AN APPLICATION OF THE MARKET MODEL TO THE STUDY OF TAKEOVERS AND MERGERS ON THE DUBLIN STOCK EXCHANGE

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Introduction

The purpose of this paper is, in the light of other relevant empirical literature on the subject, to evaluate the effects on share value of Irish takeovers and mergers. The population of firms in the study are described, the need to adapt capital market methodologies to take account of potential inefficiencies in a small market is considered, the empirical results are outlined, and they are evaluated in the context of other reported findings.

The Dublin Stock Exchange

The Dublin Exchange is a unit of the Stock Exchange, following integration in 1973. Although Irish firms do have an opportunity to seek a quotation on the London Exchange, and some have done so, the Dublin Exchange does provide a more representative picture of Irish business. It has, particularly over the period since 1945, become an important vehicle for the funding of Irish firms.

Nonetheless, the Exchange is unrepresentative of a broad range of activities in the economy. In particular, many of the subsidiaries of foreign companies that operate in Ireland have not acquired a quotation. The availability of debt finance through a range of lending institutions has also reduced the need of Irish business to avail of the facilities of the Exchange. In response to this, the Exchange has initiated other markets, such as the U.S.M. and the Smaller Companies Market, which are designed to improve access to the market for smaller firms, while continuing to protect the interests of investors.

In a study of the Irish Stock Market, Colbert and McCarthy (1981) examined the causes of any changes in the number of quotations on the market over the period 1950-1979. Using the official listings at five yearly intervals, all departures were identified, and the reasons for departure were explored. Over the full period, they found an absolute decline in the

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number of quotations from 149 to 92. Takeover or merger was identified as the main cause, accounting for up to sixty percent of the departures. For this reason, a study of acquisitions is interesting, as in terms of the proportion of Irish business represented by the Dublin Exchange, they have been responsible for a significant transfer of control over the thirty year period.

The Companies and the Acquisition Terms

The population of takeovers and mergers has been restricted to those taking place since January 1st 1965. Of the 142 departures identified by Colbert and McCarthy, 105 occured in the post-1965 period. This suggests that a similar proportion of acquisitions occurred after this date. As a result, a majority have been included, without the need to extend the study over an excessively long period of time.

The study has also been limited to those examples in which both acquirer and victim were quoted, allowing an evaluation of the full economic effect of the acquisitions on both sets of shareholders. It is possible however that by limiting the sample in this way, any findings may not be fully representative of the impact on all acquirors and victims (Palepu (1986)). In particular, by excluding acquisitions of unquoted companies, any findings in relation to the performance of acquirors may be biased.

As unquoted companies will tend to be somewhat smaller than quoted firms, the potential impact of acquisition on the share price of an acquiror would be greatly reduced. Exclusion of this group could therefore lead to overestimation of the effect of takeover on acquiror performance. In the event of there being evidence of significant price changes in the acquiror group, it would then be necessary to allow for this bias when assessing the actual economic impact.

Using the records of all Irish publically quoted companys over the period January 1965 to December 1982, forty acquisitions were identified. Data produced by Colbert and McCarthy was used to verify the selection process. In common with the U.K. experience (Cooke (1986)), the takeovers and mergers tended to be concentrated in the early/mid 70s.

The vast majority were identified as normal takeovers, in which there is an easily identifiable acquiror and victim. In any case in which there is any element of doubt, the larger firm is distinguished as the acquiror, and the smaller as the victim. This classification is used, as control can be expected to reside in the hands of the shareholders of the larger firms, and their management team. Agreed mergers were treated in a similar way.

In the event of a significant prior holdings of victim company shares by

the prospective acquiror, share price of the latter could be effected, reflecting expected benefits to this holding as a result of takeover announcement. This could occur if the prior holding is known or anticipated by the market (Franks, Broyles, and Hecht (1977)). As such a distortion could lead to double counting of any net wealth effects of merger, the potential impact is considered when performance of the acquiring group is assessed.

Data Collection

Share price data was recorded on a week to week basis. This can be considered as a compromise between amount of information provided and the size of the data collection problem. The duration should also be short enough to capture the effects of every bit of information and speculation entering the market during the period surrounding merger or takeover.

The methodology requires that a base date be identified, around which performance can be evaluated. Many earlier studies used the date of takeover, on the presumption that an exclusion period before this date should cover abnormal price behaviour. Dodd (1980) noted however that initial announcement date is more appropriate, as change in value is likely to be associated with announcement rather than acquisition. Information leakage could result in abnormal behaviour before announcement date, so the pre-announcement exclusion period would be needed to capture this. Financial pages of the Irish national newspapers were studied on a daily basis, in order to identify the date on which first announcement of the proposed takeover occurred. The week of this announcement was then designated as the base week.

Weekly price data, together with any dividend payments and capital structure changes, were recorded for each set of acquiror and victim, for a year both before and after (where appropriate) acquisition. This was considered to be of sufficient length to provide a 'normal' period, from which the regression estimates could be based.

Magenheim and Mueller (1988) have suggested that a longer post-acquisition period is required to assess the effect of acquistion on acquiror shareholders. The market, they argue, may take a considerable period to discount the long-run economic consequences, and as a result price adjustments may continue for up to three years. In support of this, they found cumulative net losses in excess of forty percentage points over this period. Significant falls in acquiror value have not been reported in other studies however.

Unlike most studies, pre-event performance of the acquiring firms had been used as the standard against which a comparison was made. Ruback (1988), commenting on this, notes however that it may not be an appropriate benchmark. Performance should be compared with an 'average measure', rather than the relatively high returns associated with the period before a takeover bid is made. Had a more appropriate benchmark been used, most negative bias would have been removed, so that the estimate of acquiror performance should correspond to other reported studies (i.e. no evidence of a significant decline in value). In this event, there is little evidence to suggest that performance should be evaluated over such a long post-event period.

Application of the Methodology to Irish Data

The Market Model has been applied to the data in order to derive the relevant market line for each share:

$R_{it} = a_i + b_i R_{mt} + e_{it}$,

where $R_{it} = P_t + D_t/P_{t-1}$,

$R_{mt} = I_t/I_{t-1}$,

and $P_{t,t-1}$: share prices, adjusted for capital changes,

D_t : dividend, payments, if any,

$I_{t,t-1}$: appropriate share price indices.

Following examination of the available price indices, it was decided to use the Irish Times all share index. This was found to be the most comprehensive that is publically available, in terms of both its coverage and the length of series available. The method of calculation is similar to that used in preparation of the F.T. thirty share index.

The two stage procedure, initially proposed by Fama, Fisher, Jensen, and Roll (1969), has been employed. As they note that the length of exclusion period could influence the regression parameters, a number of different periods were tested. A twenty-five week exclusion period was selected. Any difference in residual pattern associated with the use of a shorter period can be attributed to the inclusion of acquistion related prices in data used to estimate the regression parameters, whereas longer periods produced a similar pattern, indicating that all the distorting abnormal price movements had been excluded.

Firth (1980) noted that systematic changes in company risk may be associated with a desire to acquire or merge. The risk exposure of the acquiring firm, and the slope of its market line may therefore be altered. As a result, he proposed that seperate regression estimates be prepared using the pre- and post-merger data. This technique has been employed. Regression parameters estimated using pre-merger data were applied to the exclusion periods, up to the base dates, whereas the parameters

estimated from post-merger data were applied to the latter halves of the periods.

In a previous application of the Market Model to Irish data, O'Brien (1982) noted that imperfections in the market could cause difficulties in distinguishing the effects of any specific event. The implication is that information leakage could result in abnormal trading before announcement of a takeover bid. As base date has been designated as the date of first public announcement, the exclusion period before this date should allow for any abnormal price behaviour associated with information leakage.

The possibility of thin trading has also been catered for. This problem, first described by Fisher (1966), tends to be associated with small firms, and could therefore be a feature of any study on the Dublin Exchange. The 'trade to trade' method, originally proposed by Scholes and Williams (1977), has been employed. During periods of thin trading, returns are calculated on a trade to trade basis, and they are regressed on market movements calculated over precisely the same intervals. The Market Model parameters are calculated using these paired intervals.

This method will be relatively efficient if the index is developed from frequently traded shares. Otherwise, there may be a tendency to overestimate the slope of the market line. As the Irish Times indices are weighted by market capitalisation, and therefore favours larger firms, the risk of thin trading in the index is minimised.

Marsh (1979) noted that if a 'trade to trade' method is used, heteroscedasticity in the residuals may bias the results. The existance of varying lengths of trading interval could break the requirement that error terms have a constant variance around the regression lines, as variance will be approximately proportional to the length of the trade to trade periods.

To cope with this, a weighted least squares method has been employed. This method, origionally proposed by Fogler (1978), requires an assumption regarding the relationship between variation of the error term and the length of the trade to trade interval. In this study, it has been assumed that variance is directly proportional to the length of the trade to trade period. The assumption may not be fully correct, but application of this technique does eliminate heteroscedasticity by ensuring independence between variance and length of the trade to trade intervals (note Appendix A). The assumed relationship is probably also a very close approximation to the actual relationship.

The Market Model is therefore adapted by weighting its elements by the

square root of the length of the trade to trade intervals and it becomes:
$R_{it}/\sqrt{T} = a_i \times \sqrt{T} + b_i \times R_{mt}/\sqrt{T} + e_{it}^*$,
and $e_{it}^* = e_{it}/\sqrt{T}$,
where $\sqrt{T}$: square root of the trade to trade interval.

Cross-sectional average and cumulative average residuals can then be computed. Statistical tests have also been prepared. Such tests are of particular relevance to this research, as smaller markets, including the Dublin Stock Exchange, may have a tendancy to inefficiant price response. A 't' test (note Appendix B) has been performed on both average and cumulative average residuals, and the results are referred to during the analysis stage of the paper.

Performance of the Victim Firms Group

Average and cumulative average residuals for the group of victim firms are presented in Table 1.

The average residuals fluctuate randomly around a zero value throughout the period up to week −20. This is the expected pattern. The cumulative result does however indicate that the negative variations are somewhat larger, as the values remain negative throughout this period. This could

Table 1: *Average and Cumulative Average Residuals-Victim Firms Group*

Week	A.R.	C.A.R.	Week	A.R.	C.A.R.
−44	−0.026	−0.0268	−17	0.004	0.0013
−43	−0.011	−0.0381	−16	−0.008	−0.0066
−42	−0.004	−0.0421	−15	0.007	0.0007
−41	0.005	−0.0369	−14	−0.001	−0.0008
−40	0.002	−0.0349	−13	−0.004	−0.0058
−39	0.008	−0.0259	−12	0.006	0.0008
−38	−0.021	−0.0477	−11	0.013	0.0139
−37	0.019	−0.0277	−10	0.000	0.0136
−36	−0.018	−0.0457	−09	−0.015	−0.0021
−35	0.018	−0.0274	−08	0.005	0.0030
−34	−0.009	−0.0372	−07	0.012	0.0157
−33	−0.004	−0.0144	−06	0.024	0.0406
−32	0.004	−0.0365	−05	−0.009	0.0311
−31	−0.008	−0.0450	−04	0.058	0.0897
−30	0.011	−0.0331	−03	0.064	0.1542
−29	−0.001	−0.0343	−02	0.015	0.1390
−28	−0.017	−0.0517	−01	0.031	0.1707
−27	−0.004	−0.0559	00	0.100	0.2709
−26	0.010	−0.0456	01	0.042	0.3135
−25	0.014	−0.0314	02	0.019	0.3325
−24	−0.001	−0.0324	03	−0.036	0.2962
−23	0.008	−0.0238	04	−0.005	0.2908
−22	0.000	−0.0231	05	0.004	0.2949
−21	−0.013	−0.0362	06	0.009	0.3046
−20	−0.017	−0.0532	07	−0.004	0.2996
−19	0.008	−0.0444	08	0.028	0.3277
−18	0.041	−0.0028			

imply that the firms that are about to be the subject of a takeover bid tend to experience below average performance. A similar pattern has been identified in both American (e.g. Langetieg (1978)) and British (e.g. Firth (1979)) studies. A definitive conclusion is not possible in this case however, as statistical tests do not confirm negative performance.

There is evidence of a significant price movement in week −18 ($t = 3.164$), however as it is not supported by other adjustments in the surrounding periods, and as it occurs eighteen weeks before first public announcement, any conclusion that it is a reaction to the forthcoming takeover bid is subject to some doubt.

First reaction to the forthcoming bids is therefore indicated by the residuals for weeks −6, −4, and −3. While statistical tests indicate that the result for week −6 is insignificant, those occurring in weeks −4 and −3 are significant at both 1% and 5% levels ($t = 4.280, 4.700$). Further significant price adjustments follow in weeks −1, 0, +1, and +3 ($t = 2.310, 7.313, 3.106, -2.653$), the adjustment in week +3 being negative.

Tests on the remaining residuals confirm that none are statistically significant. It can therefore be concluded that all adjustment of victim company prices is complete within three weeks of first announcement of the bid.

This finding indicates that the Dublin Stock Exchange is reasonably efficient in its response to a takeover bid that is subsequently successful. Any adjustments after the bid date are probably the result of protracted takeover battles.

Statistical tests on the cumulative results confirm that the shareholders who maintained their holding throughout the period will have experienced real gains in the value of their holdings ($t = 3.715$). These gains represent an excess of thirty percentage points over the levels predicted by the market model.

Significant positive residuals during the pre-bid period could be the result of insider trading. As Franks (1978) has noted however, the mere existence of large positive residuals cannot be considered to be evidence in itself of information leakage. In order to test a hypothesis of insider trading, it would also be necessary to isolate the benefits to those who would be likely to gain, were they in possession of prior knowledge.

Performance of the Acquiring Firms Group

Average and cumulative average residuals for the acquiring firms group are presented in Table 2.

Table 2: *Average and Cumulative Average Residuals-Acquiring Firms Group*

Week	A.R.	C.A.R.	Week	A.R.	C.A.R.
- 44	- 0.024	- 0.0247	05	- 0.010	- 0.0376
- 43	- 0.002	- 0.0270	06	0.005	- 0.0323
- 42	- 0.006	- 0.0377	07	0.005	- 0.0269
- 41	- 0.006	- 0.0402	08	- 0.008	- 0.0355
- 40	0.007	- 0.0328	09	- 0.026	- 0.0618
- 39	0.008	- 0.0239	10	0.000	- 0.0620
- 38	0.010	- 0.0130	11	- 0.006	- 0.0687
- 37	- 0.004	- 0.0172	12	0.002	- 0.0662
- 36	- 0.003	- 0.0202	13	- 0.006	- 0.0727
- 35	0.003	- 0.0170	14	- 0.009	- 0.0825
- 34	0.008	- 0.0085	15	- 0.007	- 0.0898
- 33	0.001	- 0.0072	16	0.000	- 0.0895
- 32	0.005	- 0.0013	17	- 0.011	- 0.1007
- 31	0.000	- 0.0009	18	- 0.002	- 0.1028
- 30	0.000	- 0.0014	19	0.009	- 0.0934
- 29	0.003	0.0017	20	0.000	- 0.0941
- 28	- 0.008	- 0.0062	21	- 0.007	- 0.1012
- 27	- 0.009	- 0.0161	22	- 0.008	- 0.1098
- 26	0.010	- 0.0054	23	0.003	- 0.1067
- 25	0.002	- 0.0024	24	0.001	- 0.1053
- 24	- 0.009	- 0.0121	25	- 0.001	- 0.1072
- 23	- 0.014	- 0.0265	26	0.021	- 0.0858
- 22	0.003	- 0.0228	27	0.010	- 0.0752
- 21	- 0.002	- 0.0255	28	0.014	- 0.0610
- 20	- 0.009	- 0.0354	29	- 0.004	- 0.0654
- 19	- 0.004	- 0.0396	30	0.004	- 0.0611
- 18	- 0.008	- 0.0479	31	- 0.003	- 0.0648
- 17	0.003	- 0.0440	32	0.001	- 0.0637
- 16	- 0.007	- 0.0368	33	0.007	- 0.0559
- 15	0.002	- 0.0343	34	0.008	- 0.0472
- 14	0.001	- 0.0326	35	0.004	- 0.0424
- 13	0.008	- 0.0238	36	- 0.005	- 0.0474
- 12	- 0.006	- 0.0337	37	0.001	- 0.0464
- 11	- 0.006	- 0.0400	38	0.003	- 0.0427
- 10	- 0.004	- 0.0445	39	- 0.002	- 0.0455
- 09	0.003	- 0.0408	40	- 0.004	- 0.0500
- 08	0.014	- 0.0264	41	0.002	- 0.0474
- 07	0.002	- 0.0242	42	- 0.002	- 0.0499
- 06	0.023	- 0.0002	43	- 0.002	- 0.0527
- 05	0.000	- 0.0001	44	0.000	- 0.0532
- 04	- 0.004	- 0.0043	45	0.002	- 0.0503
- 03	0.009	0.0055	46	0.012	- 0.0376
- 02	- 0.034	- 0.0287	47	- 0.004	- 0.0423
- 01	0.002	- 0.0266	48	- 0.001	- 0.0433
00	0.002	- 0.0242	49	0.009	- 0.0333
01	0.000	- 0.0232	50	0.001	- 0.0316
02	0.014	- 0.0084	51	0.001	- 0.0391
03	- 0.025	- 0.0343	52	0.002	- 0.0370
04	0.006	- 0.0274	53	- 0.003	- 0.0408
			54	- 0.004	- 0.0453

Up to week - 10, the only sizeable price adjustment that can be identified is in week - 44. As it occurs many months before the forthcoming acquisitions, it is assumed to be unrelated, and it has been discounted in the analysis. Statistical tests confirm this observation, as no other residuals, with the exception of the marginally significant readings in

weeks −39 and −23 (t = 1.375, −1.795), indicate any departure from expected price levels. This period is therefore characterised by a pattern of normal fluctuations that produce no significant effect on the cumulative value of the shareholdings.

There is evidence of a departure from the pattern of random fluctuations after week −10. The large positive and negative residuals in weeks −6 and −2 are significant (t=2.997, −4.282), while the average residual in week −8 is marginally significant (t=1.801). This would indicate that the forthcoming bids are anticipated by six weeks.

Average residuals in the post announcement period are also significant (t(+2)=2.134, t(+3)=−3.733). A final fall in value of over two percentage points in week +9 leads to a cumulative loss of over six percentage points by week +12. Statistical tests indicate that this cumulative decline in value is not significant however (t=−1.114). This finding is in common with the results of other empirical studies. There is no evidence to support a hypothesis of decrease in value as a result of successful acquisition, in the short-term.

A further point of interest is that following a return to the pattern of random fluctuations, the average residuals for weeks +26, +27, and +28 indicate an increase in share values, leading to a net gain of four percentage points over the predicted market levels by week +28. Although only the residual for week +26 is significant (t=3.094), there is an improvement in the cumulative residuals, and tests confirm that the net fall in value is highly insignificant by week +28 (t=−0.907). Although this adjustment occurs long after the base dates, it may indicate an alteration in the market assessment of the long-term economic effects of acquisition.

Average and cumulative average residuals after this date indicate a return to a pattern of random fluctuations. By the end of the two year period, the cumulative results suggest an average net decrease in share values of 4.5 percentage points approximately. Tests confirm that this is not significant (t=−0.777).

In the event of substancial prior holding of victim company shares, it is possible that any price increases associated with announcement date could be partially due to such a holding. As any losses identified during the acquisition period are exclusive of these interests, the level of losses to acquirors may then be greater than that indicated by the residuals. Nontheless, as statistical tests suggest that average fall in value over the assessment period is strongly insignificant, the overall findings should not be altered. Also, price increases in weeks +26 to +28 may indicate

market inefficiency, but they do not lead to a significant long run change in company values.

Conclusions

The empirical findings on victim company performance are not dissimilar to the results of other studies.

The anticipation period, or length of time between first price movement and takeover, has been found to vary considerably. Halpern (1973), and Mandelker (1974), using similar methodologies, identified a reaction up to seven months prior to acquisition. These findings are not directly comparable with this study however, as performance was evaluated relative to acquisition date rather than the date of first public announcement. Early British studies by Franks, Broyles and Hecht (1977), and Firth (1976), suggested a shorter anticipation period. The Firth study, which was based on initial announcement date, found a one-month anticipation period. Later work by Firth, which improved on the basic methodology, identified a six week anticipation period. Further, more recent U.S. studies (e.g. Langetieg (1978), Dodd and Ruback (1977), Bradley (1980)) have found anticipation periods of a similar scale.

As the average anticipation period in this study was found to be four or five weeks, a comparison suggests that the Irish market may be marginally slower in anticipating a forthcoming takeover bid than its larger neighbours.

The scale of increase in victim share prices (approximately thirty-two percentage points) is also similar to that reported in other studies. Using U.S. data, Bradley (1980) found a cumulative excess of thirty-four points to shareholders who were the subject of a successful tender offer, whereas Dodd (1980) estimated excess returns that exceed this. Firth (1979, 1980), using British data, identified cumulative returns in excess of thirty points. Allowing for variations in metholodogy and length of estimation period, the results of this study are of the same magnitude.

In a review of published empirical work since 1980, Jarrell, Brickley, and Netter (1988) reported similar results. Excess positive returns were found to average between twenty and thirty percent. Evidence of significant price increases prior to formal announcement of the bids was also reported. They note however that much of this activity could be due to either media speculation or a bidder's foothold acquisition in the target, rather than illegal insider trading.

The literature has noted that the targets of a takeover bid tend to experience performance below the industry or market average. Both Mandelker

(1976) and Ellert (1976) identified poor pre-merger performance, while Kummer and Hoffmeister (1978) found evidence of poor performance for all targets, with the exception of those categorised as passive-successful. The results of this study are inconclusive. There is evidence of below average performance during the pre-acquisition phase, however it is statistically insignificant. A possible explanation is that a higher proportion of the takeovers in this study are the result of an agreed merger between firms experiencing average performance, rather than an agressive acquisition of businesses exhibiting sub-optimal performance.

Empirical evidence on the effect of takeover on acquiring company performance is less clear. Early U.S. studies found little evidence of price change, whereas more recent papers, including those of Dodd (1980), Asquith (1983), and Malatesta (1983), while finding individual positive residuals during the acquisition period, actually present evidence of a small long-run decrease in value. The cumulative price changes tend to be insignificantly small however.

British empirical research has provided more conclusive findings. Franks, Broyles, and Hecht (1977), in their study of mergers in the brewing industry, did find evidence of a permanent fall in value following acquisition, but Barnes (1978), while identifying a slight fall in acquiror values, found that the long-run effect was not significant, and concluded that acquisition did not have a permanent effect on value. Firth, in his '79 and '80 papers, found significant decreases in the value of buying firms as a result of takeover. He proposed that the existence of a more efficient acquisitions market in the U.K. may have ensured that potential gains all accrue to victim company shareholders.

Later American empirical work provides a partial explaination for the difference between these findings. A study by Jarrell and Bradley (1980) on the share price effects of acquisition, both before and after the introduction of regulations protecting the interests of victim shareholders, found that whereas both groups of acquirors did experience an increase in value, increases in the post-regulation period were smaller. Further studies by Schipper and Thompson (1983) and Weir (1983) confirm this. Poorer levels of shareholder protection in the American environment, relative to Britain and Ireland, could therefore explain the gains in acquiring company value, as the majority of potential profits may not have accrued to target company shareholders.

The absence of a significant fall in the value of Irish acquiring company shares could therefore be partially explained by two factors. Regardless of any difference in the amount of legislation regarding shareholder protection, the authorities may have been less willing than their British

counterparts to apply their powers. The market for takeovers in Dublin may also not be as efficient as London, allowing acquirors to purchase at a lower price than could be expected were there more competition. The existence of a number of agreed takeovers could, to some extent, explain this lack of competition.

If the two sets of findings are combined, the evidence would indicate that the mergers and takeovers are, on average, value enhancing. As recent U.S. studies on the potential source of takeover gains have tended to reject the redistribution theories (note: Jarrell, Brickley, and Netter (1988)), there is an implication that acquisitions on the Dublin exchange lead to an economically beneficial transfer of productive resources.

Scherer (1988) argues however that this interpretation need not necessarily be correct. If takeover does in fact lead to a more efficient management of resources, profitablity in the post-takeover period should actually be increased. If, using accounting baised measures, the researcher fails to find evidence of a significant improvement in the acquired lines of business, a hypothesis of value enhancement cannot be confirmed. Futher empirical research may therefore be required.

It can be argued that the findings of this study may, to some extent, be due to the fact that potential targets have been over-valued by the market. The existence of negative residuals in the post-acquisition period may provide support for this thesis. An absence of statistical significance could be due to the fact that variance will increase with the period of time studied, so that statistical tests may not always identify a significant fall in value.

Appendix A (Heteroscedasticity in the error terms)

Assuming that variance of the residuals is directly related to the length of the trade to trade interval, the Market Model is adapted by weighting its elements by the square root of the trade to trade time interval. It therefore becomes:

$R_{it}/\sqrt{T} = a_i \times \sqrt{T} + b_i \times R_{mt}/\sqrt{T} + e_{it}^*$,
where $\sqrt{T}$: square root of the trade to trade interval,
and $e_{it}^* = e_{it}/\sqrt{T}$

As the variance of the new error term (e_i^*) is:
$\text{Var}(e_i^*) = \text{Var}(e_i/\sqrt{T}) = 1/T \times \text{Var}(e_i)$.

Assuming that the origional variance is directly related to the length of the trade to trade interval, then:

$\text{Var}(e_i) = T\sigma^2 e_i$, therefore:
$\text{Var}(e_i^*) = T\sigma^2 e_i \times 1/T = \sigma^2 e_i$.

Variance of the error term is therefore forced to become a constant. The risk of bias associated with heteroscedasticity has therefore been eliminated.

Appendix B (Statistical tests)

As statistical significance has been assessed by means of 't' test, both average and cumulative average residuals are devided by an estimate of their standard deviation. Residuals representing the period prior to the base date are assessed using a measure prepared from an estimation period consisting of readings prior to the exclusion period, and vice versa.

The test statistic for average residuals is therefore:

't' $= AR_t/\hat{\sigma}(AR)$,

and $\hat{\sigma}(AR) = \sqrt{1/L\sum_{t=1}^{L}(AR)_t - X)^2}$,

and $X = 1/L\sum_{t=1}^{L} AR_t$,

where L : no. of av. residuals in the estimation period,
X : av. measure of av. residuals in estimation period,
$\hat{\sigma}(AR)$: time series estimate of standard deviation of the average residuals.

The test statistic on cumulative average residuals, assessing the significance of overall departures from expected price levels since the beginning of the two year period is:

't' $= CAR[T]/\hat{\sigma}(CAR)$,

and $\hat{\sigma}(CAR) = \hat{\sigma}(AR) \times \sqrt{K}$,

where CAR[T] : cululative average residual for the first T periods,
and $\hat{\sigma}(CAR)$: time series estimate of the standard deviation of the cumulative average residuals,
K : no. of observations in the cum. av. residual,
$\hat{\sigma}(AR)$: defined above.

An improvement to this test statistic, proposed by Ruback (1982), has been applied in this instance. As the residuals may be subject to a degree of first order autocorrelation, the cumulative average residuals may also be subject to this dependence. As a result:

$\text{Var(CAR)} = K.\text{Var(AR)} + 2(K-1)\text{Cov}(Ar_t, AR_{t-1})$,

where Var (CAR) : variance of the cum. av. residual,

Var(AR) : variance of the average residual,

$\text{Cov}(AR_t, AR_{t-1})$: first order autocovariance of av. residuals

K : defined above.

If this dependence does exist, an improvement to the test statistic has been proposed:

't' = CAR [T]/$\hat{\sigma}$ (CARa),

and $\hat{\sigma}$ (CARa) = $\sqrt{K(\hat{\sigma}(AR))^2 + 2(K-1)\text{Cov}(AR_t, AR_{t-1})}$,

and $\text{Cov}(AR_t, AR_{t-1}) = 1/L\left\{\sum_{t=1}^{L}(AR_t - X)(AR_{t-1} - X)\right\}$,

where CAR [T] defined above

$\hat{\sigma}$ (CARa) : estimate of standard deviation of CAR, adjusted for first order autocorrelation,

K : defined above,

L : defined above,

$\hat{\sigma}$ (AR) : defined above,

X : defined above.

In the absence of first order autocorrelation, a zero value would cause the test to revert back to that which was origionally described.

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