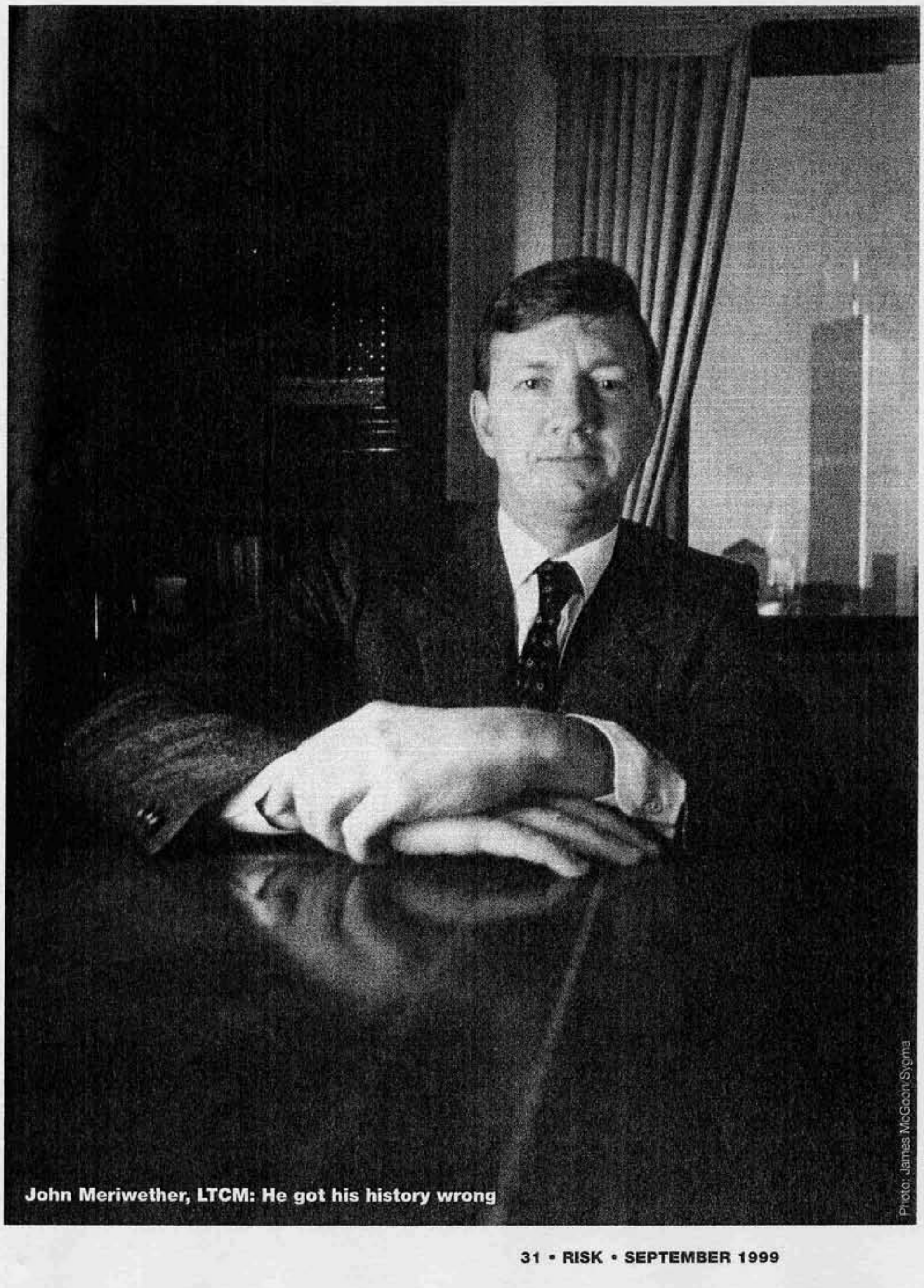
How Long-Term lost its Capital

It was a year ago this month that Wall Street's leading firms were forced to club together and bail out Long-Term Capital Management. Philippe Jorion* has produced the most detailed analysis so far of what went wrong with risk management at LTCM



John Meriwether, LTCM: He got his history wrong

The near-failure of hedge fund Long-Term Capital Management (LTCM) in 1998 is said to have nearly blown up the world's financial system. Indeed, US Federal Reserve chairman Alan Greenspan (1998) testified that "had the failure of LTCM triggered the seizing up of markets, substantial damage could have been inflicted on many market participants, including some not directly involved with the firm, and could have potentially impaired the economies of many nations, including our own".

In short, LTCM's plight was a catastrophic event. Yet the financial community has precious little in the way of information from which to draw lessons about the affair. This is due in no small part to the notorious secrecy of LTCM, which never revealed information about its positions, even to its own investors. But as the rehabilitation of LTCM progresses, the hedge fund is slowly beginning to disclose information about its risk management practices.

Capital loss

There has been much media speculation about LTCM's position – apparently, a wager of $125 billion. This represents the total assets of the fund, most of it borrowed through repurchase agreements. Compared with its equity of about $5 billion, this sum is astonishing. Even more so was the off-balance-sheet position that added up to a notional principal amount of more than $1 trillion. Admittedly, many of these trades were offsetting each other. The net result was that the fund's risk was advertised to be similar to an investment

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in the US stock market, ie, with about 15% annual volatility.

The core strategy of LTCM can be described as "convergence-arbitrage", ie, trying to take advantage of small differences in prices among near-identical bonds, such as duration-matched corporate and Treasury bonds. The position could be even more profitable if the yield spread narrows. The key is that eventually the two bonds must converge to the same value. Most of the time, this will happen – barring default or market disruption.

This strategy worked very well for LTCM in 1995 and 1996, with after-fees returns of more than 40%, as shown in figure 1. The fund placed large bets on the convergence of European interest rates within the European Exchange Rate Mechanism that paid off handsomely. By 1997, most spreads had narrowed substantially, as shown in figure 2.

But this also meant that convergence trades had become less profitable. Indeed, the fund's return was down to 17% in 1997. This performance, unfortunately, was trounced by US stocks, which gained 33%. This was embarrassing, as LTCM touted itself as having the same risk as equities. If it had lower returns, why would anybody invest in the fund? LTCM had to look for other opportunities.

To achieve the 40% returns to which it had become accustomed, the firm had to assume greater leverage. So, LTCM returned $2.7 billion of capital to investors in 1997 while keeping total assets at about $125 billion. By shrinking the capital base to $4.7 billion, the leverage ratio increased to 27 to one, amplifying returns to those investors remaining in the fund.

Unfortunately, this also increased the risks. Troubles began in May and June 1998. A downturn in the mortgage-backed securities market led to a 16% loss in LTCM's capital. Then came August 17. Russia announced that it was "restructuring" its bond payments – *de facto* defaulting on its debt. This bombshell led to a reassessment of credit and sovereign risks across all financial markets. Credit spreads jumped sharply. Stock markets dived. LTCM lost $550 million on August 21 alone on its two main bets, long interest rate swap spreads and short stock market volatility.

By August, the fund had lost 52% of its year-to-date value. With assets still standing around $125 billion, the leverage ratio had increased to 55 to one. LTCM badly needed new capital. In his September 2 letter to investors, John Meriwether, founder and chairman of LTCM, wrote: "Since it is prudent to raise additional capital, the fund is offering you the opportunity to invest on special terms related to LTCM fees." There were no takers.

The portfolio's losses accelerated. On September 21, the fund lost another $500 million, mostly due to increased volatility in equity markets. As losses mounted, counterparties feared that LTCM would soon be unable to meet further margin calls, in which case they would have to liquidate their repo collateral. This would have forced dealers to sell off tens of billions of dollars of securities and to cover their numerous derivatives trades with LTCM.

The potential effect on financial markets was such that the New York Federal Reserve felt compelled to act. On September 23, it organised a bail-out, encouraging 14 banks to invest $3.6 billion in return for a 90% stake in the firm. These fresh funds came just in time to avoid meltdown. By September 28, the fund's equity had dropped to $400 million. Investors had lost 92% of their year-to-date investment.

Too risky

How could LTCM's risk management system fail so dramatically? After all, LTCM claimed to be no riskier than an unleveraged investment in US equities, which is about $45 million daily on total equity of $4.7 billion.

Apparently, LTCM's positions were allocated so as to maximise expected returns subject to the constraint that the fund's perceived risk was no greater than that of the stock market. While there may not have been a formal optimisation process on total return and risk, the end result was the same: LTCM was maximising returns while closely monitoring its volatility.

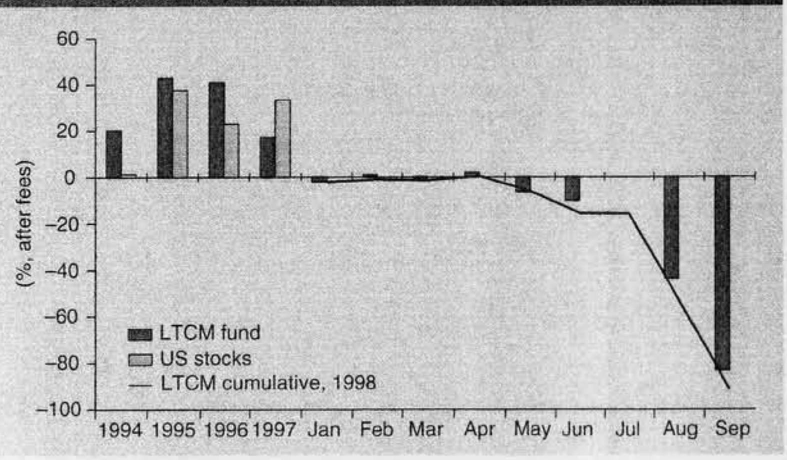
The $45 million target volatility, however, involves heroic assumptions. It assumes that volatility is constant, when in fact it can easily double in turbulent times. One must also accept that the distribution of profit and losses is symmetrical, which is obviously incorrect when dealing with credit risk. Finally, using the same data to optimise a portfolio and calculate its VAR results in biased risk forecasts.

These biases should have shown up in realised returns. Extrapolating the $45 million daily volatility to a monthly 99% VAR yields $339 million, assuming a 21-day month. With an annual 18% project-

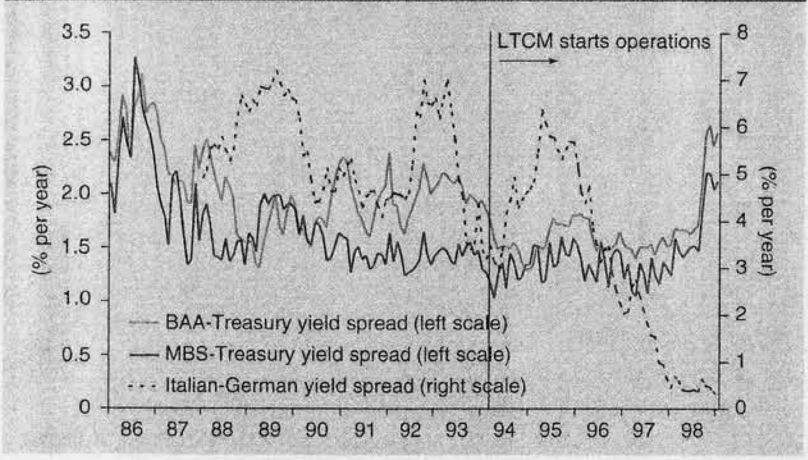
A. Portfolio optimisation with two assets

	Corporate bond	Treasury bond	Risk-free asset
Input data			
Expected return-yield (% pa)	7.28%	5.75%	5.36%
Volatility of return (% pm)	1.58%	1.90%	
Correlation	0.9654		
Output data			
Position (for $1 equity)	$19.66	–$15.60	–$3.06
Optimal portfolio		**Unit**	**Dollars**
Initial equity		$1	$4,700m
Expected return (monthly)		3.1%	$145m
Volatility of return (monthly)		8.1%	$382m
Expected return (annual)		37.0%	$1,740m
Volatility of return (annual)		28.1%	$1,322m
Volatility of return (daily)		1.8%	$83m
Ratio of equity to SD		12.31	

1. LTCM's returns to investors in freefall



2. Government bond yield spreads



ed return, the expected profit was $71 million over a month. Thus, the worst dollar loss at the 99% level over a month should have been ($339 million – $71 million) = $268 million. In May and June, the portfolio lost $320 million and $440 million. So, it must have crashed through its daily VAR limit on a number of occasions.

In response, the firm reportedly tried to reduce its risk profile, but made a major mistake. Instead of selling off less-liquid positions, it eliminated its most liquid investments because they were less profitable. This made LTCM more vulnerable to subsequent margin calls.

After this adjustment, LTCM's models indicated that its daily risk should have been reduced to $35 million. Something was wrong, however. Its actual daily volatility was closer to $100 million. Markets were either getting more volatile or the models were seriously biased. Probably both.

By August 31, the portfolio had lost $1.71 trillion in a month. Using the presumed $45 million daily standard deviation, this translates into an 8.3 monthly standard deviation event. Assuming a normal distribution, such an event would occur once every 800 trillion years, or 40,000 times the age of the universe. Surely the model was wrong.

If instead the true volatility was $100 million, this loss was a 3.7 standard deviation event. Assuming a distribution with fatter tails, such as the Student distribution that allows four degrees of freedom, such an event should occur once every eight years, which is probably not far off the mark.

LTCM underestimated its risk by relying on recent history, assigning a zero probability to events such as the Russian default and major market disruptions such as the 1987 crash, which also led to a flight to liquidity. As credit-sensitive instruments are by nature affected by rare events, this approach missed the true risks of the portfolio. Going back to figure 2, for example, it seems clear that the credit spreads of the 1995–97 period were low by historical standards. Any slowdown in the economy would widen these spreads.

For example...

To illustrate the risks of the strategy, we will now present a stylised example of a portfolio optimisation with two highly correlated assets. We use a government and a corporate bond series and find results that are consistent with LTCM's leverage. This exercise shows how leverage arises from such convergence trades and that risk measures are extremely sensitive to errors in input parameters.

Assume an investor seeks to maximise a utility function that reflects a trade-off between expected portfolio return $\mu_p = w'\mu$ and risk $\sigma^2_p = w'\Sigma w$, where w represents portfolio weights, μ expected excess returns and Σ the covariance matrix:

$$U(w|\mu,\Sigma) = \mu_p - 1/(2t)\sigma^2_p$$

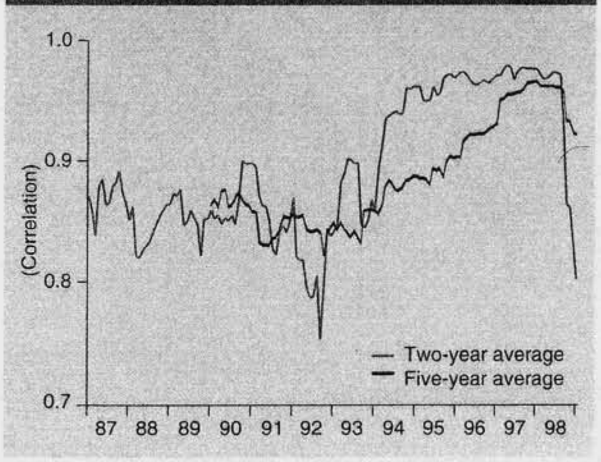
where t is the investor's risk tolerance. We choose $t = 0.25$ so that an investor would be indifferent between investing in cash and in stocks, with an excess return of 8% and volatility of 20%.

The optimal positions in risky assets are given by $w = t\Sigma^{-1}\mu$, with the remainder of the portfolio invested in the risk-free asset.

Table A presents an example of a portfolio optimisation with two risky assets, a BAA-rated corporate bond series and a 10-year Treasury note series. Using historical data from 1993–97, the two bonds have similar volatility and high correlation. Expected returns are simply taken as yields on December 1997. With a credit yield spread of 1.53% and no allowance for default, the optimisation should identify an "arbitrage" strategy.

Indeed, the portfolio takes a very large position in the corporate bond, $19.66 for every $1 of equity, offset by a large short position of $15.60 in the Treasury bond. The sum of the bond positions is $4.06,

3. Correlation between corporate and Treasury yields



which implies a loan of $3.06 at the risk-free rate. The expected return on the portfolio is 3.1% a month, which translates into 37% a year.

This simple exercise captures the essence of arbitrage strategies. The leverage ratio is close to 20 to one and the annual expected return is close to 40%, as LTCM had hoped.

The crux of the problem is the presumed risk of the strategy. For every dollar invested, the monthly volatility is 8.1%. Thus, to be wiped out over one month, the portfolio should suffer a loss of $1/$0.081, which is 12.3 times the standard deviation. Define this ratio as the monthly equity coverage, or "safety factor". As this loss appears unlikely, the amount of equity provides sufficient protection. But is this so unlikely?

There are two problems with this. The first is the combined effect of portfolio optimisation and estimation error. If the correlation happens to be high because of (positive) estimation error, the optimiser will tend to take large opposite positions in the two assets to exploit this illusory safety. The second problem is that the true correlation may change over time. Given that we start with a very high correlation, which is bounded by unity, it is more likely to drop rather than increase further.

B. Probability of ruin for various correlations

Correlation	Standard deviation	Safety factor	Monthly probability of ruin: Normal	Monthly probability of ruin: Student
0.999	2.03%	49.26	0.00000%	0.00005%
0.990	4.55%	21.98	0.00000%	0.00127%
0.970	7.58%	13.19	0.00000%	0.00954%
0.950	9.71%	10.30	0.00000%	0.02507%
0.900	13.65%	7.33	0.00000%	0.09227%
0.800	19.24%	5.20	0.00001%	0.32637%

C. Bias in VAR: ratio of true to estimated VAR

Model Observations (T)	Number of assets (N): 10	20	50	100
50	123%	164%		
100	110%	124%	201%	
200	105%	111%	133%	199%
1,000	101%	102%	105%	111%

Note: the table reports the mean ratio of true VAR to estimated VAR assuming that the trader knows the true covariance matrix and maximises expected return subject to a constraint on VAR. These numbers are independent of the true covariance matrix

Source: adapted from Ju & Pearson (1999)

D. Exposure of LTCM's portfolio to risk factors

Trade	Loss if risk factor increases: Volatility	Illiquidity	Default
Long interest rate swap	Yes	Yes	Yes
Short equity options	Yes		
Long off-the-run/short on-the-run Treasuries	Yes	Yes	
Long mortgage-backed securities (hedged)	Yes	Yes	
Long sovereign debt	Yes	Yes	Yes

This is why we need stress testing, which involves changing the parameters to assess the sensitivity of the results. Table B examines the volatility of the optimised portfolio for changing correlation coefficients. Start with a correlation of p = 0.970. Assuming that the distribution of losses is normal, the probability of monthly ruin is zero. Using a Student distribution, the probability of ruin is 0.0000954%, or one year out of 900. These odds seem low enough.

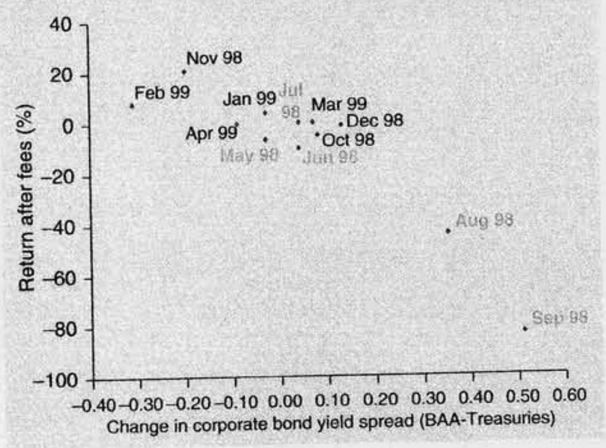
If the correlation decreases to 0.90, the portfolio volatility rises sharply, to 13.65%. For p = 0.8, the volatility increases further to 19.24%, more than twice the original estimate. At this level, the portfolio safety has fallen from 12.31 to 5.20. With a normal distribution, it is again highly unlikely that all of the equity could be wiped out. With a student distribution, however, the odds increase to one month out of 306, or one year out of 26. Now the odds of failure are not so remote.

What actually happened to this correlation is described in figure 3. The red line represents the correlation estimated with a two-year moving average, while the blue line shows a five-year moving average. In 1998, p drops sharply to 0.8, explaining why the convergence strategy suddenly went bad. Was this unexpected? Yes, if one focuses narrowly on recent history, ie, since 1994, when p remained above 0.94. This is myopic, however, as a longer history shows that p was much lower five years earlier.

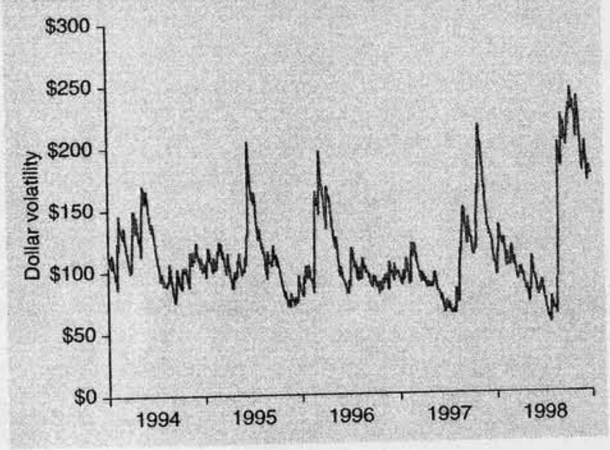
Admittedly, this example is simplistic. Can this be extended to the much larger number of positions assumed by LTCM? Yes, and the problem is probably even worse.

Estimation risk increases with the number of parameters. The more parameters are estimated, the greater the chance that errors will create a misleading picture of risk. This is a well-known problem in portfolio optimisation. One cannot rely on the same covariance matrix (ie, in-sample) to perform the optimisation and to measure risk. The optimiser will overweight assets with high recent average returns, which may simply reflect luck.

4. Explaining LTCM returns



5. Simulated daily volatility of the LTCM fund



A similar problem occurs when traders try to "game" a VAR system. If a risk manager uses a VAR system for risk control or performance evaluation, traders may have an incentive to evade their risk limits. For instance, traders could move into markets or securities that appear to have low risk for the wrong reasons. Currency traders could have taken large positions in pegged currencies, which have low historical volatility but high devaluation risk. Or, traders measured by a delta-normal VAR could enter short straddles with zero delta. Such positions appear profitable, but only at the expense of future possible losses. More generally, a trader may be aware of measurement errors in the covariance matrix used to judge him. If so, he or she may overweight assets that have low estimated risk, knowing that this will result in a downward biased risk measure.

Ju & Pearson (1999) provide estimates of this potential bias.[1] Table C shows the ratio of true VAR to the estimated VAR for various numbers of observations, T, and number of assets, N. For instance, with 100 days and 50 assets, the true VAR is 201%, or twice the estimated VAR. The bias increases as the number of assets increases relative to the number of observations, reflecting increased measurement error in the covariance matrix.

LTCM failed because of its inability to measure, control and manage its risk. This was due in no small part to the fact that LTCM's trades were rather undiversified. LTCM was reported to have lost about \$1.5 billion from interest rate swaps positions, and a similar amount from equity options. Table D describes the exposure of various reported trades to fundamental risk factors. All the trades were exposed to increased market volatility. Most were exposed to liquidity risk (which is also correlated with volatility). Many were exposed to default risk.

To illustrate the driving factor behind LTCM's risks, figure 4 plots the monthly returns against changes in credit spreads. The fit is remarkably good, indicating that a single risk factor would explain 90% of the variation up to the September bail-out. After the bail-out, the slope is markedly lower, reflecting the decrease in the risk profile of the fund directed by the consortium.

We can combine the information on the exposure of the fund with the daily volatility of credit spreads (using JP Morgan's RiskMetrics method) to simulate the fund's volatility. For illustration purposes, we assume that the investment strategy in 1998 is constant throughout the life of the fund.

Figure 5 shows the daily volatility of the fund, which should be compared with the "presumed" value of \$45 million. The figure shows wide variations in the fund's price volatility, which ranges from a low of \$55 million in July 1998 to a high of \$245 million in October 1998. It is interesting to note that, had such a historical analysis been performed, it would have shown several periods prior to 1998 when the volatility was close to \$200 million. Thus the target volatility of \$45 million was unrealistically low. This explains how the required capital cushion had been badly underestimated.

LTCM is a good example of biases in portfolio optimisation. Only a few of the "convergence" trades could truly qualify as arbitrage trades, such as positions in on-the-run and off-the-run bonds. For all other trades, the portfolio was exposed to hidden risks. The typical profile of credit spread trades is to make small profits most of the time, but to take a big loss once in a while. This profile is akin to a short position in an option. To assess the possibility of catastrophic but rare events such as sovereign defaults, market or political disruptions, one cannot focus on recent history only. Similarly, a short position in equity volatility has an asymmetric payout profile. This latent exposure to catastrophic risks explains why this hedge fund failed.

LTCM liked to compare itself to a Wall Street investment bank, such as Salomon Brothers, which was leveraged by the same amount, ie, perhaps 25 times. This comparison is faulty for various reasons. First, bank portfolios are more diversified across risk factors. They deal with fixed-income markets, currencies, equities and commodities. Second, brokers' trading activities benefit from increased volatility, as volatile markets generate greater trading volume and revenues. This provides a natural hedge against increases in volatility and allows brokers to manage their inventory dynamically. Finally, investment banks can have access to fresh funds much faster than any hedge fund.

Mismanagement

By relying on recent history, LTCM appears to have badly misjudged the possibility of a back-up in credit yield spreads. It lulled itself into believing that its VAR was manageable. In fact, it had severely underestimated its risk due to its risk concentration and reliance on short-term history.

The story of LTCM should not be taken as an indictment of VAR. Instead, it serves to illustrate the danger of traders "gaming the system". LTCM's strategy can be interpreted in terms of maximising expected returns subject to a constraint on VAR. This application is fraught with danger: optimising a portfolio risk/return profile and using the resulting VAR to measure risk leads to serious optimisation biases. In addition, LTCM committed large-scale risk management blunders, ignoring warning signs given by VAR. In the end, LTCM failed because it mismanaged its risk modelling.

The saga of LTCM has important lessons for convergence-arbitrage strategies. One view is that the strategy is fundamentally sound and that the events of 1998 were so unusual that they were impossible to forecast. Hence, these events are unlikely to happen again.

Another view is that these strategies are designed to take a big loss once in a while. The fund claimed it was taking "non-directional" bets, ie, bets that were not obviously dependent on the direction of markets. This strategy, however, induced the fund to take undiversified and highly leveraged bets on more subtle risks such as credit risks, political risks or market disruptions. The implication is that such strategies are fundamentally dangerous and much riskier than measured by traditional risk management systems. ■

[1] *Ju, Xiongwei and Neil Pearson, 1999, Using value-at-risk to control risk taking: How wrong can you be?* Journal of Risk 1, *pages 5–36*