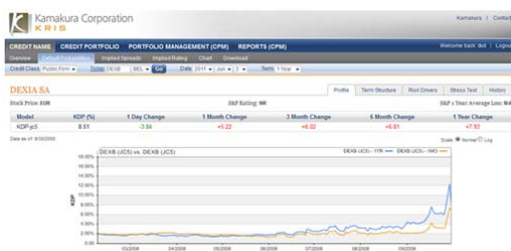
Maximum Drawn \$50.0 billion on March 12, 2009

Number of Days with

Outstanding Borrowings 334

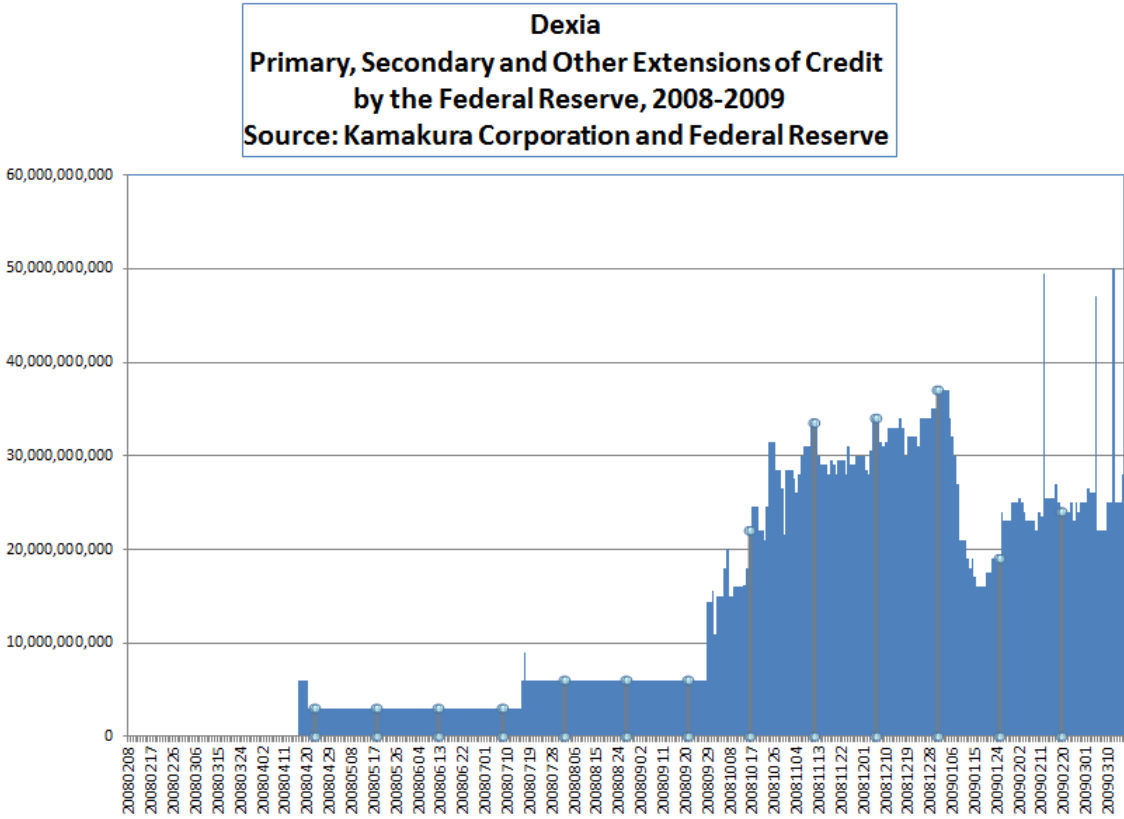
Figure 12 below shows the Dexia 1 month (yellow line) and 1 year default probabilities (blue line) for the Jarrow-Chava version 5.0 default probability models from Kamakura Risk Information Services from February 8, 2008 through the effective nationalization of Dexia on September 30, 2008.

Figure 12



Dexia's first borrowing from the Federal Reserve was \$6 billion on April 17, 2008. Dexia Credit Local New York Branch borrowed from the Federal Reserve for 311 days. The peak borrowing was \$50 billion on March 12, 2009, 5 months and 12 days after Belgium, the Netherlands, and Luxembourg announced their Euro 6.4 billion "rescue" of Dexia SA.

Figure 13



Dexia began borrowing under the Commercial Paper Funding Facility on October 27, 2008 and did a total of 42 transactions which are listed here:

Kamakura Corporation
Extensions of Credit by the Federal Reserve Under the
Commercial Paper Funding Facility

Trade and Settlement Date	Maturity Date	Commercial Paper Type	Amount (USD Millions)	Discount Rate (Percent)	Credit Enhancement Surcharge (Percent)	Total Discount Rate (Percent)	Issue Name	Parent/Sponsor at Time of Purchase
10/27/2008	1/26/2009	CP	2,978.2	1.87	1.00	2.87	DEXIA DELAWARE LLC	Dexia SA
10/29/2008	1/27/2009	CP	2,978.7	1.83	1.00	2.83	DEXIA DELAWARE LLC	Dexia SA
10/30/2008	1/28/2009	CP	2,979.5	1.73	1.00	2.73	DEXIA DELAWARE LLC	Dexia SA
10/31/2008	1/29/2009	CP	1,987.0	1.60	1.00	2.60	DEXIA DELAWARE LLC	Dexia SA
11/4/2008	2/2/2009	CP	993.5	1.60	1.00	2.60	DEXIA DELAWARE LLC	Dexia SA
11/5/2008	2/3/2009	CP	496.8	1.55	1.00	2.55	DEXIA DELAWARE LLC	Dexia SA
11/6/2008	2/4/2009	CP	298.1	1.54	1.00	2.54	DEXIA DELAWARE LLC	Dexia SA
11/7/2008	2/5/2009	CP	794.9	1.54	1.00	2.54	DEXIA DELAWARE LLC	Dexia SA
11/10/2008	2/9/2009	CP	496.8	1.53	1.00	2.53	DEXIA DELAWARE LLC	Dexia SA
11/12/2008	2/10/2009	CP	1,490.7	1.47	1.00	2.47	DEXIA DELAWARE LLC	Dexia SA
11/14/2008	2/12/2009	CP	1,192.4	1.54	1.00	2.54	DEXIA DELAWARE LLC	Dexia SA
11/17/2008	2/17/2009	CP	496.8	1.48	1.00	2.48	DEXIA DELAWARE LLC	Dexia SA
11/18/2008	2/17/2009	CP	745.3	1.48	1.00	2.48	DEXIA DELAWARE LLC	Dexia SA
11/19/2008	2/17/2009	CP	248.5	1.48	1.00	2.48	DEXIA DELAWARE LLC	Dexia SA
11/20/2008	2/18/2009	CP	497.0	1.42	1.00	2.42	DEXIA DELAWARE LLC	Dexia SA
11/24/2008	2/23/2009	CP	795.0	1.49	1.00	2.49	DEXIA DELAWARE LLC	Dexia SA
11/28/2008	2/26/2009	CP	994.0	1.41	1.00	2.41	DEXIA DELAWARE LLC	Dexia SA
12/1/2008	2/27/2009	CP	994.1	1.42	1.00	2.42	DEXIA DELAWARE LLC	Dexia SA
1/27/2009	4/27/2009	CP	2,983.2	1.24	1.00	2.24	DEXIA DELAWARE LLC	Dexia SA
1/28/2009	4/28/2009	CP	2,983.4	1.22	1.00	2.22	DEXIA DELAWARE LLC	Dexia SA
1/29/2009	4/29/2009	CP	1,988.9	1.22	1.00	2.22	DEXIA DELAWARE LLC	Dexia SA
2/2/2009	5/4/2009	CP	994.3	1.26	1.00	2.26	DEXIA DELAWARE LLC	Dexia SA
2/3/2009	5/4/2009	CP	497.2	1.26	1.00	2.26	DEXIA DELAWARE LLC	Dexia SA
2/5/2009	5/6/2009	CP	497.2	1.25	1.00	2.25	DEXIA DELAWARE LLC	Dexia SA
2/9/2009	5/11/2009	CP	497.1	1.27	1.00	2.27	DEXIA DELAWARE LLC	Dexia SA
2/10/2009	5/11/2009	CP	994.3	1.27	1.00	2.27	DEXIA DELAWARE LLC	Dexia SA
2/12/2009	5/13/2009	CP	696.0	1.27	1.00	2.27	DEXIA DELAWARE LLC	Dexia SA
2/17/2009	5/18/2009	CP	1,093.8	1.27	1.00	2.27	DEXIA DELAWARE LLC	Dexia SA
2/18/2009	5/19/2009	CP	497.2	1.27	1.00	2.27	DEXIA DELAWARE LLC	Dexia SA
2/23/2009	5/26/2009	CP	795.4	1.23	1.00	2.23	DEXIA DELAWARE LLC	Dexia SA
2/26/2009	5/27/2009	CP	994.4	1.25	1.00	2.25	DEXIA DELAWARE LLC	Dexia SA
2/27/2009	5/28/2009	CP	994.4	1.25	1.00	2.25	DEXIA DELAWARE LLC	Dexia SA
4/27/2009	7/27/2009	CP	2,981.3	1.20	1.00	2.20	DEXIA DELAWARE LLC	Dexia SA
4/29/2009	7/28/2009	CP	2,983.5	1.20	1.00	2.20	DEXIA DELAWARE LLC	Dexia SA
4/30/2009	7/29/2009	CP	1,989.0	1.20	1.00	2.20	DEXIA DELAWARE LLC	Dexia SA
5/4/2009	7/31/2009	CP	1,491.9	1.21	1.00	2.21	DEXIA DELAWARE LLC	Dexia SA
5/6/2009	8/4/2009	CP	497.2	1.21	1.00	2.21	DEXIA DELAWARE LLC	Dexia SA
5/27/2009	8/25/2009	CP	596.7	1.21	1.00	2.21	DEXIA DELAWARE LLC	Dexia SA
5/28/2009	8/26/2009	CP	994.5	1.21	1.00	2.21	DEXIA DELAWARE LLC	Dexia SA
7/29/2009	10/27/2009	CP	1,989.0	1.20	1.00	2.20	DEXIA DELAWARE LLC	Dexia SA
7/31/2009	10/29/2009	CP	1,491.8	1.20	1.00	2.20	DEXIA DELAWARE LLC	Dexia SA
8/4/2009	11/2/2009	CP	497.3	1.20	1.00	2.20	DEXIA DELAWARE LLC	Dexia SA

Dexia's peak funding need of \$50.0 billion on March 12, 2009 was almost double the \$28 billion funding shortfall at Lehman Brothers on September 15, 2008, the day after Lehman Brothers filed for bankruptcy. Again, it is clear that the U.S. government dramatically revised its decision making on which firms were too big to fail in the aftermath of the Lehman Brothers bankruptcy. What is surprising is the Fed's willingness to provide double the aid that Lehman Brothers required to a non-U.S. institution after a supposed rescue by three European governments. In reality, obviously, the United States was an eager and active participant in the September 30, 2008 rescue of Dexia SA. The internet is silent on the "thank you" to the United States from the shareholders of Dexia SA (who would otherwise have been completely wiped out) and the three European nations whose September 30, 2008 bail-out was only roughly one-fourth of the aid provided by the Federal Reserve at its peak, excluding the other amounts extended through the Commercial Paper Funding Facility.

Implications of the Credit Crisis History for Liquidity Risk Management and Analysis

In the remainder of chapter, we emphasize the fact that the Jarrow-Merton put option concept can be used to measure liquidity risk in dollar terms as well serving as an index of total risk. In effect, we are

going to use our knowledge of all of the financial institution's assets and liabilities to price the cost of an irrevocable line of credit to our institution that would supply any random cash needs from now until the maturity of the line of credit. In doing so, we will take advantage of our previous discussions from Chapter 33 on pricing and valuing revolving credits and exposure at default. We discuss liquidity risk in a step-by-step process, covering these topics:

- Types of liquidity events
- Liquidity risk and credit risk linkages
- Measuring liquidity risk as a 'line of credit' in the Jarrow-Merton put option sense
- Integrating managerial behavior and market funds supply in liquidity risk measurement

Types of Liquidity Events

In spite of the examples above, it often seems to have a lot in common with the story about the group of blind men each touching a different part of the elephant, each of them believing the elephant to be a different type of animal from the others' perceptions. In order to clearly reveal the true nature of the elephant, we want to clarify the types of liquidity conditions that can come about.

Liquidity risk crises tend to revolve around a combination of borrower credit quality (risky or safe) and market conditions (troubled or normal). Besides the 2007 to 2010 credit crisis events above, there are many examples of liquidity crises. The Asia crisis in 1997 resulted in liquidity crises from Malaysia to Korea as a combination of very difficult market conditions in the foreign exchange and money markets with a sharp rise in the credit risk of financial institutions. This increase in credit risk was in large part directly attributable to the sharp changes in macro factors that drive default risk: foreign exchange rates and interest rates. This kind of incident fits precisely in the analytical framework that we have been using throughout this book because we have successfully linked credit risk to macroeconomic conditions. This is the central theme of the reduced form modeling techniques outlined in Chapter 16. Another related incident was the 1998 Long Term Capital Management incident, where one troubled institution's holdings were so large that its need to sell off its portfolio rapidly depressed a wide array of security prices and raised the credit risk of a broad range of corporations and financial institutions.

The second type of crisis is a combination of normal market conditions and credit quality problems of a single or small number of institutions. One example is the 1992 forced acquisition of Security Pacific Corporation by Bank of America in 1992. In this case, sharp increases in credit losses in real estate at Security Pacific National Bank led regulators to cut off dividend payments to the parent company, Security Pacific Corporation. Investors were no longer willing to buy commercial paper of Security Pacific Corporation because its default risk had risen too high.

Another example of troubled institutions in what were otherwise fairly normal markets was the savings and loan crisis of the 1980s and early 1990s in the U.S. A rise in interest rates caused a sharp decline in the market value of fixed-rate home mortgages on the books of the savings and loan associations. The market value of their assets fell well below the principal amount of consumer deposits on their books. In anticipation of their failure, consumers began withdrawing their deposits in spite of the U.S. government guarantee of consumer deposits. Even if the savings and loan associations had been able to sell their mortgage holdings, they would not have had sufficient assets to meet deposit obligations. The institutions were taken over by Federal regulators and liquidated.

A final example is that of Barings in 1995, where a rogue trader in Singapore generated more than \$1 billion in losses from unauthorized futures trading. The end result, due to the impaired credit quality of Barings and the liquidity problems that it generated, was the forced sale of Barings to the ING Group.

A third category of liquidity problems is a 'systemic market crisis' that isn't directly related to a troubled financial institution. Besides the 2007 to 2011 credit crisis, perhaps the best illustration was the impact of the September 11 2001 attack on the U.S, which caused a serious disruption in operational cash flows in the U.S. financial system. While insurance-related losses from September 11 2001 did have a concrete impact on the credit quality of many financial institutions, most institutions did not suffer an impact on their credit quality. Nonetheless, they did have a cash shortfall. Other examples are disruptions caused by power failures (for example, New York and Toronto power failure of 2003), fires (First Interstate Bancorp headquarters, in 1988), and other natural disasters.

The latter kind of crisis produces a very acute need for cash in the short-term, but the need comes from an institution that has fundamentally sound credit quality in the long-term. This is a very important distinction that we explore in the next section.

Liquidity Risk and Credit Risk Linkages

As we saw in the previous section and in the five examples from the 2007 to 2010 crises, most liquidity crises occur when the financial institution itself is troubled. An important related issue is in how much company the financial institution has in its troubles—it can be alone in its difficulties (Security Pacific, 1992) or it can have lots of company (Korea, 1997-1998, 2007 to 2010 credit crisis). For that reason, we need to be more precise about the impact of a decline in credit quality of a financial institution on the willingness of other firms to lend it money. Is the decline in credit quality due to a movement in macro factors that affect many firms, or is it a Barings-type idiosyncratic risk that has gone wrong?

In either case, the market reaction to one or many firms in trouble is simple: the market reduces its extension of credit to troubled firms and a lender of last resort (like the Federal Reserve in the five examples above) either steps in or stands aside to let the firms fail (as in the savings and loan crisis in the United States in the late 1980s and early 1990s).

Measuring Liquidity Risk as a 'Line of Credit' in the Jarrow-Merton Put Option Sense

How do institutions 'buy time' when they have a credit quality problem that they hope will be rectified in time? That is the essence of liquidity risk management discipline. The root cause of the problem is a credit quality problem that affects both the financial institution itself (in the case of a company-specific problem in normal market conditions like Security Pacific in 1992) and perhaps many other peer group institutions as well (such as the 2007 to 2010 credit crisis, Mexico in 1995 or Korea in 1997). If the credit problems are driven by the credit cycle, as we discussed in Chapter 16, it is logical to think that if management can assure itself three to five years to fix the problem, they are likely to be successful. If the liquidity posture of the bank is so focused on short-term financing, the financial institution may face a cash flow need that they can't meet and fail before the credit problem can be solved. This would have happened en masse in the credit crisis of 2007 to 2010 if the Federal Reserve had not lent to troubled firms so aggressively.

The best way to assure one has years, not days, to deal with a company-specific or market-wide credit crisis is to secure protection against unforeseen funding needs with (at least in concept) an irrevocable line of credit. What is the coherent measure of the cost of liquidity risk protection for, say, 10 years?

Again, the answer is the Jarrow-Merton put option in the context of Chapters 19 (risky corporate credit risk assessment), 20 (credit default swaps) and 33 (lines of credit) where we priced a revolving line of credit to a corporate borrower. In this case, we want the price of a 10-year irrevocable line of credit for an appropriate amount of borrowings with a 10-year life and a funds provider who is not in the same market as the borrower. We remind readers of the cash needs from retail deposits who fled Washington Mutual and Wachovia, triggering their failure, in the 2007 to 2010 credit crisis. We specifically included cash needs from this source in our example of non-maturity deposit analysis in Chapter 30. We know this about an irrevocable line of credit with a 10 year maturity:

- It solves the liquidity crisis for 10 years and buys up to 10 years of time to solve the credit risk, market risk, foreign exchange risk and/or interest rate risk problem permanently.
- If the general risk level of the financial institution is low and the funding profile of the financial institution is very long term, this line of credit will be very cheap and it is confirmation that the liquidity risk of the institution is low. In an extreme case of a financial institution where all liabilities are longer than 10 years in maturity and there are no random cash needs, the price of this line of credit will be zero, because it will never be drawn down.
- If the general risk level of the financial institution is low and the funding profile of the financial institution is very short term, the line of credit will be moderately expensive.
- If the general risk level of the financial institution is high and the funding profile of the institution is very long (all liabilities longer than 10 years), then again, the line of credit will be fairly cheap because it will not be drawn if cash needs are not random.
- If the general risk level of the financial institution is high and the funding profile of the institution is very short, then the line of credit will be very expensive because the liquidity risk of the institution is very high.
- If the general risk level of the institution gets high enough, no lender will provide quotations for the line of credit because of the same phenomenon we studied above—the supply of credit of all types falls as risk rises.

Integrating Managerial Behavior and Market Funds Supply

in Liquidity Risk Measurement

How can we price the cost of a 10-year irrevocable line of credit for our own institution if we are not going to get actual market quotes to measure the degree of liquidity risk that we face? We can use exactly the same valuation and simulation techniques that we discussed in Chapter 36, but with a few important differences that revolve around building in a logical market and managerial responses to the changing interest rate risk and credit risk of the institution.

As the default probability of our financial institution rises, consumers will begin to withdraw consumer deposits. We need to specify the formula by which this will happen, exactly as we did in the non-maturity deposit Chapter 30.

As the default probability of the financial institution rises, our access to commercial paper and bond markets will decrease or even dry up completely. We need to specify how access decreases in response to the default probability. As the default probability of the institution rises, management will begin to sell assets to meet cash needs. As these sales increase in amount and urgency, the ‘transactions cost’ of each sale will get larger and larger as the percent of value of the assets sold. If the urgency and volume of sales grows too high, there will be “no bid” in the market as was seen for much of 2007 and 2008 in the recent credit crisis in the market for CDOs and mortgage-backed securities.

We value the 10-year irrevocable line of credit as a measure of liquidity risk using a process exactly like

that used in Chapter 36, but we factor in a rational market and managerial response to a change in our institution's default probability:

1. Specify how our access to the commercial paper market varies with our default probability as discussed in this chapter.
2. Specify how our access to the bond market varies with our default probability as discussed in this chapter.
3. Specify how consumers will withdraw consumer deposits as our default probability rises.
4. Specify the order in which assets will be sold to meet cash needs and the transactions cost of selling those assets as a function of the asset class and the speed with which we have to sell it.
5. Simulate the risk-free term structure for N scenarios over M time steps.
6. Choose a formula and the risk-drivers for the liquidity component of credit spread for all of the relevant asset classes we own as discussed in Chapter 17.
7. Choose a formula and the risk-drivers for the default intensity process in the Jarrow model as discussed in Chapter 17 for all asset classes that we own.
8. Simulate the random values of the drivers of liquidity premium and the default intensity for all of our counterparties for M time periods over N scenarios, consistent with the risk-free term structure.
9. Calculate the default intensity and the liquidity component at each of the M time steps and N scenarios for each counterparty, from retail to small business to corporate to sovereign. Note that these will be changing randomly over time because interest rates and other factors are each of them. This is essential to capturing cyclicalities in bond prices and defaults.
10. Apply the Jarrow model as we have done in Chapters 16 and 17 to get the zero-coupon bond prices for each maturity for each transaction for each counterparty.
11. Calculate the market value of portfolio equity for our financial institution in scenario J and time period K .
12. Calculate the probability of default for our own financial institution in scenario J and time period K (we can short cut this by using the logistic regression approach in Chapter 16 or we can be more fancy).
13. Calculate the amount of consumer deposits that we will have in scenario J and time period K based on this default probability. Do the same for commercial paper and our bond issuance capability.
14. Calculate the net needs for funds based on Steps 12 and 13.
15. Subtract from this need for funds liquid assets we can sell with no transactions costs, based on the amount of those liquid assets still remaining in time period K of scenario J .
16. The remaining funding need is X .
17. If the remaining availability on our irrevocable line of credit is more than X , we assume we draw down an additional X on the line of credit.
18. We calculate the interest rate owed on the line of credit in time period K and scenario J .
19. We simulate default/no default in period K of scenario J .
20. If we do not default, we proceed to time period $K+1$ in Scenario J .
21. If we do default, the lender on the line of credit receives our adjusted market value of portfolio assets.
22. We do this for all periods and scenarios.
23. We take the present value of these risk-adjusted, risk neutral cash flows by discounting at the risk-free yield appropriate for time period K and scenario J .
24. We calculate the value of the line of credit to the lender and the fee they need to charge us for the line of credit to be fairly priced.

This process is exactly the same process that we followed in Chapter 33 for a revolving line of credit to a corporate borrower with one major exception. Since we are evaluating the cost of a line of credit to our own institution, we have full information on every asset and every liability on the balance sheet. We know how to value each one of them, as we have demonstrated in Chapters 19 to 35. Therefore we can be much more precise in our calculations as the simulation process above outlines.

Determining the Optimal Liquidity Strategy

What is the optimal maturity structure of our institution's liabilities from a liquidity risk perspective? This question is easy to answer since we now have an explicit process for measuring our current liquidity risk—the cost of a 10-year irrevocable line of credit using the Jarrow-Merton put option concept. The optimal liquidity strategy is that which maximizes the risk-neutral value of the firm. This will not necessarily be the liability maturity structure which minimizes the cost of eliminating liquidity risk, i.e. the liability maturity structure which produces the lowest cost for the 10-year irrevocable line of credit.

Summing Up

In Chapter 36, we showed how to use the Jarrow-Merton put option as a comprehensive index of the level of integrated credit risk, market risk, foreign exchange risk, and interest rate risk. This measure of risk is more than that—it tells us the dollar cost of eliminating the risk.

We can do the same thing with liquidity risk by pricing an irrevocable line of credit for any maturity. We used a 10-year maturity since 10 years is likely to get us all of the way through a full interest rate cycle and credit cycle, giving us time to recover from interest rate or credit risk-related losses that would have produced a liquidity crisis if we did not have (hypothetically) the irrevocable line of credit. In practice, the cost of liquidity protection for any user-defined maturity can be calculated using the same process.

Next, we take the discipline and insights of the Jarrow-Merton put option measure of risk to performance measurement in order to improve on the conventional wisdom of the early chapters in this book.