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Adjusting for Beta Bias: An Assessment of Alternate Techniques: A Note

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ABSTRACT

This paper tests the effectiveness of techniques proposed by: Scholes-Williams; Dimson; Fowler, Rorke, and Jog; and Cohen, Hawawini, Maier, Schwartz, and Whitcomb to control for bias in beta estimates from thin trading and price adjustment delays. Each technique produces beta estimates that reduce the amount of this bias, but the amount of reduction in the best case is only 29%.

AT LEAST TWO SOURCES of beta bias have been well-documented—trading delays and price adjustment delays. Fisher [7] was the first to recognize the potential problems caused by nontrading which, subsequently, has been shown to bias beta estimates. For a given differencing interval length and market index, Scholes and Williams [24], Dimson [5], and Fowler, Rorke and Jog [9, 10] (FRJ) present analytical and empirical evidence that betas of securities that trade less (more) frequently than the index used in their estimation are downward (upward) biased.

Cohen, Hawawini, Maier, Schwartz, and Whitcomb [CHMSW] [3] were among the first to recognize the importance of price adjustment delays as a source of beta bias. McInish and Wood [19] provide evidence of the potential for price adjustment delays and thin trading delays to affect the results of studies in which segmentation of returns into periods is important. CHMSW describe a number of different sources of price adjustment delays including transactions costs and actions of market makers. These authors show that for a given differencing interval length, a security with more (less) trading delay than the market will have its beta biased downward (upward). Thus, price adjustment delays and thin trading result in similar bias in beta estimates. Clearly, these two sources of bias are related since *prices* (as opposed to quotations) cannot adjust to reflect a changed market equilibrium without a transaction occurring.

Techniques for estimating betas so as to control for thin trading bias have been proposed by Scholes and Williams [24], Dimson [5], and FRJ [11].[1] Each

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[1] Marsh [16] and Dimson [5] propose the use of trade-to-trade betas to control for thin trading bias. But Dimson and Marsh [6] and Ord, McInish, and Wood [20] find that trade-to-trade betas do not effectively correct this bias. McInish and Wood [18] suggest the use of a linear programming model to construct portfolios with the same level of thin trading, but with maximum differences between portfolios in another variable of interest, thereby controlling for thin trading in research designs.

of these authors offers evidence that their technique adequately controls for thin trading. But Fowler and Rorke [8] and FRJ [9] offer evidence that the Scholes-Williams and Dimson approaches do not adequately control for thin trading bias in beta estimation.

Previous tests of the efficacy of these three beta estimation techniques have two shortcomings. First, in most cases, simulated or artificially created data are used. It is impossible to be confident that the results of tests using artificial and simulated data will hold for actual data since the error structure of returns is inadequately understood at this point. Second, when actual data are used, the true beta of each security is unknown. Hence, previous researchers who used actual data were unable to ascertain how much bias results from thin trading. Consequently, they could not measure how effectively their techniques controlled for thin trading.

CHMSW [4] have proposed a technique for adjusting beta estimates which involves estimation of the cross-sectional interval/thinness relationship. This technique is based on the proposition that as the differencing interval is lengthened, OLS betas approach true betas.[2] CHMSW [4] and Fung, Schwartz, and Whitcomb [12] offer empirical evidence of the effectiveness of the CHMSW approach.

This paper extends previous work by providing evidence of the extent of bias from thin trading and price adjustment delays for OLS betas estimated using daily data. Further, the effectiveness of the Scholes-Williams, Dimson, FRJ, and CHMSW techniques for adjusting beta estimates for the bias created by thin trading and trading delays is investigated using a new approach which employs actual data and allows for the construction of portfolios with known true betas.

This paper is divided into four parts. The next section discusses the data and methodology. Then the following two sections present the results and discuss limitations of the study. The final section provides a summary.

I. Data and Methodology

The results described below are based on data for 958 firms listed on the NYSE. A tape was obtained which contains the price of every trade on the exchange from September 1, 1971–February 28, 1972. Prices were adjusted for dividends and changes in capitalization. The proxy for thin trading used is the average time in minutes from last trade to market close (LTIME). LTIME is a direct measure of trading delays. CHMSW [3, 4] and Theobald [26] suggest a number of reasons that a lower value of a measure such as LTIME should be associated with shorter price adjustment delays. Among these reasons are that actively traded securities have a greater following among security analysts and a smaller bid/ask spread.

LTIME and average stock price over the test period (STOCK PRICE) are

[2] CHMSW [4] proposed a second technique (in addition to the one examined in this paper) to control for beta bias; this technique involves estimating the asymptotic value that beta approaches as the differencing interval is lengthened. The data employed in this paper, which only spans six months, does not permit a test of this CHMSW beta adjustment technique.

calculated from the tape just described. Daily returns (PORTFOLIO RETURN) for the period March–August 1971 are taken from the CRSP tape. Market value of common stock outstanding (MARKET EQUITY) is estimated by taking the closing price of each security as of December 31, 1971 from the transactions tape and multiplying by the number of shares outstanding (from the COMPUSTAT tape). Each of the remaining variables is measured as the average of annual values for 1969 to 1973 using data from the COMPUSTAT tape.

In order to isolate the beta bias, portfolios are formed which have equal risk attributes and for which known return anomalies are controlled while the difference in LTIME is maximized across the portfolios. To meet this objective, five portfolios are constructed using a linear programming model which maximizes the difference in LTIME while holding the levels of portfolio geometric mean holding period return (PORTFOLIO RETURN), debt/assets (FINANCIAL LEVERAGE), dividend/earnings (PAYOUT RATIO), average stock price (STOCK PRICE), book value of assets (ASSETS), and standard deviation of both STOCK PRICE and ASSETS approximately equal. The difference in the level of LTIME is maximized between the extreme portfolios, but held constant between each consecutive portfolio. Thus, the difference in the level of LTIME between portfolios one and two is about the same as that between portfolios two and three, etc. The control variables are chosen because of the possibility that they might be systematically related to market risk or to return anomalies. This belief is based, at least in part, on the following references: ASSETS (Thomadakis [27], Banz [2], and Reinganum [21]); FINANCIAL LEVERAGE (Hamada [14]); PAYOUT RATIO (Ball [1]); and STOCK PRICE (Roll [23]).

According to the CAPM developed by Sharpe [25] and Lintner [15], on an ex ante basis, portfolios with equal expected returns should have equal betas. Thus, holding the portfolio returns equal should equalize their true betas to the extent that ex post returns are unbiased estimators of ex ante returns. Returns for the six months prior to the beta estimation interval are used as the ex ante return proxy. While this allows some divergence in the level of returns across portfolios during the test interval, it prevents the same set of errors from entering the analysis twice—first as the difference between ex post and ex ante returns, and second as residuals for the beta estimates.

In part, the error introduced by the assumption that ex post returns are valid estimators of ex ante returns can be corrected by controlling for other known risk determinants. In the LP model, this is accomplished by constraining FINANCIAL LEVERAGE, STOCK PRICE, PAYOUT RATIO, and ASSETS to be equal for each portfolio.

Controlling for ASSETS and STOCK PRICE prevents errors associated with these variables. Merely holding the mean of ASSETS and STOCK PRICE equal for each portfolio may be inadequate, since the LP model will meet these constraints for an extreme portfolio by selecting very large and small firms as well as very high- and low-priced stocks (if an increase in the objective function can be obtained from this solution strategy). Holding the standard deviation of these attributes approximately constant across the portfolios prevents this occurrence. Standard deviation of a portfolio attribute is indirectly held constant by equalizing the sum of the squared deviations from the mean of the portfolio attribute. The LP model could also be used to equalize higher moments of the portfolio attributes in each portfolio, but an examination of the higher moments indicated that this was unnecessary.

The mean of the OLS beta estimates for the individual securities in each of the five portfolios will reveal the extent of beta bias for NYSE stocks. Further, if they successfully correct for beta bias, the Scholes-Williams, Dimson, FRJ, and CHMSW betas should equal approximately 1.0 for each portfolio. A comparison of these three beta estimates with the mean of the OLS betas for each portfolio will show the extent that each technique corrects for this bias.

The research design assumes that all significant determinants of beta have been held equal across the five portfolios. This research design is compromised only if determinants of beta which are also correlated with LTIME are omitted. While this represents a limitation of the approach, it seems reasonable to believe that the control variables (identified above) are the most important determinants of beta.

The formulation of the linear programming model is as follows:[3]

Maximize:

$$\textstyle\sum_j f_{5j}\ \mathrm{LTIME}_j - \sum_j f_{1j}\ \mathrm{LTIME}_j, \quad j = 1, \cdots, 958 \text{ firms} \tag{1}$$

Subject to:

$$\textstyle\sum_j f_{i-k,j}\mathrm{LTIME}_j - \sum_j f_{i-k-1,j}\mathrm{LTIME}_j = \sum_j f_{i-k-1,j}\ \mathrm{LTIME}_j - \sum_j f_{i-k-2,j}\mathrm{LTIME}_j, \quad i = 1, \cdots, 5 \text{ portfolios}, \quad k = 1, 2, 3 \tag{1a}$$

$$\textstyle\sum_j f_{ij}X_j = \sum X_j/5_j \pm \Delta \quad i = 1, \cdots, 5 \text{ portfolios.} \qquad \text{(1b)–(1h)}$$

X = PORTFOLIO RETURN (1b), ASSETS (1c), FINANCIAL LEVERAGE (1d), PAYOUT RATIO (1e), STOCK PRICE (1f), squared deviation of STOCK PRICE (1g), and squared deviation of ASSETS (1h)

$$\textstyle\sum f_{ij} = 958/5 \pm \Delta \tag{1i}$$

$$\textstyle\sum_i f_{ij} = 1 \pm \Delta \qquad j = 1, \cdots, 958 \text{ firms} \tag{1j}$$

where f_{ij} is the LP solution variable which represents the amount of the i^{th} portfolio's funds invested in firm j, and the remaining variables are as previously described. The Δ has a value of 1% of each of the right-hand side values, which allows the LP to attain feasibility. The functions of the constraints and the objective function will be explained next.

The objective function maximizes the difference in the level of LTIME between portfolios one and five, while constraint (1a) equalizes the difference in the mean level of LTIME between portfolios one and two, two and three, etc. Constraints (1b) through (1f) equalize the means of the respective portfolio attributes. Constraints (1g) and (1h), in conjunction with (1c) and (1f), equalize portfolio STOCK PRICE and ASSETS standard deviations, respectively. Constraint (1i) divides the 958 firms approximately evenly across the five portfolios, while

[3] A comparable model is applied to accounting data in Hill and Stone [13].

constraint (1j) forces each firm into at least one portfolio. Note that firms may be split between portfolios, although this occurs infrequently—97% of the non-zero solution values (f_{ij}'s) were 1.0.

For the period September 1, 1971–February 28, 1972, daily returns are calculated (using the NYSE tape) for the common stock of each of the firms and for an equally weighted market index comprising the returns of the 958 sample firms. Then, OLS, Scholes-Williams, Dimson, and FRJ betas are estimated for each of the five portfolios. The Scholes-Williams method uses

$$\hat{\beta} = \frac{\beta_n^- + \beta_n + \beta_n^+}{1 + 2\rho} \tag{2}$$

where β_n^-, β_n, and β_n^+ are the coefficients of the return on the market from three separate regressions in which the return on the security or portfolio is regressed, in turn, on lagging, coincident, and leading returns on the market, and ρ is the first-order autocorrelation coefficient of the market return proxy. The Dimson betas are estimated using 21 leads and 5 lags (the same lead/lag structure used by Roll [22]), one lead and one lag and five leads and five lags. Betas for the individual firms are combined using the linear programming solution value weights for each of the five portfolios. For a description of the FRJ technique, interested readers are referred to [11].

As noted in the previous section, CHMSW [4] propose to adjust OLS betas using the cross-sectional interval/thinness relationship. First, for each firm, j, in the sample (CHMSW use 50 firms), the usual market model is estimated for a variety of differencing interval lengths (CHMSW use 14; $L = 1, \cdots, 6, 8, 10, 12, 14, 15, 16, 18$, and 20 days). Then, for each security, CHMSW estimate the following equation:

$$\hat{\beta}_{jL} = a_j + b_j L^{-n} + \varepsilon_{jL},\ n > 0, \quad \forall \quad L \text{ and } j. \tag{3}$$

where $\hat{\beta}_{jL}$ is the security's OLS beta (from the market model) estimated for differencing interval length, L (in days), ε_{jL} is a random error term, and a_j and b_j are parameters to be estimated. The value of n is chosen to give the best linear fit. For the sample of 50 firms, CHMSW [4] then estimate the cross-sectional interval/thinness relationship as follows:

$$\hat{b}_j = c + b \ln V_j + \varepsilon_j, \quad j = 1, \cdots, 50. \tag{4}$$

where $\hat{b}_j$ = the coefficient of L^{-n} from Equation (3), V_j = the market value of shares outstanding as of December 31, 1971 (MARKET EQUITY), ε_j = a random error term, and c and b are parameters to be estimated.

For a sample of 50 NYSE firms, CHMSW obtained the following estimates for Equation (4):

$$\hat{b}_j = -2.637 + 0.181 \ln V_j. \tag{5}$$

Once Equation (5) has been obtained, an "inferred" asymptotic beta can be calculated for each firm by subtracting $\hat{\beta}_j$ from the OLS beta for that firm. Fortuitously, CHMSW used an estimation period that spans the sample period used in his study. Hence, using MARKET EQUITY as of December 31, 1971, Equation (5) can be used to calculate inferred asymptotic betas for each of the 958 firms in the sample. The effectiveness of these inferred betas in correcting for beta bias can be tested using the LP model described above.

II. Results

For each of the five portfolios, Table I presents the mean and standard deviation of various portfolio attributes. It is evident that the model has created portfolios that maximize the difference in LTIME while holding PORTFOLIO RETURN, FINANCIAL LEVERAGE, PAYOUT RATIO, STOCK PRICE, ASSETS, and the standard deviations of these last two attributes approximately equal.

The two primary questions addressed in this paper are: (1) What is the extent of bias in beta estimates due to thin trading and price adjustment delays? (2) How effective are the techniques proposed by Scholes-Williams, Dimson, FRJ, and CHMSW in controlling for this bias?

Table II presents the mean OLS, FRJ, Scholes-Williams, Dimson, and CHMSW beta estimates for the securities in each of the five portfolios, their overall averages, and the spread of beta estimates. Recall that because of the portfolio formation technique, the betas should be equal to each other except for the influence of thin trading and price adjustment delays. Further, since the same sample of stocks and the same weighting are used in the construction of the market index and the estimation of the betas, in the absence of beta bias, the

Table I

Statistics for Portfolio Attributes (Weighted by LP Solution Values)

(a) Means of Portfolio Attributes

Level of Non-Synchronous Trading (LTIME)	PORTFOLIO RETURN	ASSETS	FINANCIAL LEVERAGE	PAYOUT RATIO	STOCK PRICE	MARKET EQUITY
48.52	0.00069	923.0	0.53	0.42	32.16	609
37.54	0.00076	924.7	0.53	0.42	32.16	609
26.56	0.00078	921.9	0.53	0.42	32.16	609
15.59	0.00094	924.7	0.53	0.42	32.16	609
4.63	0.00080	928.6	0.53	0.42	32.16	611

(b) Standard Deviation of Portfolio Attributes

ASSETS	FINANCIAL LEVERAGE	PAYOUT RATIO	STOCK PRICE	MARKET EQUITY
2750	0.17	0.26	21.24	2701
2750	0.17	0.26	21.20	2111
2750	0.17	0.26	21.24	1755
2730	0.17	0.26	21.08	1782
2778	0.17	0.26	21.52	1412

Note: Level of thin trading represents average time from last trade to market close; PORTFOLIO RETURNS are natural logarithms of average daily return relatives for period September 1971–February 1972; means and standard deviations of ASSETS and MARKET EQUITY are in million $.

Table II

Beta Estimates

Portfolio Level of Thin Trading (LTIME)	OLS	FRJ	Scholes-Williams	Dimson (Leads/Lags) 1/1	5/5	5/21	CHMSW
48.52	0.744	0.815	0.779	0.785	0.805	0.805	1.213
37.54	0.785	0.847	0.812	0.804	0.834	0.808	1.256
26.56	0.864	0.915	0.900	0.911	0.951	0.950	1.310
15.59	1.075	1.114	1.094	1.112	1.068	1.102	1.523
4.63	1.494	1.524	1.424	1.394	1.348	1.341	1.901
Means:	1.000	1.041	1.000	1.000	1.000	1.000	1.439
Beta Spread: (High-Low)	0.750	0.709	0.64	0.609	0.543	0.536	0.688

OLS betas must average 1.0 cross-sectionally. Note that the OLS betas are biased in the expected directions—betas for those portfolios comprising stocks traded more frequently than the market proxy are above 1.0, while those comprising stocks traded less frequently are less than 1.0. The range of the OLS betas, 0.744 to 1.494, suggests that the bias from thin trading and price adjustment delays is substantial for NYSE stocks when daily returns are used for beta estimates.

If the Scholes and Williams, Dimson, FRJ, and CHMSW techniques were sufficient to correct for beta bias, then betas estimated using each technique should be approximately 1.0 for each of the five portfolios. Instead, even the best of the four adjustment techniques produces a spread from low to high beta estimates only 29% less than that experienced for OLS betas. Further, beta estimates for each technique remain monotonic across the LTIME ranks.

Of course, it would not be surprising that methods designed to adjust for trading delays were insufficient if price adjustment delays were also an important source of beta bias. Interestingly, both the Scholes-Williams and Dimson methods achieve a greater reduction in beta spread than the CHMSW technique (which controls for both sources of bias). Possible reasons for this result are discussed in the next section.

Because the CHMSW approach requires the use of MARKET EQUITY as a proxy for thinness, MARKET EQUITY could not be used as a constraint in the LP model when all four techniques were to be tested. The LP results reported below were also replicated using MARKET EQUITY and squared deviation of MARKET EQUITY as constraints with substantially similar results for the three techniques other than CHMSW.

III. Discussion

This study has limitations, several of which are reviewed in this section. It should be evident that much remains to be done.

This is the first use of a linear programming model to develop portfolios with equal risk (betas). Naturally, the results are a joint test of the beta adjustment techniques examined and the methodology used. While the linear programming approach to portfolio formulation holds promise, additional work may uncover weaknesses in the approach that are not now known. For example, if variables in the objective function or constraint rows are measured with error, and if these errors are correlated with estimated betas, a problem analogous to OLS errors-in-variables arises.

The results obtained for the portfolios created by the linear programming model may not be representative of the results that would be achieved for randomly selected portfolios. This is especially likely for the CHMSW method. The CHMSW method examined in this paper uses (the natural log of) MARKET EQUITY as a proxy for thinness in Equation (5), leading to several problems. The correlation between MARKET EQUITY and ASSETS (which is held approximately constant across portfolios by the LP model) is 0.85. To examine whether the results for the CHMSW approach are due to the similiarity of MARKET EQUITY for the five portfolios, portfolios are created using additional LP constraints that result in a greater variability of MARKET EQUITY across the five portfolios. But the results are essentially unchanged.

Also, it seems likely that use of a more refined proxy for thinness would improve the CHMSW results. The R^2 for Equation (5) of 0.66 indicates that cross-sectional variation in beta is not fully explained by differences in MARKET EQUITY. This conclusion is reinforced by the coefficient of correlation between LTIME and MARKET EQUITY which is only −0.19. McInish and Wood [17] have developed a proxy for the average time between trades (MINTERVAL), achieving a correlation of over 0.95 between the proxy and MINTERVAL for a holdout sample. MINTERVAL, in turn, has a correlation of over 0.98 with LTIME.

As shown in Table II, the CHMSW technique imparts an upward bias to beta estimates. The mean CHMSW beta reported here is similar to that reported by CHMSW [4] (calculated from their Table IV) and probably results from the use of Equation (5). The Scholes-Williams and Dimson techniques also produce beta estimates with substantial upward bias when an equally weighted market proxy is used to estimate betas. For this reason, a value-weighted proxy is employed.

Another source of limitations is differences in assumptions concerning the nature of the data. Scholes and Williams [24] omit returns for any day a security does not trade and for the following day. Dimson [5] assumes that true returns are generated continuously through time. The present study uses a transactions time assumption. If a security trades, its return for the day is the difference (in logs) between the last trade of the day and the last trade on the most recent day on which the security traded (even if there have been several intervening trading days); returns for days on which no trade occurred are zero.

In the process of developing their beta adjustment procedure, FRJ [9, 10, 11] identify three types of securities: fat securities have a closing trade on the last trading day of every month; moderate securities have a trade during each month, but not always on the last day; and infrequent securities do not have a trade in every month. This study extends their work by substituting "minute" for "day" and "day" for "month" in these definitions. As a result, there are no fat securities

(securities that trade in the last minute of every day) in the sample used in this paper.

The research design assumes that LTIME is an appropriate measure of the factor(s) that each of the beta adjustment techniques seeks to control and that this factor(s) is the determinant (or is a proxy for the determinant) of beta bias. While LTIME is an obvious measure of trading delays, it may or may not be a good proxy for price adjustment delays. Such a circumstance could explain why the techniques tested are not completely successful in correcting beta bias. There is a need for both theoretical and empirical work to develop and test suitable measures of price adjustment delays, and to determine the relative impact of both trading delays and price adjustment delays on beta bias.

IV. Summary and Conclusions

It is well-known that beta estimates are biased due to thin trading and price adjustment delays. A linear programming model is used to investigate the extent of beta bias for NYSE stocks and the effectiveness of techniques proposed by Scholes and Williams; Dimson; Fowler, Rorke, and Jog (FRJ); and Cohen, Hawawini, Maier, Schwartz, and Whitcomb (CHMSW) in correcting this bias.

Five portfolios are created with maximum differences in LTIME (average time in minutes from last trade to market close) and with return and a number of other variables related to risk held approximately equal across the portfolios. Since the return and other risk attributes of each of the portfolios are equal, in the absence of bias, the betas estimated for each portfolio should equal each other. In addition, because the same securities used in constructing the portfolios (weighted in the same way) are also used to build the market index, the betas of the five portfolios must average 1.0 cross-sectionally. Since the betas of the five portfolios should equal each other and must average 1.0, it follows that the betas of each of the five portfolios should also equal 1.0. The extent to which the OLS betas diverge from 1.0 provides a measure of OLS beta bias.

The OLS beta estimates for the five portfolios vary monotonically from 0.744 to 1.494 in the direction expected for thin trading and price adjustment delay bias—portfolios comprising securities traded less frequently than the market proxy have beta estimates less than 1.0 while those with more frequently traded securities have beta estimates greater than 1.0. Thus, evidence is provided that bias due to thin trading and price adjustment delays is substantial for NYSE stocks when daily returns are used.

Each of the four beta adjustment techniques considered moves the portfolio beta estimates in the direction of reducing the amount of bias. However, the best technique, Dimson betas, reduced the bias by only 29% compared with the spread in OLS beta estimates.

Several limitations that may serve as the basis for future research are discussed in the final section.

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