# Market Risk Modelling – The Next Generation

Paper prepared for Risk Management Symposium, March 2010.

The task I've been given today is to discuss some of the weaknesses in market risk modelling that were uncovered by the GFC. What mistakes were made in market risk modelling and what can be done better? Which risk models work best? The table below provides some insights.

**VaR methodologies During 2008[1] with α=1%**

| Bank | Observation period | Number of exceptions[2] | Methodology | Characteristics |
|---|---|---|---|---|
| Lehman Brothers | 4 years | 2-3 | Historical simulation | Heavier weight for recent time periods |
| Goldman Sachs | | 2-3 | | Heavier weight for recent time periods |
| Morgan Stanley | 4 years | 4-5 | Historical simulation | Equal weighting |
| BNP Paribas | | 7 | Monte Carlo simulation | |
| JP Morgan | 1 year | 10 | Historical simulation | Equal weighting |
| Bear Stearns | | 12 | Historical simulation | Equal weighting |
| Credit Suisse | 3 years | 25 | Historical simulation | Equal weighting |
| Societe Generale | 1 year | 29 | Historical simulation | Equal weighting |
| Deutsche Bank | 1 year | 35 | Monte Carlo simulation | |
| UBS | 5 years | 50 | Historical simulation | Equal weighting |

Source: Risk magazine, Jan 2010

[1] For most banks, the number of VaR exceptions realised in 2008 has been considered. For Bear Stearns and Lehman Brothers, the full year before their bankruptcy has been considered.

[2] US banks typically calculate VaR with α=5%. The actual number of exceptions has been adjusted to estimate the number of exceptions that would have been realised had α been equal to 1%. See source for further information.

There are a number of technical issues that have been much discussed following the period of market turbulence such as the assumption of normality, appropriate observation periods and weighting schemes. Those who have heard me talk at previous industry forums will know that I have strong views about the importance of volatility clustering. The most popular risk model used in the industry (historical simulation with equal weightings), does not capture this feature of markets, despite the fact that it is probably the market's most pervasive characteristic. It is disturbing to me that banks around the world, including the big four here in Australia, are still using historical simulation with equal weightings – a methodology that has been thoroughly discredited in research studies. The table shown above confirms my views. The best performing risk models in 2008 were those that put more weight on recent observations; they were responsive to the current market environment. But I won't go over that ground again as it's been well covered.

The table makes another interesting point – a good risk model does not necessarily ensure success, neither does a bad risk model necessarily lead to insolvency. After all Lehman Brothers had a great model but unfortunately is no longer with us. In my view the single biggest problem in market risk modelling is not the models themselves but the way they are used and interpreted. There have been a large number of papers released in the last year examining lessons from the crisis. One of my favourites is the one by Golub and Crum from BlackRock. In it they exhort the industry to adopt a style of risk management called "Bottoms-Up Risk Management". This is not risk management conducted in the pub, but an approach that requires people ***throughout*** the organisation to intellectually 'get their hands dirty'. Risk management and risk modelling is difficult, complex. We can't afford to leave it in the hands of only a few highly quantitative experts. Thorough knowledge of the risk model, including a clear appreciation of its shortcomings and the assumptions it makes, should be widespread through the organisation. The risk management unit also needs to be well-resourced with people who really know their stuff, and who know how to communicate what they know. Until this happens I think it's likely that we will continue to make the mistakes of the past i.e. many risk models will continue to perform poorly and they will be used inappropriately.

It's in this spirit that today I want to focus on the issue of market liquidity. My feeling is that market liquidity remains the last frontier for market risk management. It is the aspect of market risk that is probably least understood and very few risk models incorporate liquidity risk explicitly. This was arguably one of the factors that caused some market risk models to falter during the crisis.

One has only to look at recent regulatory proposals to see that liquidity is very high on the agenda of many in the industry today. "Revisions to the Basel II Market Risk Framework" were announced by the Basel Committee in July 2009 (to be implemented end 2010). This initiative includes an incremental risk capital charge (for unsecuritised credit products) that includes (amongst other things) liquidity risk.

The issue of liquidity is also high on the agenda for stress testing. In January 2009 the Basel Committee produced "Principles for Sound Stress Testing Practices and Supervision". This report identified a series of methodological flaws requiring correction in relation to stress testing. Stress tests were found to overestimate market liquidity and to underestimate the links between market liquidity and funding liquidity.

So clearly I am not alone in thinking that market liquidity is an area needing much greater attention. In recent years we have learned a great deal about liquidity and its role in financial markets. In part this is due to the increased availability of high-frequency data that has revolutionised research in this field. The next generation of risk models must harness this knowledge so that we are better prepared for the next crisis. My aim today is to provide an overview of what we know about liquidity risk and how it relates to market risk generally. I hope this overview will help all of us identify issues for further analysis, and to better understand how risk models will perform during periods of turbulence. Better understanding is the key to effective risk management.

**"Liquidity is an illusion. It is always there when you don't need it and rarely there when you do." -** Michael Milken, progenitor of 'junk bonds'.

**Definitions**

*Market Liquidity* – also known as asset liquidity - refers to the ability to *quickly* convert an asset to cash (or vice versa) with minimal costs of trading including spreads, commission and market impact. Consequently, market liquidity *risk* refers to the potential for an increase in the costs of trading or the inability to transact within the timeframe expected.

*Funding Liquidity Risk* – The risk of inability to fund current obligations, or of being forced to fund obligations at penalty rates. Inability to fund obligations might arise because access to external sources of funding is inadequate or is withdrawn. Funding liquidity risk often arises from the excessive use of leverage and a mismatch in the term of assets and liabilities, especially if sources of funding are not well diversified.

Clearly these two liquidity concepts are connected. If there is a hole in the balance sheet because a lender doesn't want to refinance at current rates, the institution has a choice: either to pay more for funding, or to sell assets to reduce funding requirements. If market liquidity is poor, and assets cannot quickly be converted to cash at an acceptable price, then the institution is forced to pay more for funding.

Risk managers rely on both market liquidity and funding liquidity to manage risk. For example, market valuations, VaR estimates, hedging strategies and funding strategies all make certain assumptions concerning liquidity. The dislocations to liquidity in 1997, 1998, 2007 and 2008 have created concern in the risk management community, including regulators. Part of the concern relates to the fact that these episodes of financial distress were followed by protracted periods of reduced liquidity.

**Other Related Terms**[3]

*Tightness* – the difference between buy and sell prices.

*Depth* – the size of the transactions that can be absorbed without affecting prices.

*Immediacy* – the speed with which orders can be executed.

*Resiliency* – the ease with which prices return to "normal" after temporary order imbalances.

[3] Most of these definitions from Borio (2000)

## Measuring Liquidity

One of the difficulties in this area is that it is by no means obvious how liquidity should be measured.

1. ***Relative Spread*** = $\dfrac{\text{Highest Bid - Lowest Offer}}{\text{Mid-price}}$

This can understate the true liquidity for larger investors who typically cannot trade at these prices (see discussion of normal market size below).

Other spread measures include realized spread (gap between weighted averages of the bid and ask prices for executed trades) and effective spread (based on actual transaction price rather than the quoted price).

2. **Order Depth** = $\dfrac{\text{Volume of orders on the bid and ask side of the order book}}{\text{Number of shares on issue}}$

The amount of order flow on the order book is considered a key indicator of liquidity, but is available only in exchange-traded markets. Note that Order-based measures of liquidity have an advantage in that they indicate current liquidity rather than what has traded in the past. But, there are some potential problems:

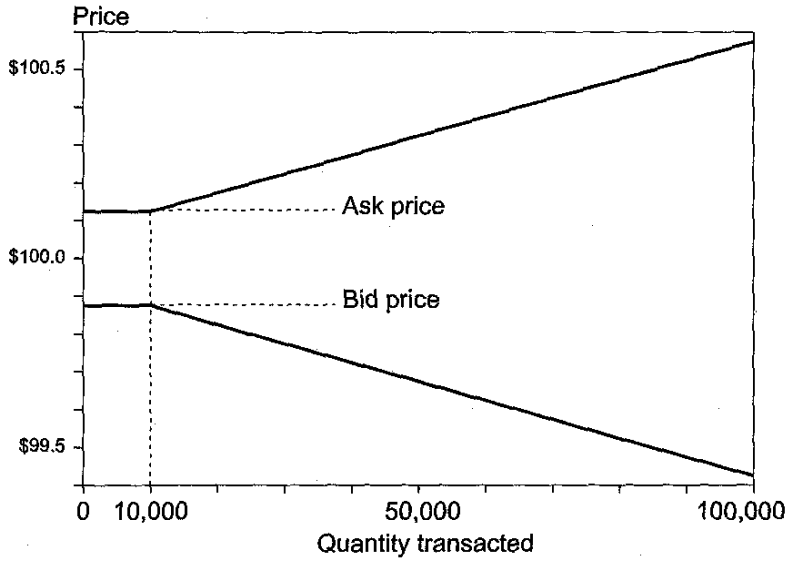
- Some orders may be stale.
- If the price changes, then some new orders may come into the system and others may be cancelled.
- If orders are a long way from the current price, they are not very meaningful.

3. ***Normal Market Size (NMS)***

This is often used to measure liquidity in dealer-markets. It is the maximum size of transaction at which a dealer is prepared to transact at the stated bid and ask prices. In most markets the spread is a function of the quantity transacted. The standard bid-ask spread in the market is only valid up to some limit which may be called the normal market size. The greater the NMS, the greater the liquidity is considered to be.

This measure brings out the fact that liquidity can have an endogenous component i.e. costs of trading are determined in part by our own behavior. This is why so much effort is now devoted to algorithms that maximize trading efficiency. Very often it's possible to reduce trading costs by spreading a large order out over a period of time rather than executing the entire order instantly. Of course, the downside of this is greater exposure to market risk.

Price-quantity function.




*Source: Jorion, pg. 341*

4. ***Volume*** = Number of shares × Price over a defined time interval.

Volume is usually associated with good liquidity – the more trading in a market, the more likely it is that an investor can execute a transaction quickly at close to fair value. Usually the assets with the greatest traded volumes and the largest normal market size (NMS) have the tightest bid-ask spread.

Table 2
**Comparison of basic market liquidity measures**

| | | Canada | Italy | Japan | UK | US |
|---|---|---|---|---|---|---|
| Bid-ask spread: | | | | | | |
| Fixed coupon[1] | 2 years | 2 | 3 | 5 | 3 | 1.6 |
| | 5 years | 5 | 5 | 9[4] | 4 | 1.6 |
| | 10 years | 5 | 6 | 7 | 4 | 3.1 |
| | 30 years | 10 | 14 | 16[5] | 8 | 3.1 |
| Volume outstanding (a)[2] | | 285 | 1,100 | 1,919 | 458 | 3,457 |
| Yearly trading volume (b)[3] | | 6,243 | 8,419 | 13,282 | 3,222 | 75,901 |
| Turnover ratio (b/a) | | 21.9 | 7.7 | 6.9 | 7.0 | 22.0 |

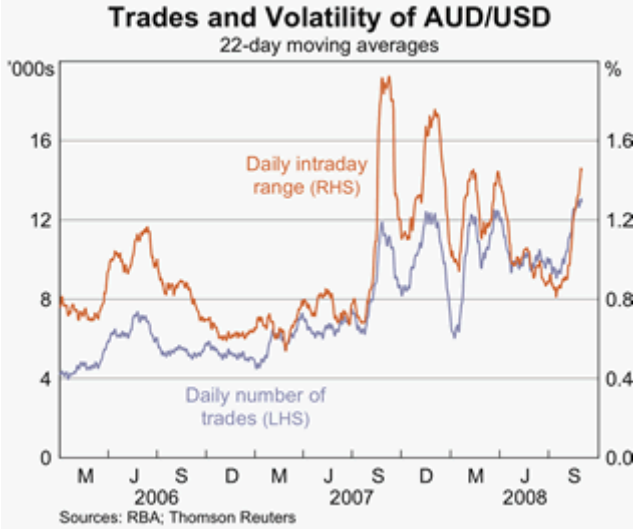
Notes: For detailed notes, see Inoue (a).

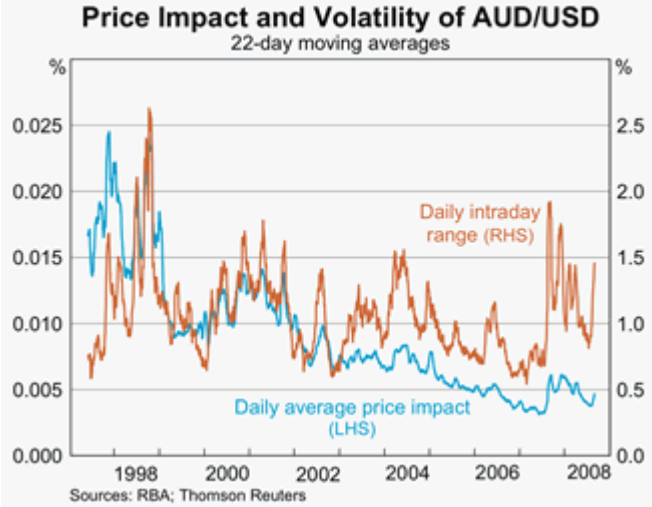
[1] The table shows the bid-ask spreads of on-the-run issues, given in one-hundredth of a currency unit for the face amount of 100 currency units. [2] The figures are as of end-1997, in billion US dollars, converted at the exchange rates of end-1997 (US$1 = C$1.43 = ITL1770 = ¥130, £1 = $1.65). [3] The figures are for the 1997 calendar year, on a two-way basis. [4] 6-year bonds. [5] 20-year bonds.

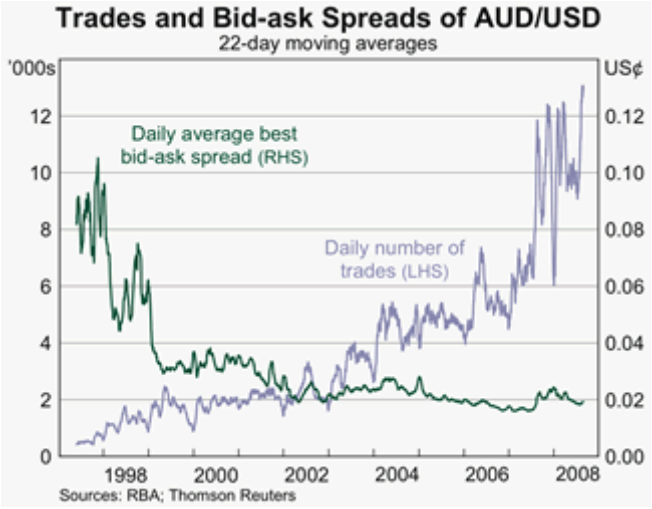
*Source: CGFS 1999*

When we look at trading volumes over time, however, we discover that increases in volume do not necessarily indicate an increase in liquidity (see Johnson, 2008). In a market crisis, for example, the trading volumes can increase without necessarily providing greater genuine liquidity. Greater volumes can indicate that investors are leaving the market and hence that liquidity is declining! If trades result in large price moves then arguably market liquidity is poor.

The following charts from Poole and D'Arcy (2008) show how trading volumes in the AUD/USD market increased during the market turbulence in 2007-08 while other measures of liquidity (price impact and bid-ask spreads) indicated that liquidity was declining.






## 5. Price Impact Measures

- Price impact can be measured using high-frequency data e.g. price impact is the increase (decrease) in the buy-sell midpoint over a five minute interval beginning at the time of the initial transaction. Note that price impact can be transient or permanent.
- Price impact can also be measured using low-frequency data using, for example, Amihud (2002):

$$\text{Illiquidity} = \text{Average}\left(\frac{(|r_t|)}{\text{Volume}_t}\right)$$

where $r_t$ is the stock return on day *t* and $\text{Volume}_t$ is the dollar volume on day *t*. The average is calculated over all positive volume days over, say, a month.

## 6. Liquidity Premia

- Investors require higher returns to compensate for liquidity risk.
- Corporate bonds spreads can be compared with the estimated credit spread. The difference is a liquidity premium.
- Interest rate swap data can also be used i.e. changes in the spread of Libor over a government bond yield may be due to changes in liquidity.

## 7. Summary Indicators

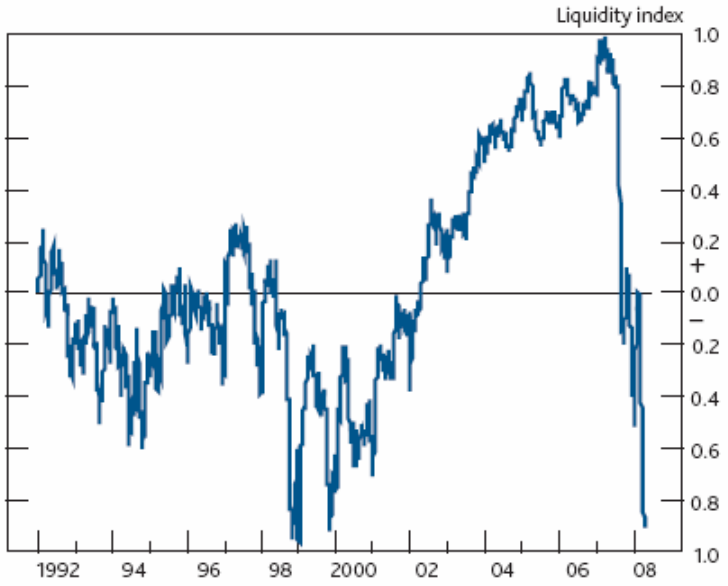
The Bank of England reports a composite measure of liquidity[4] based on markets in which major UK banks are likely to be active. It considers bid-ask spreads (Gilt repo, Exchange rates, FTSE 100), Price Impact (Gilt market, FTSE 100, equity options) and Liquidity premia (corporate bonds and Libor spread).

[4] See the April 2007 edition of Financial Stability Report for a detailed description.

In April 2007 the Bank of England noted “markets are currently very liquid and have been so for a number of years. This may partly reflect structural features, including the increasing role of new investors, such as hedge funds, and innovation in financial instruments” (Financial Stability Review, p. 18).

Look what happened next, as reported in the same publication in May 2008…

Financial market liquidity




Sources: Bank of England, Bloomberg, Chicago Board Options Exchange, Debt Management Office, London Stock Exchange, Merrill Lynch, Thomson Datastream and Bank calculations.
Index of financial market liquidity. See *FSR* Chart 3.2 for details.

The main lesson of this chart is the extraordinary fragility of liquidity!

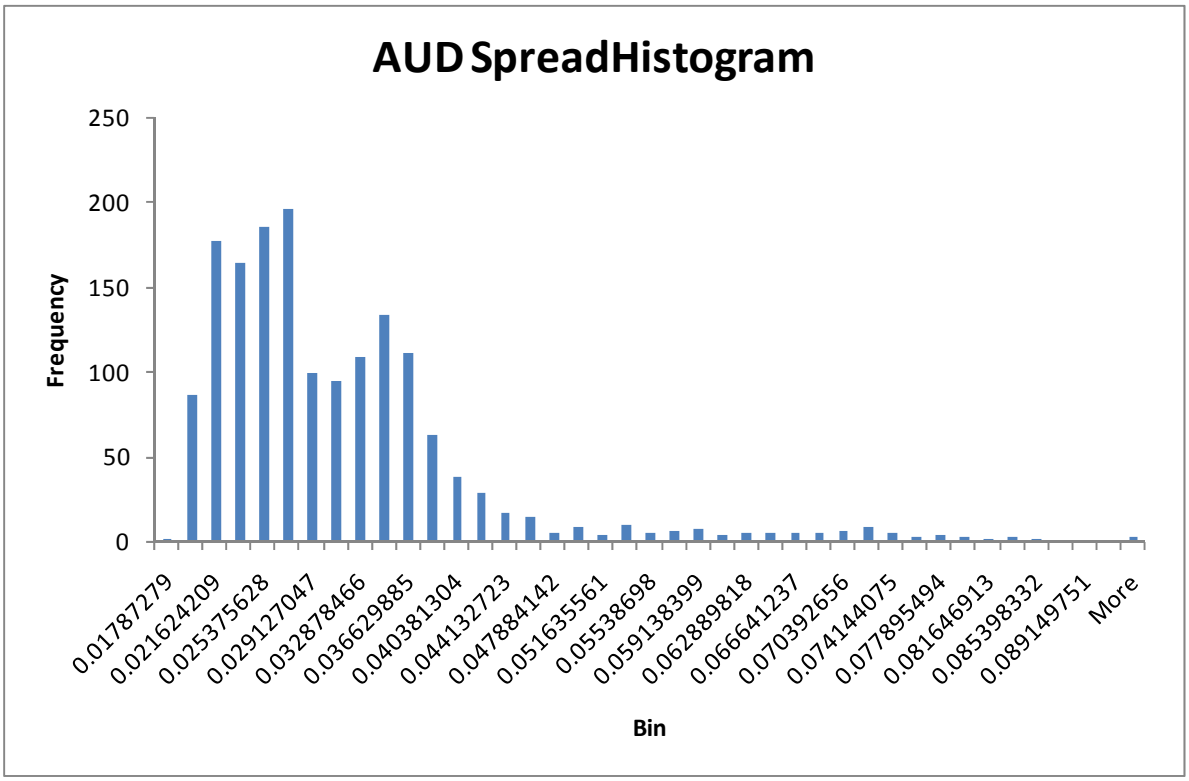
Liquidity changes over time. It varies during the course of the trading day, it varies across the days of the week, and it varies when new information comes to the market.

Why can a liquidity crisis leave long-term scars in market liquidity? The consequences can be long-lasting if market participants change their behaviour in one of the following ways:

- Some participants may leave the market entirely (eg LTCM);
- Some participants may change their trading/hedging strategies to be less reliant on certain instruments (eg swaps vs bonds);
- Some participants, after reviewing the risk/return tradeoff in a market, may decide to limit their exposure to it eg may reduce limits.

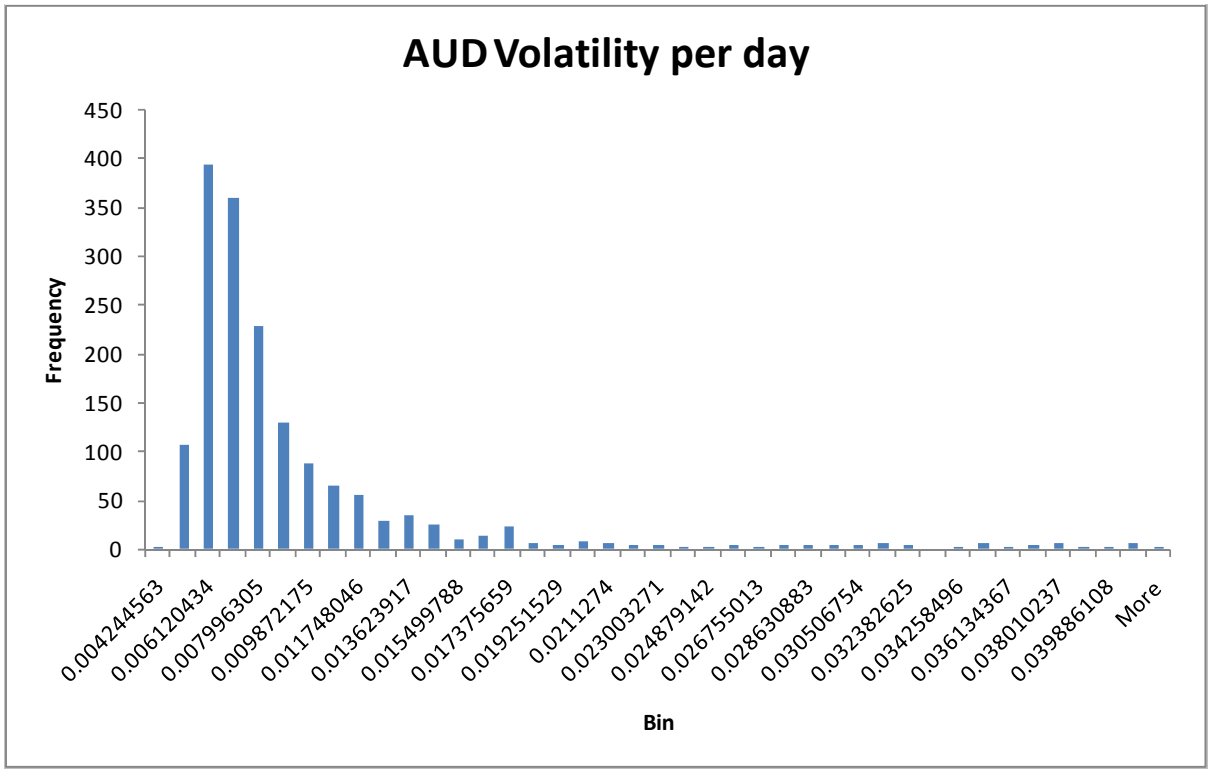
## Data Analysis

I examine data obtained from SIRCA relating to the AUD/USD market from January 2003 to June 2009. Liquidity is measured here[5] on a daily basis as the average best bid-ask spread (expressed as a percentage of the exchange rate).



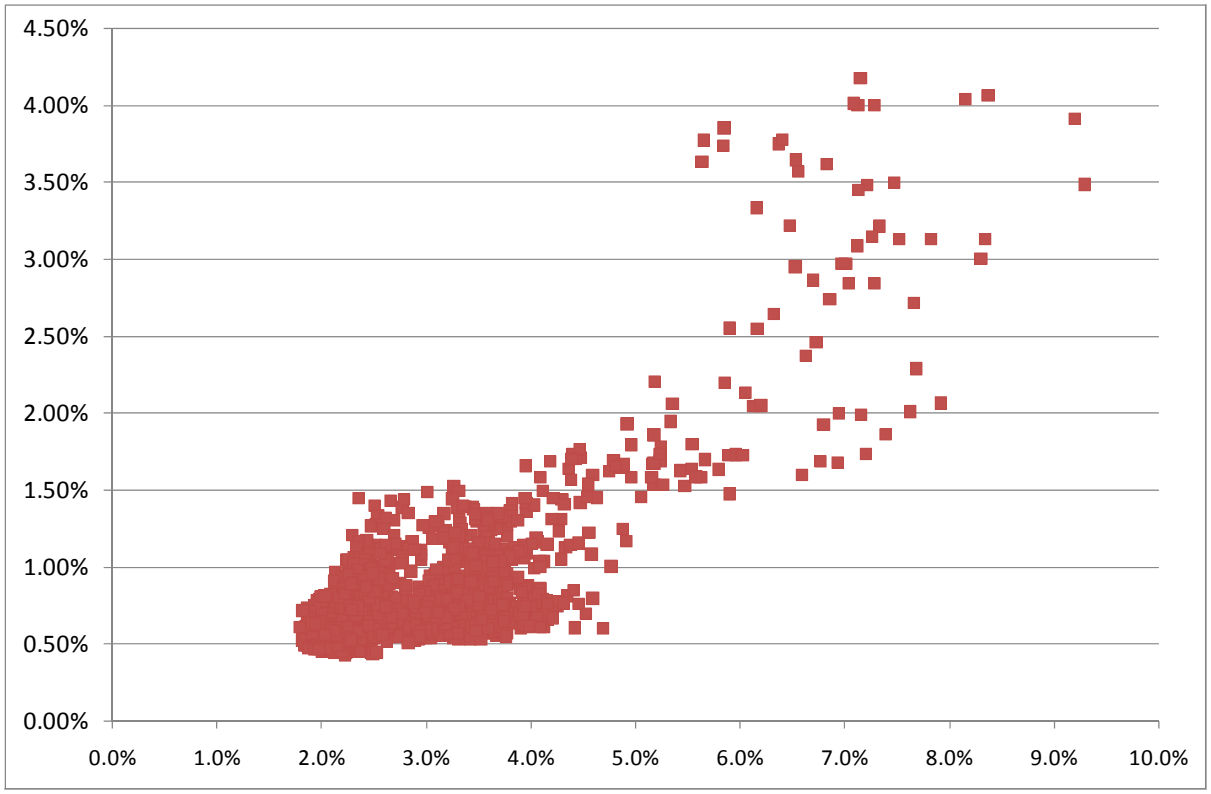

A simple histogram shows that spreads are heavily skewed (skewness coefficient is 2.25). Most days the spreads are at relatively low levels, but just occasionally the spreads increase dramatically, indicating deterioration in liquidity. What I find fascinating about this is that volatility behaves in exactly the same way. On a 'typical' day the volatility is relatively low, less than 1% per day. But volatility increases quite dramatically sometimes. Here I am measuring conditional volatility[6] which is sensitive to recent data. It has a skewness coefficient of 3.73.

[5] Thanks to staff at the RBA for providing these initial calculations.
[6] Conditional volatility is estimated here using an asymmetric GARCH model.



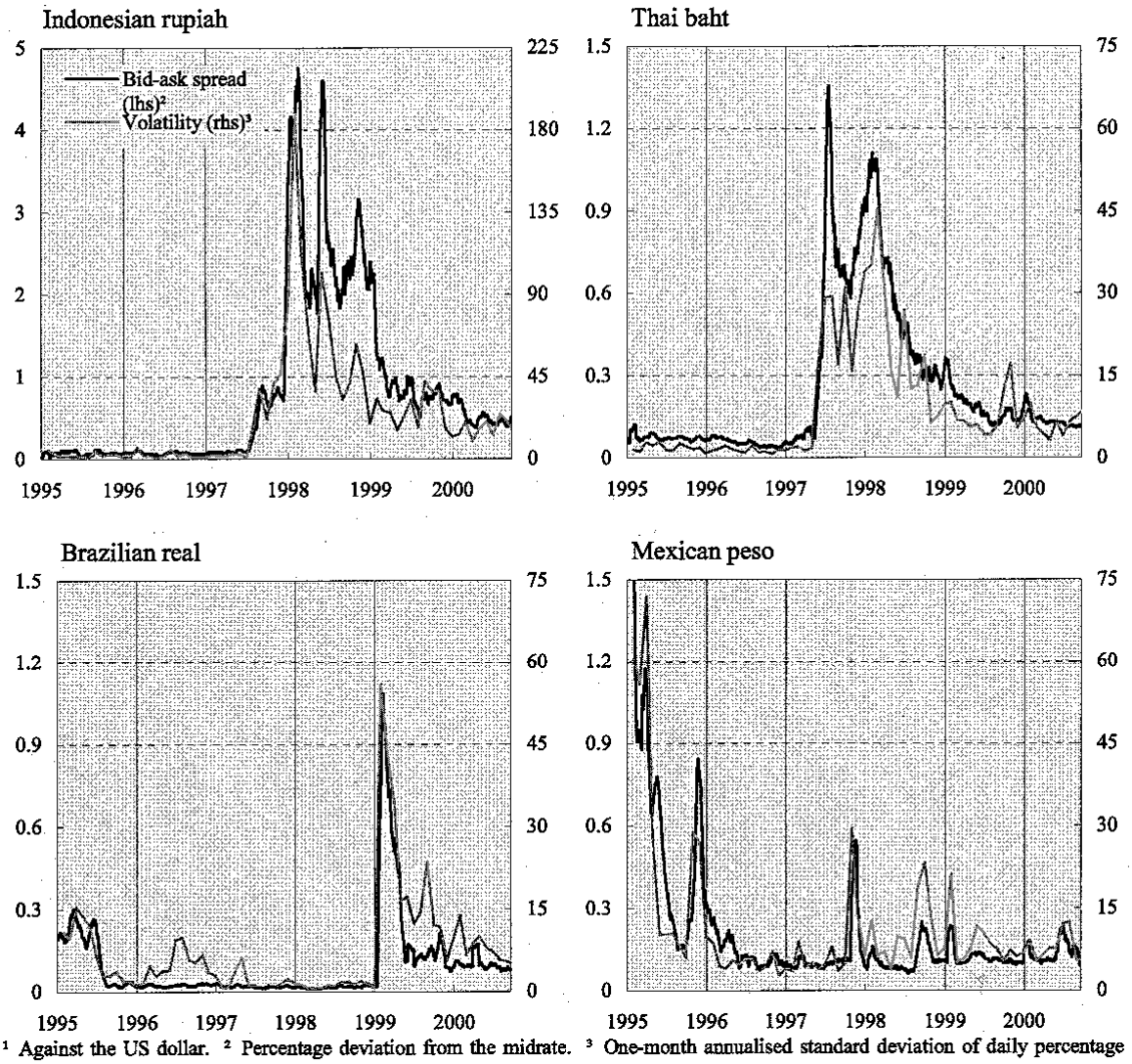

We can further analyse the relationship between these two variables with a scattergram.

AUD/USD Daily Volatility (y-axis) vs Relative Spread (x-axis)



The correlation between the two variables is close to 0.9! Notice that spreads increase (liquidity deteriorates) at exactly the same time that volatility increases. This relationship has been noted in previous studies.

**A. Volatility and bid-ask spreads in selected foreign exchange markets[1]**




[1] Against the US dollar. [2] Percentage deviation from the midrate. [3] One-month annualised standard deviation of daily percentage changes.

Sources: Datastream; Reuters America.

*Source: Borio, Pg. 49*

How can we explain this close connection between volatility and liquidity? I believe that both volatility and liquidity are driven by a common cause – they both react to new information coming to the market. A price shock (usually the result of new and unexpected information reaching the market) leads to subsequent large price moves. This is the well-known volatility clustering effect.

The same price shock also leads to deterioration in market liquidity. It could be argued that it's the deterioration in market liquidity that produces the volatility clustering. Some possible mechanisms which have been highlighted by recent research (see for example Brunnermeier and Pedersen, 2009) include:

1. Participants (including market makers) become less confident in their price expectations and less willing to take new or large positions when risk increases. Limits may be reduced.
2. Market makers demand a higher risk premium (higher spread) as volatility increases.
3. Participants expect liquidity to fall i.e. a self-fulfilling prophecy.
4. Panic buying/selling causing a market that is one-sided. That is, participants are more homogeneous in their views/positions, with few willing counter-parties to take the other side. Flight to quality means that more liquid assets are favoured over those with lesser liquidity e.g. on-the-run favoured over off-the-run.
5. Credit limits may become full after large market movements, reducing the number of available counterparties.
6. Margin calls can lead to funding shortfall. Consequently there is less capital to invest in new speculative positions and it may be necessary to close-out existing positions at fire-sale prices (contributing further to panic buying/selling).
7. Margin requirements may be increased as volatility increases following a price shock. As a result, it becomes increasingly uneconomic for speculators to maintain open positions.
8. Price shocks can cause trading limits to be breached. Positions must then be closed or at least partially hedged. Some observers have even suggested that the prevalence of VaR methodologies for capital adequacy may aggravate this problem.

It has also been observed in recent research that market liquidity seems to be asymmetric i.e. tends to worsen more after a price drop (or price increase, depending on the market). In markets such as equities where most participants tend to be long, a big negative price shock has a greater impact on liquidity than a big positive price shock because of the impact on margins and panic reactions as discussed above. The AUD behaves in the same way; the impact of the carry trade[7] means that most market participants are long the AUD. Market liquidity will therefore deteriorate more after a negative price shock than after a positive price shock.

[7] The carry trade is investing in high-interest rate currencies while funding the position in low-interest rate currencies e.g. invest in AUD cash, with funding in JPY.

Another similarity between volatility and liquidity is that they both display 'autocorrelation' i.e. today's value will be determined to a significant extent by yesterday's value. Days of high volatility and poor liquidity are not randomly scattered over time. Rather they are clustered together.

I performed a simple linear regression where the dependent variable is the daily relative spread in the AUD/USD. I found that today's value is a function of three explanatory variables being conditional volatility (positive association), its own past values (positive association), and finally today's return (negative association so spreads increase when the return is negative). The adjusted $R^2$ for this regression is 0.90 and t-statistics are shown in parenthesis.

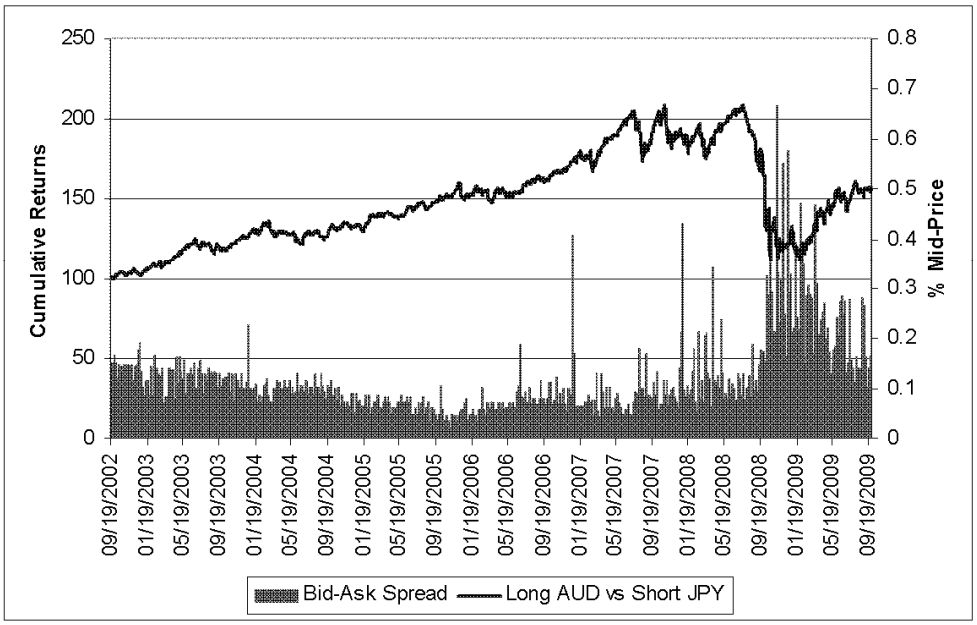
$$\underset{}{\text{Spread}_t} = \underset{}{0.0023} + \underset{(8.96)}{0.205}\text{Volatility}_t + \underset{(7.34)}{0.855}\text{Spread}_{t-1} - \underset{(66.18)}{0.097}\text{Min}(0,R_t)_{(-7.45)}$$

Regardless of its cause the close connection between volatility and liquidity is an empirical fact. The relationship is bad news for risk managers because it means that everything will tend to go pear-shaped simultaneously. This makes it even more crucial that the relationship should be incorporated in risk models.

We have also learned that market liquidity is a common risk factor (see Golub and Crum, 2009 and Mancini et al., 2009). It's now established that illiquid assets earn a higher return to compensate investors for taking liquidity risk. For example, one of the longstanding puzzles in finance, the apparent success of the 'carry trade', can be explained by liquidity risk (see Brunnermeier et al. 2008). Between 2002 and 2008 investors in the AUD (funded in JPY) enjoyed consistently strong returns. In late 2008 there was a mass liquidation of the carry trade as funding constraints impacted on many participants at around the same time. Most of the gains were wiped out in late 2008. This occurred despite the fact that the AUD and the JPY are usually some of the most liquid markets in the world. Golub and Crum argue that the most liquid assets are sometimes particularly hard hit early in a period of turbulence; they become quasi 'ATM machines' for many liquidity strapped market participants who have suffered losses in other markets. It's often only as the crisis progresses that the less liquid securities are affected. One of the mechanisms for this is that lenders refuse to take illiquid securities as collateral for loans, leading to forced sales.

**Figures**

**Figure 1: AUD/JPY Carry Trade Cumulative Returns and Bid-Ask Spread**




*Source: Golub and Crum 2009*

So what do we know about market liquidity?

1. It's extremely fragile and can deteriorate rapidly as new information comes to the market causing price shocks.
2. It's closely connected to volatility i.e. liquidity deteriorates as volatility increases.
3. All assets are affected in a liquidity crisis; even those that are typically very liquid (witness the AUD in 2008).
4. Both volatility and liquidity have a positive skew meaning that when things get bad, they get really bad.
5. Liquidity has an asymmetric element. If you are long in a market that suffers a big deterioration in liquidity as prices fall, the risks are particularly dire.

My hope is that these are the issues that risk analysts will be grappling with as they develop their new StressVaR models which are due for implementation by the end of 2010. The revised capital framework for market risk will require banks to compute two VaR measures: the standard one that captures the current market environment and a second one (StressVaR) that captures risk in turbulent conditions. In my view this is an excellent initiative that has potential to enhance our understanding of and management of risk.

In conclusion I would just like to come back to my initial comments about 'bottoms-up management'. Modelling risk is complex and it's unlikely that a single model will ever be able to capture all the complexities of the real world. The industry needs traders, risk managers, analysts, senior management and directors that have a deep and intuitive understanding of the issues that drive risk. Only then will our risk models start to be understood and used appropriately. I hope my presentation today has made a small contribution towards achieving that goal.

Fundamentally, bottoms-up risk management requires a commitment to risk education for all employees. As you know, I teach at Macquarie University in the Master of Applied Finance program. We require ALL our graduates to complete a unit in Financial Risk Management, regardless of their specialisation. For those wishing to specialise in risk management we have challenging elective units in credit risk, operational risk and market risk modelling. In addition we offer executive training programs in risk management. I hope that we will see some of you (or your staff) participating in these programs in the future. Please see me afterwards if you would like more information.

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