# Endogenous Risk*

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## 1  Introduction

Endogenous risk refers to the risk from shocks that are generated and amplified *within* the system. It stands in contrast to exogenous risk, which refers to shocks that arrive from *outside* the system. Financial markets are subject to both types of risk. However, the greatest damage is done from risk of the endogenous kind. This is our central thesis. We will substantiate our claim by reference to three episodes - the stock market crash of 1987, the LTCM crisis of 1998, and the collapse of the dollar against the yen in October 1998.

Our main concern is with financial markets. However, endogenous risk is important in other contexts, and it is illuminating to begin with an example drawn from engineering - that of the wobbly Millennium Bridge over the river

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*First version. comments are welcome. Revised versions of the paper can be obtained from the authors' homepages on `www.nuff.ox.ac.uk/users/shin/working.htm` and `www.riskresearch.org`.

Thames. This was a classic case where neglect of endogenous risk led to a serious and highly publicized blunder in bridge design and construction.

## 2   Millennium Bridge

On June 10th 2000, the Queen opened the Millennium bridge - the first new Thames crossing for over a hundred years, constructed at a cost of 18 million pounds. The 325 metre-long structure used an innovative "lateral suspension" design, built without the tall supporting columns that are more familiar with other suspension bridges. The vision was of a "blade of light" across the river Thames, connecting St. Paul's with the new Tate Modern gallery. Many thousands of people turned up on the opening day - a sunny but slightly windy English summer's day - and crowded on to the bridge. The structure was designed to cope easily with this kind of weight. However, within moments of the bridge's opening, it began to wobble violently. The wobble (or "lateral excitation" in the jargon) was so violent that some pedestrians had to cling on to the side-rails of the bridge, and others suffered from nausea. News videos of the day can be obtained from several websites[1] that show some of the drama. The wobble was so bad that the bridge had to be closed down - and it was to remain closed for over 18 months. What went wrong? How could such a prestigious project suffer from such a highly publicized debacle? The answer is revealing. It goes to the heart of the nature of endogenous risk, and how we should neglect it at our peril.

When engineers used shaking machines to send vibrations through the bridge, they found that horizontal vibrations at 1 hertz (one complete cycle per second) set off the S-shaped wobble seen on the opening day. This was

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[1]See, for example, the realplayer videos of the opening day on the BBC news site on http://news.bbc.co.uk/hi/english/static/in_depth/uk/2000/millennium_bridge/default.stm

Figure 1: Millennium Bridge

an important clue. Normal walking pace is around two strides per second which produces vertical force of around 250 Newtons (55 pounds) at 2 hertz. However, there is also a small sideways force caused by the sway of our body mass due to the fact that our legs are slightly apart.[2] This force (around 25 Newtons or 5.5 pounds) is directed to the left when we are on our left foot, and to the right when we are on our right foot. This force occurs at half the frequency (or at 1 hertz). This was the frequency that was causing the problems. But should this matter? The sideways movement when we walk need not matter if one person's sway to the left is cancelled out by another person's sway to the right. It is only when many people walked in step that the sideways force would be a problem. It is well known that soldiers should break step before they cross a bridge. But for thousands of individuals each walking at random, could this be a problem?

Or to put it another way, what is the probability that a thousand people

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[2]See "Bad Vibrations" *New Scientist*, vol. 167, issue 2246, July 8th 2000, page 14. See also the webpage set up by Arup - the contruction engineers of the bridge on: http://www.arup.com/millenniumbridge/challenge/oscillation.html.

walking at random will end up walking exactly in step? It is tempting to say "close to zero", or "negligible". After all, if each person's step is an independent event, then the probability of everyone walking in step would be the product of many small numbers - giving us a probability close to zero. Presumably, this is the reason why Arup - the bridge engineers - did not take this into account. However, this is exactly where endogenous risk comes in. What we must take into account is the way that people react to their environment. Pedestrians on the bridge react to how the bridge is moving. When the bridge moves under your feet, it is a natural reaction for people to adjust their stance to regain balance. But here is the catch. When the bridge moves, everyone adjusts his or her stance at the same time. This synchronized movement pushes the bridge that the people are standing on, and makes the bridge move even more. This, in turn, makes the people adjust their stance more drastically, and so on. In other words, the wobble of the bridge feeds on itself. When the bridge wobbles, everyone adjusts their stance, which sets off an even worse wobble, which makes the people adjust even more, and so on. So, the wobble will continue and get stronger even though the initial shock (say, a gust of wind) has long passed. It is an example of a force that is generated and amplified *within* the system. It is an *endogenous* response. It is very different from a shock that comes from a storm or an earthquake which are *exogenous* to the system.

So, let us reconsider the question. On a blustery day, what is the probability that a thousand people walking at random on the Millennium bridge will end up walking exactly in step? Far from the probability being close to zero, the probability is close to one! Sooner or later, a gust of wind will set off a movement in the bridge, and when there are enough people of the

bridge, they will end up walking in step for sure.[3]

# 3   Financial Risk Management

What lessons can we draw from the Millennium bridge for the practice of financial risk management? Financial markets are the supreme example of an environment where individuals react to what's happening around them, but where individuals' actions drive the realized outcomes themselves. The feedback loop of actions to outcomes back to actions has a fertile environment in which to develop. Endogenous risk appears whenever there is the conjunction of (i) individuals reacting to their environment and (ii) where the individual actions affect their environment.

The idea that market distress can feed on itself is not new. The idea is quite intuitive, and the theme is familiar among front-line market traders and the financial press. When asset prices fall and traders get closer to their trading limits, they are forced to sell. But this selling pressure sets off further downward pressure on asset prices, which induces a further round of selling, and so on. Here, the downward spiral in asset prices is endogenous. It is a response that is generated *within* the financial system. Just as a gust of wind can set in motion the wobble in the Millennium bridge, an outside shock has the potential to send the market into a tailspin if the conditions are right. The following passage from the *Economist* magazine[4] is typical.

"So-called value-at-risk models (VAR) blend science and art. They

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[3]In the tests that followed the closure of the bridge, Arup found that the wobble was a highly non-linear function of the number of pedestrians. The critical number of people that started the wobble was 156. Up to that number, the movement increased only slightly as more people came on the bridge. However, with ten more people, the wobble increased at a sharply higher rate. See http://www.arup.com/millenniumbridge/challenge/results.html.

[4]The Economist Magazine, Oct 12th 2000.

estimate how much a portfolio could lose in a single bad day. If that amount gets too large, the VAR model signals that the bank should sell. The trouble is that lots of banks have similar investments and similar VAR models. In periods when markets everywhere decline, the models can tell everybody to sell the same things at the same time, making market conditions much worse. In effect, they can, and often do, create a vicious feedback loop."

To their credit, many regulators have recognized the potentially destabilizing effects of market sensitive risk regulation. More thoughtful members of the central banking community have recognized and highlighted the dangers of endogenously generated risk (see, for instance, Crockett (2000)). This concern has also been reflected in practice. In the days following the terrorist attack on New York and Washington on September 11th 2001, financial markets around the world were buffeted by unprecedented turbulence. In response to the short term disruption to the smooth functioning of markets, the authorities responded by suspending various solvency tests applied to large financial institutions such as life insurance firms. In the U.K., for instance, the usual 'resilience test' applied to life insurance companies (in which the firm has to demonstrate solvency in the face of a further 25% market decline) was suspended for several weeks. More recently, following the renewed declined in stocks markets in the summer of 2002, the Financial Services Authority - the U.K. regulator - has diluted the resilience test so as to pre-empt the destabilizing forced sales of stocks by the major market players[5].

Nevertheless, the fact remains that the overall framework for risk regu-

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[5] *Financial Times, Weekend Money,* June 28th 2002, "Insolvency rules are eased for life offices" by Jason Corcoran.

lation relies on a prudential perspective that views each financial institution on its own. The framework tends to neglect the system-wide perspective. Hence, the blindspot in conventional risk management techniques, and especially the supervisory approach to the regulation of risk, is the presumption that risk management is a single-person decision problem - i.e. a *game against nature*. That is, uncertainty governing price movements is assumed to be exogenous, and assumed not to depend on the actions of other decision makers. The analogy is with a meteorologist trying to predict the weather. The weather is unaffected by the predictions issued by weather forecasters and the consequent actions that these forecasts generate. Financial markets are different. When short run price changes are influenced by the trading decisions of market participants (as surely they must), then shifts in the beliefs of market participants will lead to actions that precipitate certain outcomes. There is, in other words, a feedback effect from the beliefs of market participants to the actual outcome in the market. Indeed, there are strong reasons to believe that this feedback effect will reinforce any exogenous pressures on prices arising from the fundamentals.

A gambling analogy is useful. If the underlying uncertainty facing a trader were exogenous, modelling risk is akin to a gambler facing a spin of a roulette wheel, where the bets placed by him and other gamblers do not affect the outcome of the spin. However, when the outcome depends on the actions of other traders, risk modelling resembles poker more than roulette. Current risk management practices rest on the roulette view of uncertainty. The roulette wheel may have an unknown number of outcomes with differing probabilities, but as long as the outcome is unaffected by the actions of other gamblers, it is simply a matter of applying standard statistical techniques to past outcomes to enumerate what these outcomes are, and to estimate their

respective probabilities. Many of the sophisticated techniques in the current state of the art can be seen as alternative ways of refining such estimation procedures, as well as tracking the non–linear payoff structures arising from derivative securities. To the extent that the stochastic process governing asset prices depends on what traders do, this view of the world is invalid. The uncertainty facing traders is endogenous, and depends on the actions of market participants. To neglect this is to commit the same error as the engineers of the Millennium bridge.

In normal market conditions, when trading is orderly and markets function well, there is little harm in treating uncertainty as being exogenous. However, during a crisis, such a naive world view is likely to throw up nasty surprises. Since risk management systems are in place precisely to deal with such exceptional episodes, what happens during tranquil market conditions is largely irrelevant. When short run changes in prices depend on the actions of other traders, the "roulette wheel" view of uncertainty is no longer adequate.

Major disruptions to financial markets almost always arise from the whiplash effect of endogenous risk. Let us flesh out our argument by reference to three episodes which must rank as the most dramatic episodes in financial markets in recent memory - the 1987 crash, the LTCM crisis, and the collapse of dollar/yen in October 1998.

## 3.1 Crash of 1987

The Brady Commission's report (1988) attributed the magnitude and swiftness of the price decline in the 1987 stock market crash to practices such as portfolio insurance and dynamic hedging techniques. Such trading techniques have the property that they dictate selling an asset when its price falls

and buying it when the price rises. In other words, it dictates a "sell cheap, buy dear" strategy. It generates precisely the kind of vicious feedback loop that destabilizes markets. Best estimates then suggested that around $100 billion in funds were following formal portfolio insurance programs, representing around 3 percent of the pre-crash market value. However, this is almost certainly an underestimate of total selling pressure arising from informal hedging techniques such as stop-loss orders (see the survey evidence presented in Shiller (1987)).

To understand why portfolio insurance dictates a "sell cheap, buy dear strategy", it is worth recounting how the payoff from holding a put option on an underlying asset can be approximated by a dynamic trading strategy on the underlying asset. In its simplest form, the strategy relies on the *delta* of the put option. The delta of a put option is the rate of change of its price with respect to the change in the underlying fundamental asset. Thus, if $\Pi$ the price of the put option and $p$ is the price of the underlying asset, the delta $\Delta$ is given by

$$\Delta = \frac{d\Pi}{dp} < 0$$

Black and Scholes (1973) in their celebrated paper on option pricing noted that the portfolio consisting of:

$$\begin{cases} \Delta & \text{underlying asset} \\ -1 & \text{put option} \end{cases}$$

is locally risk-free with respect to changes in $p$. This is because when the price changes slightly, the gain or loss from the holding of the underlying asset (given by $\Delta$) is matched by an exactly offsetting loss or gain from the change in the price of the put option $(-\Delta)$. This insight is used in the derivation of the Black-Scholes formula by arguing that the above portfolio must earn same return as risk free asset.

An analogous argument can be used to show that the payoff from the put option can be replicated by holding a suitable portfolio of the underlying asset and cash. Suppose a trader starts with a cash balance of $\Pi$, which also happens to be the price of the put option that the trader wishes to replicate. With this wealth, the trader can either purchase the put option itself, or purchase the portfolio:

$$\begin{cases} \Delta & \text{underlying asset} \\ -p\Delta + \Pi & \text{cash} \end{cases} \tag{1}$$

Since the trader wishes to replicate a put option, $\Delta$ is negative. This portfolio is financed by selling short $|\Delta|$ units of underlying asset at price $p$, and adding the proceeds to the cash balance.

Now, suppose price changes to $p'$. The value of the portfolio at the new price is

$$\begin{aligned} \overbrace{\Delta p'}^{\text{short asset}} + \overbrace{\Pi - p\Delta}^{\text{cash holding}} &= \Pi + \Delta\,(p' - p) \\ &\simeq \Pi' \end{aligned}$$

where $\Pi'$ is the price of the put option given $p'$. Thus, the trader manages to approximate the wealth of a trader who starts out by holding the put option itself. Since the approximation is linear, the accuracy of the approximation is greater the smaller is the price change. The trader then forms the new portfolio:

$$\simeq \begin{cases} \Delta' & \text{underlying asset} \\ -p'\Delta' + \Pi' & \text{cash} \end{cases} \tag{2}$$

which is affordable given his wealth of $\Pi'$. Proceeding in this way, the trader reaches the date of maturity of the option. If option expires in the money, (2) is

$$\begin{cases} -1 & \text{underlying asset} \\ p + (x - p) & \text{cash} \end{cases}$$

while if the option expires out of the money, (2) is

$$\begin{cases} 0 & \text{underlying asset} \\ 0 & \text{cash} \end{cases}$$

Either way, the final value of the trader's portfolio is

$$\max\{x - p, 0\}$$

which is the payoff to buying and holding one put at beginning.

Traded options exist only for well-established markets, and only for relatively short maturities. For very long-dated options, or for specific assets, dynamic replication is the only avenue open to traders if they wish to hedge an implicit short put position. For instance, a fund manager who has sold long-term retail funds that guarantee the capital, the implicit put must be replicated in some way. If an investment bank has sold the fund manager an over-the-counter put, then the burden of replication is placed on the investment bank that has sold the option.

More directly relevant for our purposes is the practice of portfolio insurance that was quite common until the 1987 stock market crash, and identified in the Brady Commission report as being an important contributory factor in the crash. The dynamic hedging strategy sketched above has the property that it dictates selling of the underlying asset when its price *falls*, and dictates buying the underlying asset when its price *rises*. This is because the delta of a put option becomes more negative as the price of the underlying asset falls. In other words, the dynamic replication entails a "sell cheap, buy dear" strategy.

When the trader is small relative to the market as a whole, or when the active traders in the market hold diverse positions, one would expect little or no feedback of the traders' decisions on the market dynamics itself. However, when a large segment of the market is engaged in such trading strategies, the

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market dynamics may be affected by the trading strategy itself, and hence lead to potentially destabilising price paths. The stock market crash of 1987 is a classic example of endogenous risk, and the potentially destabilising feedback effect on market dynamics of concerted selling pressure arising from mechanical trading rules.

The Brady Commission Report (1988) notes that whereas some portfolio insurers rebalanced several times per day, many others followed the strategy of rebalancing their portfolios once a day - at the open, based on prior day's close. The sparse trading ensured that transaction costs would be low, but this was achieved at the cost of the accuracy of the approximation, especially if the price moved in one direction only over several days. More seriously, the implicit selling pressure arising from the mechanical trading rules of the traders had the potential of influencing the price of the underlying asset itself, thereby introducing further rounds of selling. During the days leading up to the crash of October 19th, the stock market had experienced sharp falls. In the period from Wednesday October 14th to Friday October 16th, the market declined around 10%. The sales dictated by dynamic hedging models amounted to around $12 billion (either in cash or futures), but the actual sales had only been around $4 billion. This meant that by the time of the open on Monday morning, there was a substantial amount of pent-up selling pressure. The imbalance between purchases and sales meant that much of the underlying market for stocks did not function. Instead, traders attempted to use the index futures market to hedge their exposures. The S&P index futures sold at large discounts to the cash market on Monday 19th and Tuesday 20th for this reason.

The important lesson to emerge from the 1987 stock market crash is that the dynamic replication of put options by portfolio rebalancing may not be

possible in times of market distress. When a large segment of the market attempts to follow identical trading strategies, the liquidity of the market is impaired to such an extent that the market ceases to function in the way necessary for the dynamic trading strategy. In situations such as this, the uncertainty governing stock returns is better described as being *endogenous* rather than *exogenous*. The returns are generated partly by the increased selling pressure from the traders.

## 3.2   The LTCM Crisis of 1998

The summer of 1998 was a particularly turbulent episode for the mature financial markets of the United States and Europe. The events are well summarized in two official reports into the events by the BIS and the IMF[6]. The origins and the personalities behind Long Term Capital Management have been well aired through books such as that by Lowenstein (2000). The mainstay of LTCM's trading strategy were convergence or relative value trades in which a long position in one asset would be hedged by having a matching short position in another asset whose returns were highly correlated with the first. The motivation was to reap the rewards of higher returns of the long position, while hedging away the risks by means of the matching short position. Usually, the long position would be in a relatively illiquid or riskier asset whose expected returns were higher than the hedging asset. For instance, a trader would hold a long position in off-the-run treasuries which traded at a higher yield, but then hedge the interest rate risk by holding a short position in on-the-run treasuries. Other examples include mortgage

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[6]The BIS report *A Review of Financial Market Events in Autumn 1998* can be obtained from: www.bis.org/publ/cgfs12.htm. See also chapter III of the IMF's *World Economic Outlook and International Capital Markets: Interim Assessment*, www.imf.org/external/pubs/ft/weo/weo1298/index.htm,
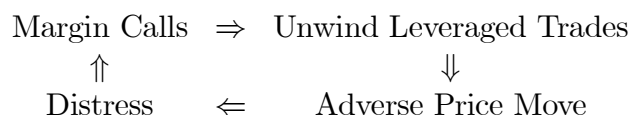
backed securities, swaps, and corporate bonds, all hedged with short positions in on-the-run treasuries. Another favourite trade of LTCM was the European convergence trade of Italian government bonds against German bunds as the launch date of the Euro approached.

For several years, the convergence trades of LTCM produced rich rewards, and spawned many copycat funds. More importantly, LTCM's very success bred many imitators in the proprietary trading desks of the major investment banks. As more and more players with similar trading strategies crowded into the market, the spreads narrowed on the favoured convergence trades, eroding the profit margin for all the players. The relative tranquility of the markets also lulled the players into a false sense of security and spurred them on to increase their leverage, which reduced the spreads further. By the spring of 1998, the convergence funds were having to venture into new and uncharted markets in order to find profitable trades. The scene was set for a reversal of some kind.

The exact date of the reversal is difficult to pinpoint, but the disbanding of the Salomon Brothers bond arbitrage desk on July 6th was a clear milestone[7]. As the convergence trades were unwound, the long positions were sold, and the short positions were bought back. This entailed adverse price shocks for all other traders that started out with similar positions. For some traders whose leverage was high relative to capital, this would entail losses on their positions sufficient to trigger margin calls on their losing positions. They would be forced to unwind their trades, which tended to reinforce the adverse price moves. Given the huge levels of leverage and the widespread nature of the trades, the vicious feedback loop was gradually set in motion in which adverse price moves led to liquidations, which further fed the adverse price

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[7]The added irony being that the main protagonists at LTCM began their careers at Salomons.

moves. Schematically, we would have the following feedback loop where market distress would feed on itself.

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\begin{array}{ccc}
\text{Margin Calls} & \Rightarrow & \text{Unwind Leveraged Trades} \\
\Uparrow & & \Downarrow \\
\text{Distress} & \Leftarrow & \text{Adverse Price Move}
\end{array}
$$

This is a classic example of endogenous risk. The unprecedented price movements were not simply a freak of nature, much like a "perfect storm" that would hit perhaps only once in the lifetime of the Universe. To believe this would be to make the same mistake as the engineers of the Millennium bridge. The probability of a thousand people (walking at random) all ending up walking in perfect step is not close to zero. Given the right conditions, it is a near certainty. Similarly, the unprecendented price moves in the summer of 1998 were not simply the result of extremely bad luck. Given the extensive copycat behaviour of other traders and the large implicit leverage involved, it was only a matter of time before the system would be hit by a small outside shock that would send it into reverse. Once the system began to go into reverse, the internal dynamics of the feedback loop would take hold with a vengeance, and send it into a tailspin. The probability of this collapse is far from zero. Under the right conditions, it is a near certainty. Again, it is the *endogenous* risk that is doing all the harm.

## 3.3  Dollar/yen in October 1998

The same perspective is useful in understanding the behaviour of the dollar agains the yen over two memorable days last October - 7th and 8th - when the dollar fell from 131 yen to 112 yen by lunchtime in London on Thursday the 8th, bouncing back sharply to end New York trading at 119 yen. October 7th

and 8th were two of the most turbulent days of trading in financial markets in recent memory, which also saw sharp falls in longer dated government bonds and the virtual seizing up of markets for corporate debt, and for less liquid government debt instruments.

The fall in the dollar was especially dramatic given its strength throughout the spring and summer of 1998, reaching its high of 147.26 yen on August 11th. Many commentators were predicting that dollar/yen would reach 150 or perhaps 200 by the end of the year, especially in the light of the apparent failure of the joint intervention by the U.S. and Japan on June 17th to support the yen more than temporarily. The conventional wisdom among academics, commentators and traders alike was that the yen was bound to fall, and that it was a matter of the speed and the magnitude of its fall rather than the directon. Indeed, by the summer of 1998, this conventional wisdom had almost acquired the status of an immutable truth. Although such arrogance seems misplaced with the benefit of hindsight, it is easy to see how such a confident view arose. Since the spring of 1995, the dollar had continued to appreciate against the yen (with a brief respite in mid-1997), and the contrasting macroeconomic fortunes of the U.S. and Japan, with strong growth in the former and weakness in the latter - seemed to presage more of the same in the months ahead.

The combination of an appreciating dollar and the large interest rate differential between Japan and the U.S. gave rise to the singularly profitable trading opportunity of borrowing yen, buying dollar assets, and gaining both on the appreciation of the dollar and the interest rate differential. This "yen carry" trade was widespread among hedge funds, the proprietary trading desks of investment banks, and even some corporations. Funds were raised in the interbank market through term repo agreements, or by issuing money

market paper. Then these funds would be swapped for foreign currency or exchanged in the spot market to fund purchases of higher-yielding assets, including U.S. corporate bonds, mortgage-backed securities and also even riskier instruments such as Russian GKOs. Japanese banks also resorted to the yen-carry trade by accumulating foreign assets. In the first three quarters of 1998, the net holdings of assets denominated in foreign currencies increased by about $44 billion, while the holdings of yen-denominated assets abroad declined by $103 billion (IMF (1998, p.127)). Thus, the conventional wisdom concerning the relentness rise in dollar/yen was also apparently shared by the Japanese instutitions.

The initial weakening of the dollar was relatively orderly, falling by less than 10 percent against both the yen and the deutschmark between mid-August and early October. However, in the week beginning October 5th, the decline of the dollar against the yen accelerated sharply - closing down roughly 15 percent over the week. Significantly, the fall in the dollar against the deutschmark was much less pronounced, falling less than 2 percent during the week. It was also noteworthy how this fall in dollar/yen coincided with an unprecendented steepening of the yield curve for mature markets outside Japan, as bond yields bounced back from their historical lows. During the same week, the yield gap between three month rates and 10 year rates widened by 85 basis points in the U. S., 60 basis points in the U. K., and 50 basis points in Germany. The coincidence of (i) the rapid fall in dollar/yen (ii) less precipitous fall in dollar/deutschmark and (iii) rapid steepening of the yield curve in markets outside Japan is consistent with the rapid unwinding (or attempted unwinding) of the yen carry trades in place at the time.

One of the implications of a highly leveraged market going into reversal

is that a *moderate* fall in asset value is highly unlikely. Either the asset does not fall in value at all, or the value falls by a large amount. The logic of the mutually reinforcing effects of selling into a falling market dictates this conclusion. The fall in dollar/yen is also likely to have been exaggerated by stop-loss orders, and by the cancellation of barrier options and the unwinding of associated hedging positions by dealers. One estimate of the volume of outstanding yen foreign currency contracts at the end of June was in excess of \$3.3 trillion (Bank of Japan (1998)). Just as in the stock market crash of 1987, the effect of such trading techniques is to exaggerate price movements, by selling into a falling market. In retrospect, the bi-modal distribution of asset prices referred to above is exactly what one should expect in a market which is marked by such high levels of leverage, undertaken by so many diverse institutions. The unwinding of yen carry trades proceeded at such a pace that press reports referred to market rumours of imminent collapse of one or more hedge funds. The Bank of Japan reported large buying of yen by at least one large hedge fund (Financial Times, October 9th, p.19).

The poignant irony could not have been lost on observers of the Asian financial crisis. Just a year earlier, the hedge funds and assorted proprietary trading desks of investment banks had profited handsomely from the stampede by Asian borrowers with unhedged dollar liabilities to cover their positions in a desperate attempt to keep afloat. In October 1998, these same "sharks" had become their own bait. It was now they, who were scrambling to cover their positions. The logic of mutually reinforcing sales meant that the harder they tried to swim away, the more they provoked the feeding frenzy. The sense of fear was palpable during the turbulent trading of October 8th. With sentiment already fragile after the forced rescue of LTCM, rumours of the immient collapse of a major hedge fund further reinforced the

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disengagement from risk. Yet again, it was endogenous risk that drove the most dramatic market movements.

# 4   Lessons

What lessons should we draw from all this? The first general lesson is that an effective risk manager should be able to make an intelligent distinction between those cases where the standard "roulette wheel" view of uncertainty is sufficient, and to distinguish those cases from instances where the endogeneity of risk is important. Common sense and a feel for the underlying pressures lying dormant in the market are essential complements to any quantitative risk management tool that merely looks back at the recent past.

When there are diverse opinions in the market, and where these diverse opinions are reflected in the diversity of trading strategies and positions, treating risk as being exogenous would be appropriate. When risk is exgenous, the trader is playing a game against Nature - that is, the statistical relationships are determined *outside* the system. Hence the roulette wheel view of the world suffices, and efforts can be directed towards the refinements of statistical or engineering tools of measurement and pertubation, such as identifying the correct probability densities from past data, estimating the co-movements in returns and dealing with the non-linear payoffs from derivatives. Stress testing in such a context is simple, since the shocks that arrive are correctly modelled as being something that hits the market from the outside.

Endogenous uncertainty matters whenever there is the conjuction of (i) traders reacting to market outcomes and (ii) where the traders' actions *affect* market outcomes. These conditions are most likely to be in effect when there is a prevailing orthodoxy concerning the direction of market outcomes, and

where such unanimity leads to similar positions or trading strategies. In such an environment, the uncertainty in the market is generated and modified by the response of individual traders to the unfolding events. Recognizing these features is essential to intelligent risk management that takes account of endogenous risk.

What of the implications for quantitative risk management and of stress testing? What are the alternatives to the current suite of techniques that draw from engineering analogies? First, the margin of error in the stress test must be chosen intelligently. When a bank's portfolio is subject to a simulated shock, the margin of error should not be based on the assumption that all other market conditions remain unchanged. If the shock is likely to affect the actions of *other* market participants, the system-wide impact of the shock may be much larger in practice that the initial shock that one is simulating. For the engineers of the Millennium bridge, it was not enough simply to subject the model of the bridge to strong storms or other outside shocks assuming that other things would remain unchanged. The system has the potential for its own dynamic response, and this potential should be explicitly modelled.

So, what is to be done? For financial markets, tracking the potential for the dynamic response of the market entails solving explicitly for the equilibrium of the system and track its evolution over time. This is not the place to embark on a full description of the kinds of methods that can be employed, but it suffices to say that models drawn from financial economics - both of the competitive equilibrium variety and game-theoretic variety - are promising future directions for research. The reader is referred to Danielsson, Shin and Zigrand (2002), Danielsson and Zigrand (2002) and Morris and Shin (2000) for examples.

# References

[1] Bank for International Settlements (1999) "A Review of Financial Market Events in Autumn 1998", CGFS Publication Number 12, Bank for International Settlements, http://www.bis.org/publ/cgfs12.htm.

[2] Bank of Japan (1998) *Regular Derivatives Market Statistics in Japan*, Bank of Japan, Tokyo.

[3] Black, F. and M. Scholes (1973) "The Pricing of Options and Corporate Liabilities," *Journal of Political Economy*, 81, 637-659.

[4] Brady, N. (1988) *Report of the Presidential Task Force on Market Mechanisms*, Government Printing Office, Washington D. C.

[5] Crockett, A. (2000) "Marrying the Micro- and Macro Prudential Dimensions of Financial Stability" Bank for Intrnational Settlements, Basel. http://www.bis.org/review/rr000921b.pdf

[6] Danielsson, Jon, Hyun Song Shin and Jean-Pierre Zigrand (2002) "The Impact of Risk Regulation on Price Dynamics" http://www.riskresearch.org

[7] Danielsson, Jon and Jean-Pierre Zigrand (2002) "What Happens when you Regulate Risk? Evidence from a Simple Equilibrium Model" http://www.riskresearch.org

[8] International Monetary Fund (1998) *World Economic Outlook and International Capital Markets: Interim Assessment*, http://www.imf.org /external/pubs/ft/ weo/weo1298/ index.htm

[9] Lowenstein, Roger (2000): *When Genius Failed – The Rise and Fall of Long-Term Capital Managment.* New York: Random House.

[10] Shiller, Robert (1987) "Investor Behavior in the October 1987 Stock Market Crash: Survey Evidence" NBER discussion paper 2446, reprinted in *Market Volatility*, MIT Press, 1990.

[11] Morris, Stephen and Hyun Song Shin (2000) "Market Risk with Interdependent Choice" http://www.nuff.ox.ac.uk/users/shin/working.htm