In search of chaos

Australia's stockmarket: not linear but not chaotic

A range of statistical tests fail to detect the presence of chaos in the Australian stockmarket, although there is evidence of a non-linear structure. This has implications for stockmarket analysis, argue Graeme Newell, Max Stevenson and Maurice Peat. They recommend that non-linear forecasting models should be developed.

The impact of chaos theory in a wide range of applications has been well documented. Chaotic systems are not random, but have a well-defined structure. Small changes in system variables may result in extreme volatility and abrupt change, and present major analysis and forecasting difficulties.

The issue of chaos has been the focus of conjecture and active debate in many international financial markets. Its potential influence on the Australian stockmarket was initially raised in this journal by Sherris (1990). The implications of chaos for stockmarket performance are highly significant for investment analysis, modelling and forecasting.

Recent years have seen the application of chaos theory to a range of financial markets, including equities, futures, treasury bills and foreign exchange. In many instances, the returns series were not found to be random, and more sophisticated non-linear models were needed to explain the complex dynamics of the capital markets. Use of the standard linear forecasting and asset-pricing models would present problems for short-term and long-term stockmarket analysis. Little relevant Australian empirical research exists. This purpose of this paper is to examine for the presence of chaos in the Australian stockmarket and identify the analysis, modelling and forecasting implications.

DATA ANALYSIS

Effective examination for the presence of chaos requires lengthy data series of at least 2,000 returns. Daily share price or index data over the period 1980-94 (comprising up to 3,660 data points) were obtained for each of the following 10 Australian stockmarket series:

- All-Ordinaries index;
- Property Trust index;
- Developers and Contractors index;
- seven property-related companies – Lend Lease, Leighton Holdings, General Property Trust, Westfield Trust, Stockland Trust, Schroder Property Trust and Capital Property Trust.

The full battery of econometric tests to assess for chaos were used, including:

- rescaled range analysis (H-measure);
- modified rescaled range analysis (Lo's test);
- correlation dimension;
- Lyapunov exponents;
- BDS test; and
- three-moments test.

These tests involved many hours of detailed computer analysis, often involving considerable fine-tuning of

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specially written routines. As no single test provides full information about the presence of chaos and the returns structure, the analysis requires the adoption of conclusions from several tests to form an “on the balance of evidence” picture.

**IS THERE CHAOS?**

The following summarises the results of the various tests without giving full technical or statistical details; rather, the intention is to enable an overall evaluation.

Table 1 presents the H-measure for each of the Australian stockmarket series, with H-measures in the range of .439-.532 obtained. The H-measures were not significantly different from 0.5 and do not provide any support for the presence of chaos.

To account for the presence of any short-term dependence, the results for Lo’s test using the modified rescaled range analysis are also presented in the table. No significant evidence of long-term persistence was present, providing further support for an absence of chaos.

The correlation dimension estimates for each of the stockmarket series are also shown, with estimates generally in the range of 3 to 9. The evidence based on these correlation dimensions again supports lack of chaos in these stockmarket series. In contrast, previous US stockmarket studies (for example, Peters 1991) have reported correlation dimensions of less than 3, providing some evidence of chaos.

Estimates of the largest Lyapunov exponents for each of these stockmarket series are given. Positive Lyapunov exponents are needed for evidence of chaos. While tests of statistical significance of the Lyapunov exponent estimates are not available, the values are only in the range of .009-.049 and do not provide any substantive support for the presence of chaos.

If linear models of Australian stockmarket performance are appropriate, then the BDS test results shown in the table should not be significant. However, this is not the case, pointing to some degree of non-linear structure in each of the series.

Having identified the presence of non-linearity through the BDS test, the three-moments test is used to determine whether this non-linearity is due to chaos. The table shows the results of the three-moments test for each of the stockmarket series. None of the statistics is significant at the 5% level. While it can be observed that all of the series exhibit some degree of non-linear structure, it is clearly not associated with chaos.

To determine whether this finding resulted from the use of daily returns and the possible presence of noise, the various econometric tests were applied using weekly returns. Equivalent results were found for weekly returns, reinforcing the “on balance of evidence” conclusion that some non-linear structure (but not chaos) was present in these Australian stockmarket returns.

**STOCKMARKET IMPLICATIONS**

The results indicate that the underlying structure and processes present in the various Australian stockmarket series are not chaotic, and that non-linear models are likely to prove more appropriate in capturing the underlying dynamic processes of the market. Neither a random nor chaotic process is supported as the preferred underlying structure for these series.

This has significant implications for stockmarket modelling. There is clearly a need for forecasting and analysis models to recognise this non-linear behaviour. To maximise the accuracy of forecast returns, suitable non-linear models need to be identified and empirically tested. Potential non-linear models include threshold autoregressive models, exponential autoregressive

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**Table 1: Analysis of chaos in the Australian stockmarket 1980-94**

<table>
<thead>
<tr>
<th>Index or company</th>
<th>H-measure</th>
<th>Lo’s test</th>
<th>Correlation dimension</th>
<th>Largest Lyapunov exponent</th>
<th>BDS test</th>
<th>Three moments test</th>
<th>BDS test GARCH (1,1) residuals</th>
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</thead>
<tbody>
<tr>
<td>INDEXES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-Ordinaries index</td>
<td>.500</td>
<td>ns</td>
<td>9</td>
<td>.014</td>
<td>*</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>Property trust index</td>
<td>.491</td>
<td>ns</td>
<td>4</td>
<td>.009</td>
<td>*</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>Developers and contractors index</td>
<td>.512</td>
<td>ns</td>
<td>6</td>
<td>.018</td>
<td>*</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>COMPANIES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lend Lease</td>
<td>.503</td>
<td>ns</td>
<td>3</td>
<td>.030</td>
<td>*</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>Leighton Holdings</td>
<td>.532</td>
<td>ns</td>
<td>7</td>
<td>.049</td>
<td>*</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>General Property Trust</td>
<td>.491</td>
<td>ns</td>
<td>4</td>
<td>.027</td>
<td>*</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>Westfield Trust</td>
<td>.500</td>
<td>ns</td>
<td>4</td>
<td>.028</td>
<td>*</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>Stockland Trust</td>
<td>.439</td>
<td>ns</td>
<td>3</td>
<td>.029</td>
<td>*</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>Schroder Property Trust</td>
<td>.512</td>
<td>ns</td>
<td>4</td>
<td>.027</td>
<td>*</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>Capital Property Trust</td>
<td>.489</td>
<td>ns</td>
<td>2</td>
<td>.022</td>
<td>*</td>
<td>ns</td>
<td>*</td>
</tr>
</tbody>
</table>

* = significant at 5% level  ns = not significant at 5% level

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models and smooth-transition autoregressive models.

The extent of any improvement in the accuracy of stockmarket analysis and forecasts as a result of employing non-linear models, rather than the standard linear models, needs to be evaluated. However, the trade-off between improved accuracy and model complexity will also have to be considered.

NOTES
1. The property focus of the series selected reflects the specialist research of Graeme Newell; the study results are considered to be generally representative and applicable to all stockmarket sectors.
2. A full technical description of these econometric techniques is given in Peters (1991, 1994).

REFERENCES

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scale of zero to ten, depending on where they fall relative to their peers.

VALUATION WITH RESPECT TO RISK AND RETURN
It should be noted that risk and return are not determined by the market; they are factors intrinsic to the companies themselves. However, valuation is determined by the market.

A company that has a very favourable risk/return profile is not necessarily a "buy" if that company's stock carries a huge valuation. Similarly, a very unfavourable risk/return profile can be bought if the discount is large enough.

However, we have noted that less-favourable profiles are generally so because of a higher forecasting error and therefore are generally not appropriate for risk-averse investors.

The objective is to identify stocks whose risk/return profile is not appropriately valued by the market at any given time. Once again, valuation is a relative thing and therefore we have plotted the universe of stocks for illustration (Figure 2).

The closer the stock is to the bottom right-hand corner of the graph, the more attractive its valuation relative to its risk/return profile. The stocks below the line would comprise our "buy" list, with the strength of the recommendation increasing as we move towards the bottom right-hand corner. The corollary is true and stocks become less attractive as we move to the top left-hand corner.

For the purposes of our analysis, we believe that a 50% discount to the market average is appropriate for stocks with a very unfavourable risk/return profile, and a 50% premium is appropriate for a very favourable profile. Investors may substitute their own rules with regard to valuation.

Theoretically, over time stocks should move to a fair valuation. We believe companies that offer low risk and high return will be re-rated as they have a high probability of demonstrating a strong and consistent operating performance.

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average price of tea auctioned in London leads the quarterly change in US bond prices (and to a lesser extent Australian bond prices), by approximately five months. This implies that a rise in tea prices will be followed five months later by a fall in bond prices.

The table indicates that since January 1990 there has been a statistically significant relationship between the quarterly percentage change in the price of tea auctioned in London and the quarterly change in US and Australian bond prices (lagged by five months). However, the relationship is by no means perfect. The low Durban Watson statistic indicates serial correlation in the residuals and hence exaggerated t statistics. Still, a strong directional relationship is evident in the charts (particularly with US bonds), even if the correlation in magnitude is not as well defined.

The determination of the London tea price is outside the scope of this exercise; however, while there is a justifiable economic rationale for using commodity prices as an indicator of inflation and or bond prices, it is highly unlikely that the price of tea in London should indicate future trends in US and Australian inflation.

Footnote:
The London Tea Auctions, where the data is sourced, closed in June 1998 after operating for nearly 320 years.

Unfortunately, this prevents further testing of the relationship.

NOTES
Australian bond prices = the SBC Composite All Maturities Index (inception October 1989).
US bond prices = the US All Maturities Salomon World Government Bond Index, local currency.

The quarterly percentage changes in bond and tea prices have been standardised and normalised. The change in the tea price has then been inverted and smoothed by a three-month weighted moving average and given a five-month lead.