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Measurement Effects and the Variance of Returns After Stock Splits and Stock Dividends

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This article examines the relation between two factors affecting stock returns, the bid-ask spread and price discreteness, and the increase in return variance after ex-dates of stock splits and stock dividends. Controlling for these effects, the variance of daily returns still increases significantly. The variance of weekly returns also increases significantly, and the variance of returns for a control sample of nonsplitting firms shows no significant increase. Variance ratio tests show that bid-ask errors are small for these stocks and therefore cannot explain the large increase in variance. Spreads and price discreteness do not explain increased variance after stock distributions.

In a perfect market, the market value of a firm's equity is independent of the number of shares outstanding. Therefore the ex-date for a stock dividend or stock split should simply involve a change in the number of shares outstanding along with a change in the level of the stock price. There should be no change in the distribution of stock returns around ex-dates of stock dividends and stock splits. Previous research has documented changes in stock return distributions

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around these ex-dates, however. Grinblatt, Masulis, and Titman (1984) and others find positive abnormal ex-dividend returns, and Ohlson and Penman (1985) and Dravid (1987) show that return volatility changes after a split. Since the ex-dates of stock splits and stock dividends contain no information and do not alter firm cash flows, these findings are anomalous.[1]

Other authors have analyzed biases caused by the bid-ask spread and price discreteness on stock return distributions. Blume and Stambaugh (1983) show that the bid-ask spread causes an upward bias in rates of return. Gottlieb and Kalay (1985) and others show that rounding continuous prices to discrete price levels causes an increase in the variance of observed returns. Amihud and Mendelson (1987) and Kaul and Nimalendran (1990) show that measured return variances are also biased upward by the bid-ask spread. All of these biases increase at lower price levels. Some authors have suggested that these and other measurement effects may be responsible for the apparent changes in return distributions around ex-dates of stock splits and stock dividends [see, for example, Ohlson and Penman (1985), Dravid (1989), Conroy, Harris, and Benet (1990), Dubofsky (1991), Maloney and Mulherin (1992), Kryzanowski and Zhang (1993), and Conrad and Conroy (1994)]. Specifically, bid-ask spreads and price discreteness, which become larger in relative magnitude at lower postsplit price levels, may contribute to the changes in return distributions. If so, then the previously documented changes in ex-stock split return distributions may result from institutional factors that affect observed prices. Prior empirical studies have been limited by lack of bid and ask quotations data for New York Stock Exchange (NYSE) firms to test this hypothesis.

Using extensive bid and ask quotations data, this article explicitly examines the relation between certain measurement effects and the variance of returns after ex-days of stock splits and stock dividends. These data allow simple, direct tests of the impact of measurement effects on return variances. Consider, first, the impact of the bid-ask spread. As noted by Kaul and Nimalendran (1990), returns computed using transaction prices include bid-ask errors, but returns computed using bid-to-bid quotations exclude the effect of the bid-ask spread. Therefore a comparison of bid-to-bid returns (or ask-to-ask returns) to transaction price returns allows a direct test of the impact of the bid-ask spread on measured return volatility.

[1] Accounting rules require that stock dividends be accompanied by a decrease in retained earnings. If loan covenants or other contracts are based on the level of retained earnings, stock dividends may indirectly affect cash flows. This effect is likely to be minor, and does not apply to stock splits.

Second, concerning price discreteness, for most stocks on the NYSE, price changes occur in multiples of $0.125. Since the order of magnitude of the rounding bias is relatively larger at lower, postsplit prices, a systematic bias due to price discreteness may be partly responsible for the change in return distributions around stock splits. Furthermore, Dravid (1989) argues that the effect of price discreteness on return distributions after stock splits is correlated with, but smaller than, the effect of the spread. It has been difficult, therefore, to isolate the impact of price discreteness. However, returns based on bid-to-bid quotations are not affected by bid-ask bounce. Other things equal, differences between bid-to-bid returns for stocks trading at high postsplit price levels and those trading at low postsplit price levels may be due to the greater bias caused by rounding prices at lower price levels. Ohlson and Penman (1985) partition their stock split sample based on the magnitude of the postsplit stock price and find significant increases in transaction price volatility at all price levels. However, the cause of these increases is not clear. A similar partition of bid-to-bid returns should provide additional evidence on this question.

Results presented in this article show that almost none of the increase in daily return volatility after splits is due to bid-ask measurement error. Controlling for the bid-ask spread, the increase in volatility is also not significantly correlated with the price level. Measurement effects should become less important for longer return intervals, but weekly returns also demonstrate significant increases in volatility for all distribution types and at almost all price levels. The increase in volatility is associated with an increase in actual daily trading volume, but a decrease in volume on a split-adjusted basis. A matched control sample of nonsplitting firms shows no corresponding increase in volatility. Variance ratio tests show that bid-ask bounce is small in magnitude relative to the daily return variance for stocks in the sample that split. This is further evidence that bid-ask errors do not cause the large increase in return variance after splits. Volatility increases do not appear primarily due to the two measurement effects considered in this article. The anomaly associated with the change in return distributions around ex-stock distribution days remains an open question.

The remainder of the article is organized as follows. Section 1 describes the samples. Section 2 outlines the theory and statistical tests. Section 3 reports results for daily return volatility. Section 4 analyzes weekly return variances. Section 5 concludes.

1. Description of Samples

This article analyzes two samples, a sample of splitting stocks and a matched sample of nonsplitting stocks. The sample of splitting firms consists of New York Stock Exchange (NYSE) listed firms implementing stock splits and stock dividends during the period 1987–1989. The splitting sample excludes any event that has an announcement or an ex-date for any other type of dividend (for example, a cash dividend) within 5 days of the stock distribution ex-date.[2] The splitting sample includes 361 stock split or stock dividend events.

The matched control sample also consists of 361 stocks; one control firm is matched to each stock distribution ex-date. Control firms are chosen according to the following criteria. The matched firms are NYSE listed stocks that have no stock split or stock dividend during the sample period. Firms in the matched sample also have no ex-date for other types of dividends within 5 days of the ex-date for the corresponding split. Since the hypotheses of interest relate to measurement effects that are a function of spreads and price levels, control stocks are matched to the splitting firms based on bid-ask spreads and price levels. Specifically, all firms satisfying the above criteria are sorted based first on bid-ask spread and then on price level. Bid-ask spread is defined as the average closing bid-ask spread during the week prior to the ex-date. The control stock with the spread and presplit price level closest to those of each splitting firm using this sorting procedure is chosen.[3]

The Institute for the Study of Security Markets (ISSM) tapes provide closing transaction prices, bid and ask quotations, and trading volume for a period from the announcement date through the ex-dividend date plus 45 days for both samples.[4] Cash dividend information (to compute returns) comes from the Standard & Poor's Corporation *Weekly Dividend Record, Annual Issue*. The ex-dividend date is defined as day 0.

Table 1 summarizes information about the stock distributions for the overall sample and for subsamples based on size of the split. Stock dividends are a natural subgroup because the accounting treatment differs from that for stock splits. Since previous researchers have found

[2] Results are not sensitive to the screen that excludes events with other announcements close to the stock distribution ex-date.

[3] To explore the sensitivity of results for the control stocks to the specific matching criteria chosen, two other control samples are constructed. The first alternative control sample does not match based on price and spread, requiring instead only that the price level be at least $5.00. Control stocks in this alternative group also do not have a dividend announcement within 5 days of the ex-date for the corresponding split. The second alternative control group addresses the concern that any change in volatility might be related to the large increase in price that typically precedes stock splits. Control stocks are matched based on the price increase in the month before the split rather than the price level and bid-ask spread. Inferences based on these alternative control groups are essentially identical to those reported in this article.

[4] If the announcement date precedes the ex-date by more than 45 days, only 45 days of presplit data are obtained. Observations during the period October 12, 1987–October 30, 1987, are excluded to eliminate any unusual effects of the October 1987 stock market crash.

Table 1
Summary information for 1987–1989 stock splits and stock dividends

Sample	Number	Split size			
		Mean	Median	Minimum	Maximum
Overall	361	1.7611	2.00	1.01	5.00
Stock dividends	44	1.0552	1.05	1.01	1.20
Small splits	130	1.4409	1.50	1.25	1.67
Large splits	187	2.1497	2.00	2.00	5.00

Stock dividends include distributions less than 1.25 for 1. Small splits represent splits of at least 1.25 for 1 but less than 2 for 1. Large splits are distributions of 2 for 1 or more.

that abnormal returns vary for splits of different magnitudes, stock splits are separated into two groups based on split size. One group includes small splits of at least 1.25:1 but less than 2:1. The other group includes large splits of 2:1 or more.

The hypotheses of interest are based on the premise that price levels decline and that relative spreads increase as a result of stock distributions. To verify the magnitude of these changes, Table 2 documents changes in price levels, spreads, and volume after ex-dividend days for the splitting firms and for the matched control firms. The bid-ask spread is computed two ways for each bid-ask pair; the absolute ($) spread is defined as the closing ask quote minus the bid quote, and the percentage spread is defined as the absolute spread scaled by the average of the ask and bid quotes. The presplit and postsplit event periods represent periods N days before and after the ex-dividend day, respectively, where N is the number of days between the announcement and the ex-date. Results are virtually identical when the sample is restricted to those events with at least 20 days between the announcement and ex-date, and an event window $+/-$ 20 days from the ex-date is considered.

As can be seen in Table 2, prices decline after the ex-date for all types of events. This decline is significant for all groups except stock dividends. For the overall sample, the average price declines from $50.81 before splits to $28.24 after splits. Presplit prices and spreads are close to those for the matched control stocks during both periods, reflecting the matching criteria. Measurement error caused by rounding prices to the nearest $0.125 should become larger in relative magnitude at the lower, postsplit price levels. Table 2 also shows that the average dollar bid-ask spreads decrease after the ex-date, from $0.2987 to $0.2581 for the overall sample, but this decline is less than proportional to the decline in stock prices. Therefore the percentage bid-ask spread, representing the transaction cost per dollar invested, increases significantly after the ex-date for the overall sample and

Table 2
Prices, spreads, and volume before and after stock distributions

Sample	Presplit Mean	Presplit (Std. Dev.)	Postsplit Mean	Postsplit (Std. Dev.)	t-statistic	Pr(Pre > Post) (%)
			Closing price level ($):			
Overall	50.81	(30.60)	28.24	(13.92)	−62.78	95.2
Stock dividends	14.74	(13.29)	13.90	(12.56)	−1.17	62.8
Small splits	36.42	(17.59)	25.91	(12.08)	−28.49	99.2
Large splits	65.92	(30.62)	31.80	(13.69)	−70.32	100.0
Control stocks	47.27	(33.74)	47.77	(35.25)	0.98	39.9
			Absolute spread ($):			
Overall	0.2987	(0.1470)	0.2581	(0.1094)	−20.79	78.2
Stock dividends	0.2187	(0.1180)	0.2215	(0.1124)	0.42	48.8
Small splits	0.2840	(0.1128)	0.2659	(0.1144)	−6.56	71.4
Large splits	0.3193	(0.1661)	0.2574	(0.1043)	−21.86	89.3
Control stocks	0.3148	(0.2374)	0.3105	(0.2386)	−1.20	53.2
			Percentage spread (%):			
Overall	0.8210	(0.6634)	1.1685	(0.8339)	30.73	7.7
Stock dividends	2.1068	(1.2248)	2.3124	(1.4639)	2.67	39.0
Small splits	0.9254	(0.5135)	1.2084	(0.6887)	19.32	4.0
Large splits	0.5839	(0.4017)	0.9914	(0.6774)	36.02	3.2
Control stocks	0.8848	(0.7761)	0.8809	(0.7599)	−0.34	55.7
			Ave. dollar volume per trade (1000s):			
Overall	169.25	(931.63)	139.11	(909.54)	−2.18	60.6
Stock dividends	26.17	(103.35)	23.20	(82.14)	−0.57	41.9
Small splits	92.92	(400.68)	84.13	(458.89)	−0.84	59.2
Large splits	242.96	(1215.15)	192.78	(1165.18)	−2.07	66.0
Control stocks	122.09	(735.01)	115.74	(533.04)	−0.66	47.2

Comparison of price levels, spreads, and trading volume before and after the ex-dividend date for the splitting sample and for the matched control sample. The absolute spread is defined as the closing ask quote minus the closing bid quote, and the percentage spread is defined as the absolute spread scaled by the average of the bid and ask quotes. The presplit and postsplit periods represent the N days before and after the ex-dividend day, respectively, where N is the number of days between the announcement and the ex-date. The t-statistic compares the means of the two periods. Pr(Pre > Post) denotes the percentage of events for which the presplit mean exceeds the postsplit mean.

for each type of split. The average dollar volume of closing trades decreases significantly after ex-days for large splits. Previous research has established a relation between volume and volatility; this relation within the context of stock splits is discussed more fully in Section 3. The control firms show no significant change in price levels, spreads, or trading volume between the two periods.

2. Theory and Statistical Tests

Ohlson and Penman (1985), Dravid (1987), and others show that stock return volatility increases after stock splits. Previous authors have analyzed biases caused by the bid-ask spread and price discreteness on return volatility. Schwartz and Whitcomb (1977) and Gottlieb and

Kalay (1985) show that when continuous prices are rounded to discrete price levels, the variance of returns computed using the rounded prices exceeds the variance of unrounded returns. The magnitude of this bias increases at lower price levels. Amihud and Mendelson (1987) and Kaul and Nimalendran (1990) show that the bid-ask spread introduces an upward bias in measured return variances that increases at lower price levels and higher (percentage) spreads.

Dravid (1989) and Conroy, Harris, and Benet (1990) apply these analyses to stock splits and suggest that measurement effects such as the bid-ask spread and price discreteness may contribute to the increase in postsplit return variance. Both of these studies rely on theoretical models relating observed returns to measurement effects. As such, their tests are joint tests of the models and the actual impact of measurement effects on stock split volatility. Furthermore, Dravid (1989) relies on estimates of the bid-ask spread, and Conroy, Harris, and Benet (1990) have only a limited subsample of bid and ask quote data with which to implement their tests. Ohlson and Penman (1985), Conroy, Harris, and Benet (1990), and Dubofsky (1991) analyze the impact of measurement effects by comparing daily return variances to weekly return variances. Results concerning weekly return variances are discussed in Section 4. Kryzanowski and Zhang (1993) analyze splitting firms on the Toronto Stock Exchange, and also use bid and ask data to distinguish between changes in true variances and changes in measured return variances. Finally, Maloney and Mulherin (1992) and Conrad and Conroy (1994) examine the impact of measurement effects on abnormal returns around ex-days of stock splits. Neither article specifically analyzes return volatility.

Using extensive bid and ask data for NYSE firms, I employ three statistical tests to examine the relation between measurement effects and stock split volatility changes. First, assuming that the pooled presplit daily returns and postsplit daily returns are respectively drawn from two different normal distributions, an F-test examines the equality of variances between the two samples. Reported results use $+/-N$-day event periods, where N is the number of days between the announcement and the ex-date.

Second, assuming differences between the presplit sample variance and the postsplit sample variance for each firm are independent and normally distributed, a paired t-test tests the hypothesis that the paired differences have mean zero.

Finally, Ohlson and Penman (1985) argue for a conservative nonparametric test. They present a binomial proportionality statistic [also used by Dravid (1987) and Dubofsky (1991)], p, where

$$p \equiv \Pr(\tilde{R}_2^2 > \tilde{R}_1^2) \tag{1}$$

and test the hypothesis

$$H_0 : p = 0.5 \tag{2}$$

versus the alternative

$$H_A : p \neq 0.5 \tag{3}$$

where $\tilde{R}_1$ and $\tilde{R}_2$ denote pre- and postsplit returns. Ohlson and Penman (1985) compare pre- and postsplit returns by matching the first trading day following the announcement with the first same day of the week following the ex-date, the second day after the announcement with the second same day of the week following the ex-date, and so on in order to control for day of the week variations in volatility. Assuming independence across M observations, the related binomial statistic

$$z \equiv 2(p - 0.5)(\sqrt{M}) \tag{4}$$

is asymptotically standard normal. I duplicate the Ohlson and Penman matching technique to compute the binomial statistic.

All statistics are computed for daily closing transaction price returns, bid returns, and ask returns, and results are reported for a partition based on postsplit price levels.

3. Volatility of Daily Returns

Table 3 reports results of the tests for change in variance of daily returns for the splitting sample, sorted by split factor, and Table 4 reports similar results sorted by ex-dividend price level.[5] Table 3 also reports results for the matched control sample.

Both Table 3 and Table 4 show consistent significant increases in postsplit volatility for the splitting firms.[6] Point estimates of the variance increase for every subgroup considered in the two tables. The order of magnitude of the increase is comparable to that found by previous researchers. For example, Conroy, Harris, and Benet (1990) find that the average daily return variance increases from $4.61\%^2$ be-

[5] In computing the binomial z-statistic, there are a nontrivial number of cases in which the squared presplit return exactly equals the matched squared postsplit return. Dravid (1987) allocates these ties equally between the null and the alternative hypotheses. Ohlson and Penman (1985) adopt a more conservative treatment and count ties in favor of the null hypothesis. Reported results use the more conservative treatment of Ohlson and Penman.

[6] Several other tests confirm these results. First, statistics are computed for a clean sample that eliminates any ex-dividend event with a nontrivial announcement listed in the *Wall Street Journal Index* within 5 days of the ex-date. This screen eliminates about 20% of the ex-dividend events. Second, to check for the possibility that the abnormal mean returns are affecting variance computations, statistics are computed excluding days 0–3 from the postsplit sample. Third, to check the sensitivity of the binomial matching procedure, returns are matched symmetrically around the ex-date. These alternative statistics yield inferences essentially identical to those reported.

Table 3
Change in variance of daily returns by magnitude of stock distribution

Sample	Mean presplit var. (%^{2})	Mean postsplit var. (%^{2})	F-stat	Paired t-stat	z-stat	$\Pr(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$	$\Pr(\tilde{R}_2^2 > \tilde{R}_1^2)$
			Closing transaction price returns				
Overall	3.25	5.46	1.75**	7.14**	8.69**	0.714	0.556
Stock dividends	5.85	7.17	1.50**	0.76	0.62	0.583	0.519
Small splits	3.10	5.05	1.55**	3.71**	4.94**	0.654	0.553
Large splits	2.97	5.48	1.89**	6.99**	7.23**	0.758	0.559
Control stocks	3.72	3.37	0.88**	−0.98	−2.09*	0.441	0.487
			Closing bid-to-bid returns				
Overall	3.09	5.37	1.78**	8.29**	7.52**	0.721	0.548
Stock dividends	4.15	6.87	1.68**	2.14*	0.00	0.583	0.500
Small splits	3.10	5.07	1.57**	3.79**	3.63**	0.654	0.538
Large splits	2.91	5.40	1.89**	7.60**	6.88**	0.764	0.556
Control stocks	3.61	3.24	0.88**	−0.95	−0.58	0.438	0.496
			Closing ask-to-ask returns				
Overall	3.03	5.20	1.74**	8.09**	6.23**	0.714	0.539
Stock dividends	4.08	6.85	1.49**	2.38*	0.26	0.625	0.508
Small splits	2.98	4.89	1.61**	3.88**	2.48*	0.664	0.526
Large splits	2.91	5.20	1.82**	7.01**	6.04**	0.747	0.549
Control stocks	3.45	3.04	0.86**	−1.15	−1.28	0.438	0.492

Comparison of pre- and postsplit variance by magnitude of split factor. F-stat is the result of the pooled F-test of change in variances. Paired t-stat reports results of the paired t-test comparing the mean presplit sample variance to the mean postsplit sample variance. z-stat is the result of the binomial z-statistic. $\Pr(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$ represents the proportion of observations for which $(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$, and $\Pr(\tilde{R}_2^2 > \tilde{R}_1^2)$ represents the proportion of observations for which $(\tilde{R}_2^2 > \tilde{R}_1^2)$. * denotes statistics significant at 5%, and ** denotes significance at 1%.

fore the split to 6.34%^{2} afterward; these values compare to an average variance of 3.25%^{2} before the split and 5.46%^{2} after the split for the overall sample examined in this article. Ohlson and Penman (1985) find that $\Pr(\tilde{R}_2^2 > \tilde{R}_1^2) = 0.577$ for their overall sample, as compared to 0.556 for the sample analyzed here. Volatility increases significantly for all types of stock dividends and splits, although the change in volatility for stock dividends is not significant according to some of the test statistics reported. Both Ohlson and Penman (1985) and Dravid (1987) find significant increases for stock splits, but Dravid (1987) finds a significant decrease in volatility for stock dividends.

The results in Table 3 show no similar increase in postsplit volatility for the control firms. The average daily return variance for the overall control sample decreases slightly, from 3.72%^{2} to 3.37%^{2}. Similar results (not reported) hold when the control firms are sorted by the magnitude of the split factor of the matching splits, and by the price level of the control firms. To the extent that there is any change in variance for the control firms, it is a slight, marginally significant decrease in volatility. Since there is one matched firm for each splitting

Table 4
Change in variance of daily returns by ex-dividend price level

Ex-dividend price level	Mean presplit var. (%²)	Mean postsplit var. (%²)	F-stat	Paired t-stat	z-stat	$\Pr(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$	$\Pr(\tilde{R}_2^2 > \tilde{R}_1^2)$
			Closing transaction price returns				
$P \leq 15$	5.11	7.97	1.75**	2.17*	2.70**	0.636	0.544
$15 < P \leq 20$	3.78	5.13	1.58**	2.04*	3.33**	0.680	0.557
$20 < P \leq 25$	2.62	5.29	2.22**	4.67**	5.04**	0.818	0.574
$25 < P \leq 30$	2.63	5.04	1.63**	4.21**	5.09**	0.768	0.579
$30 < P \leq 40$	3.50	5.53	1.61**	2.89**	2.75**	0.686	0.546
$40 < P$	2.63	4.26	1.57**	2.38*	2.36*	0.618	0.533
			Closing bid-to-bid returns				
$P \leq 15$	4.10	7.46	1.89**	3.57**	2.55*	0.702	0.541
$15 < P \leq 20$	3.62	4.93	1.48**	1.94	1.61	0.688	0.527
$20 < P \leq 25$	2.78	5.45	2.10**	4.53**	4.94**	0.783	0.570
$25 < P \leq 30$	2.54	4.98	1.70**	4.17**	4.69**	0.755	0.575
$30 < P \leq 40$	3.36	5.51	1.67**	3.10**	2.51*	0.720	0.542
$40 < P$	2.61	4.14	1.57**	2.62*	1.97*	0.600	0.528
			Closing ask-to-ask returns				
$P \leq 15$	3.88	6.97	1.71**	3.19**	1.16	0.705	0.519
$15 < P \leq 20$	3.74	4.97	1.52**	1.80	0.66	0.640	0.511
$20 < P \leq 25$	2.54	5.38	2.35**	5.12**	3.77**	0.788	0.554
$25 < P \leq 30$	2.70	4.84	1.57**	3.98**	3.87**	0.741	0.561
$30 < P \leq 40$	3.28	5.37	1.66**	3.29**	3.21**	0.712	0.552
$40 < P$	2.57	4.03	1.52**	2.47*	2.36*	0.618	0.533

Comparison of pre- and postsplit variance by ex-dividend price level for the splitting firms. Price level categories are selected to maintain approximately equally many observations in each subgroup. F-stat is the result of the pooled F-test of change in variances. Paired t-stat reports results of the paired t-test comparing the mean presplit sample variance to the mean postsplit sample variance. z-stat is the result of the binomial z-statistic. $\Pr(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$ represents the proportion of observations for which $(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$, and $\Pr(\tilde{R}_2^2 > \tilde{R}_1^2)$ represents the proportion of observations for which $(\tilde{R}_2^2 > \tilde{R}_1^2)$. * denotes statistics significant at 5%, and ** denotes significance at 1%.

firm, the documented increase in variance for splitting firms is not merely an artifact of overall, marketwide increases in volatility.

The volatility changes observed for transaction prices are remarkably similar in magnitude and significance level to those found for bid or ask returns. Significant increases in volatility exist for both the bid and ask return series that are not subject to bid-ask bounce. Average transaction price return volatility increases from 3.25%^{2} to 5.46%^{2}; this compares to an increase from 3.09%^{2} to 5.37%^{2} for bid quote returns and from 3.03%^{2} to 5.20%^{2} for ask quote returns. Paired t-statistics testing the significance of these changes are 7.14 for transaction prices, and 8.29 and 8.09 for bid and ask quote returns, respectively. Similarities between trade returns and quote returns hold across split type and price level. There are at least two possible explanations for these similarities. First, it is possible that the closing quotations are not indepen-

Table 5
Variance ratio results

Sample	Daily returns: Presplit mean ratio	Daily returns: Postsplit mean ratio	Weekly returns: Presplit mean ratio	Weekly returns: Postsplit mean ratio
Overall	0.087	0.122	0.045	0.044
Stock dividends	0.250	0.190	0.108	0.079
Small splits	0.111	0.146	0.039	0.071
Large splits	0.050	0.099	0.017	0.033
Control stocks	0.184	0.133	0.040	0.066

Estimates of the mean ratio of the variance of bid-ask errors to the variance of transaction price returns. Bid-ask errors are defined as the difference between transaction price returns and bid quote returns [see Kaul and Nimalendran (1990)].

dent of the closing trades. Closing quotes may reflect revisions made by market makers in response to closing trades. To examine this possibility, Table 3 was recalculated using quotations prior to the closing trade.[7] Results using quotes prior to the closing trade are essentially identical to those reported in Table 3. For example, the mean variance estimated using closing bid quotes increases from 3.09%^{2} to 5.37%^{2}. These values compare to an increase from 3.10%^{2} presplit to 5.35%^{2} postsplit estimated using bid quotes prior to the closing trades. Lack of independence between the closing trades and the closing quotes does not appear to generate the results reported in this article.

Second, it is possible that bid-ask bounce is trivial in magnitude for these stocks. Kaul and Nimalendran (1990, p. 85) suggest that bid-ask errors should contribute 23% to 33% of daily return volatility for NYSE firms. However, stocks that split are not typical of all NYSE firms. Table 2 shows that they have average presplit prices over $50 per share; a random sample of nonsplitting NYSE firms during this period has an average price under $30 per share. Bid-ask bounce is very sensitive to price level. To determine the magnitude of bid-ask bounce for this sample, Table 5 reports results of variance ratio tests similar to those reported in Kaul and Nimalendran. Table 5 reports the ratio of the mean variance of bid-ask errors (defined as the difference between transaction price returns and bid quote returns) to the mean variance of transaction price returns. For the overall sample, bid-ask errors contribute 8.7% of the variance of daily returns before splits and 12.2% after splits. Although bid-ask errors increase slightly, they are small in relative magnitude before splits and still small afterward. Bid-ask error is not large enough for these stocks to explain the large

[7] Quotations at least 5 seconds prior to the closing trade are used, following the convention of Hasbrouck (1991), Lee and Ready (1991), and others to adjust for reporting delays in the sequencing of trades and quotes.

increase in observed variance. For the control sample, bid-ask error contributes between 13% and 18% of the daily return variance. These results are further support for the conclusion that bid-ask bounce does not explain the observed increase in return variance after stock splits.

We may use the results reported in Table 5 to estimate what percentage of the change in daily return variances is due to the spread. For large splits, 5.0% of the presplit variance of 0.000297 is due to bid-ask error, and 9.9% of the postsplit variance of 0.000548 is due to bid-ask error. Therefore change in the bid-ask spread component represents approximately 16% of the total change in daily return variances for large splits. A similar estimate for small splits indicates that approximately 20% of the change in daily variances is due to the change in the spread for these stocks.

Collectively the results in Tables 3–5 suggest that only a small proportion of the observed increase in transaction price volatility results from bid-ask bounce. These results relate to the findings of Conroy, Harris, and Benet (1990), who conclude that part but not all of the increase in return volatility can be attributed to bid-ask spreads. To compare more directly results in this article to Conroy, Harris, and Benet (CHB), I estimate a regression based on CHB Equation (2),

$$\Delta OV = \Delta TV + \frac{1}{2}\Delta S^2, \tag{5}$$

where OV = the observed variance of return, TV = the "true" variance of return, S = the percentage bid-ask spread, and Δ = change from presplit to postsplit periods. CHB derive this equation from results in Amihud and Mendelson (1987), but do not have sufficient bid and ask data to estimate the "true" variance of return. Instead, they conduct several indirect tests comparing splitting firms to nonsplitting firms. Assuming that the "true" variance of return is well approximated by the variance of the bid quote series, I estimate the following regression:

$$\Delta OV_i = b_0 + b_1 \Delta TV_i + b_2 \Delta S_i^2 + \varepsilon_i, \tag{6}$$

where ε_i is a random error term. Regression results for the overall sample, for subgroups based on distribution size, and for the control group are summarized in Table 6. For the overall sample, the coefficient on the change in true variance is highly significant, and the coefficient on the change in the square of the percentage spread is also significant. Results by split size, however, show that the spread coefficient is significant only for large splits. For stock dividends and small splits, the increase in observed return variance results from an increase in true variance rather than bid-ask bounce. For large splits, both the bid-ask spread and an increase in true variance appear to

Table 6
Results for regression model

Sample	Intercept	ΔTV	ΔS^2	R^2
Overall	−0.00002451	0.9128	0.6075	0.9232
	(−1.15)	(53.88)	(4.63)	
Stock dividends	0.00002954	1.0735	−0.4361	0.9654
	(0.30)	(10.16)	(−0.97)	
Small splits	0.00002165	0.8623	−0.0285	0.8791
	(0.49)	(27.11)	(−0.09)	
Large splits	−0.00005790	0.9677	0.9152	0.9691
	(−3.29)	(64.31)	(8.98)	
Control stocks	−0.00001905	0.9830	−0.1833	0.9692
	(−2.04)	(91.96)	(−3.39)	

Results of the regression model $\Delta OV_i = b_0 + b_1 \Delta TV_i + b_2 \Delta S_i^2 + \varepsilon_i$, where OV is the observed variance of return, TV is the estimated true variance of return, S is the percentage bid-ask spread, and Δ is the change from presplit to postsplit periods. t-statistics are reported in parentheses.

contribute to the increase in variance of observed returns. Results for large splits support the findings of Conroy, Harris, and Benet (1990), who consider splits of 1.2 for 1 or greater and conclude that the increase in observed variance appears attributable to both an increase in true variance and the bid-ask spread. These findings contrast with the results in Kryzanowski and Zhang (1993), who conclude that for a sample of Toronto Stock Exchange firms, the increase in return volatility around splits is due to increased bid-ask spreads and trading volume, but not true return variance.

The second important conclusion relating to daily returns concerns price discreteness. As discussed above, lower postsplit price levels are associated with higher relative spreads and greater potential bias due to price discreteness, both of which could increase postsplit volatility. Previously it has been impossible to distinguish between the effect of bid-ask spreads and price discreteness on postsplit volatility. Controlling for the spread by examining bid-to-bid returns, Table 4 shows that increases in volatility are present at essentially all price levels. Similar results (not reported) hold when Table 4 is recomputed for large splits only. The statistical tests in Table 4 are highly significant at all price levels. Ohlson and Penman (1985) also find significant increases in volatility at all price levels. The rounding of prices to the nearest $0.125, which represents a more significant constraint at lower postsplit price levels, does not appear to be a major cause of changes in return volatility.

There is significant literature examining the relation between volume and volatility; see Karpoff (1987) for a review of this research through 1987. Perhaps the increase in daily return variance is related to a change in trading volume. Recent articles in this area fall into two general categories: theoretical models describing the predicted relation between volume and stock returns [Foster and Viswanathan (1993), Harris and Raviv (1993), Shalen (1993), and Andersen (1996), for example], and empirical investigations of this relation [Schwert (1989) and Gallant, Rossi, and Tauchen (1992)]. The models predict that volume and volatility will be positively related, and empirical tests support this hypothesis. Table 2 reports that the average dollar volume per trade declines significantly for the overall stock split sample, but Table 2 is computed using closing trades only rather than total daily trading volume.

To analyze the relation between volume and volatility in more detail, I compute several statistics to measure trading volume throughout the trading day before and after ex-dates for splits. The average number of shares traded per day for the splitting sample increases significantly from 98,872 shares before a split to 160,440 shares after the ex-date, but decreases significantly to 84,287 shares after the ex-date on a split-adjusted basis.[8] Conroy, Harris, and Benet (1990) also find that daily volume for their sample increases from 39,400 shares before splits to 60,400 shares after splits, but that split-adjusted volume decreases significantly. The average number of shares traded per day for the control firms decreases from 103,584 shares to 95,656 shares during the comparable periods. The average size of an individual trade for the splitting firms increases from 1267 shares before splits to 1699 shares after splits, but decreases to 984 shares adjusting by the split factor. Jones, Kaul, and Lipson (1994) show that the relation between total daily volume and volatility is driven by the number of trades rather than the size of each trade. For the splitting firms, the average number of trades per day increases signficantly after ex-days, from 64 to 75.

The increase in volatility after ex-dates is associated with an increase in (unadjusted) share volume, but a decrease in split-adjusted volume, indicating that the increase in actual volume is not proportional to the split factor.[9] In order for the theoretical models relating volume and volatility to explain the volatility results documented for stock splits, it would be necessary that the ex-day be associated with an abrupt change in fundamental features of the volume models such as the information arrival process [e.g., Foster and Viswanathan (1993) or Andersen (1996)], the function individual traders use to relate news and asset returns [Harris and Raviv (1993)], or the dispersion of beliefs [Shalen (1993)]. This issue is left as a topic for future research.

[8] All intraday results weight each firm day equally. In other words, the average for an individual day for a single firm is computed first, and reported results reflect the average across these firm days during the pre- or postsplit period.

[9] The market value of shares per trade (as reported in Table 2 for closing trades, or throughout the day) and per day also decreases, consistent with this finding.

4. Volatility of Weekly Returns

To analyze the role of measurement effects, Ohlson and Penman (1985), Conroy, Harris, and Benet (1990), and Dubofsky (1991) examine weekly returns. Measurement effects such as bid-ask spreads and price discreteness should become less important for longer holding periods. These authors all find that the increase in volatility decreases as the return interval increases, although for NYSE firms the volatility of weekly returns still increases significantly after splits. Dubofsky (1991) also shows that the variance of weekly returns for American Stock Exchange firms does not increase after splits.

Any difference between daily and weekly transaction price returns may be attributable to either the bid-ask spread or price discreteness and other measurement effects. As discussed previously, returns computed using bid or ask quotations do not suffer from bid-ask bounce. Therefore quotation return series may be analyzed to disentangle potential influences of the bid-ask spread from other measurement effects.

Tables 7 and 8 report results of tests for changes in weekly trade and quote return variances for the overall sample and for subgroups based on split factor (Table 7) and price level (Table 8).[10] For the overall sample, weekly transaction price return variances increase from 18.52%^{2} before splits to 33.14%^{2} after splits; these values compare to weekly variances of 26.38%^{2} before splits and 32.67%^{2} after splits reported by Conroy, Harris, and Benet (1990). Results of F-tests of changes in weekly variances are comparable in significance to those found for daily variances, although results of some of the other tests are marginally less significant. In particular, the change in weekly variance for stock dividends is not significant according to many of the reported statistics. For the overall sample, $\Pr(\tilde{R}_2^2 > \tilde{R}_1^2) = 0.546$ for weekly transaction price returns versus 0.556 for daily returns. Ohlson and Penman (1985) found that this proportion declined from 0.577 using daily returns to 0.567 using weekly returns, and Dubofsky (1991) found a decrease from 0.582 (daily returns) to 0.549 (weekly returns) for the NYSE firms in his sample.

Results based on bid and ask quote returns are essentially identical to those based on transaction prices. Although the volatility increases for weekly bid or ask quote returns are slightly less significant than for daily returns, volatility still increases significantly for all split types and at all price levels. If measurement effects such as the bid-ask spread and price discreteness are the primary sources of the documented

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[10] Weekly returns are computed using nonoverlapping 5-day holding period returns for a period from the announcement date through the ex-day plus 45 days.

Table 7
Change in variance of weekly returns by magnitude of stock distribution

Sample	Mean presplit var. (%^{2})	Mean postsplit var. (%^{2})	F-stat	Paired t-stat	z-stat	$\Pr(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$	$\Pr(\tilde{R}_2^2 > \tilde{R}_1^2)$
			Closing transaction price returns				
Overall	18.52	33.14	1.73**	4.13**	2.93**	0.629	0.546
Stock dividends	23.50	34.69	1.38	0.62	0.32	0.571	0.525
Small splits	17.86	32.24	1.58**	2.79**	0.53	0.653	0.514
Large splits	18.24	33.63	1.86**	3.20**	3.27**	0.614	0.565
Control stocks	22.01	19.51	0.89*	−0.64	−1.06	0.516	0.484
			Closing bid-to-bid returns				
Overall	18.30	32.52	1.76**	3.90**	3.43**	0.637	0.554
Stock dividends	20.35	37.78	1.69**	1.05	0.82	0.643	0.568
Small splits	18.07	31.05	1.51**	2.25*	1.88	0.663	0.549
Large splits	17.91	33.10	1.86**	3.18**	2.76**	0.615	0.555
Control stocks	20.46	20.13	0.91	−0.24	−0.43	0.508	0.493
			Closing ask-to-ask returns				
Overall	18.22	31.76	1.73**	3.78**	3.81**	0.656	0.559
Stock dividends	20.81	34.59	1.62**	0.88	0.82	0.714	0.568
Small splits	17.58	30.05	1.54**	2.34*	2.40*	0.673	0.563
Large splits	18.12	32.61	1.81**	3.00**	2.84**	0.635	0.557
Control stocks	20.09	19.86	0.92	−0.21	−1.55	0.523	0.476

Comparison of pre- and postsplit variance by magnitude of split factor. F-stat is the result of the pooled F-test of change in variances. Paired t-stat reports results of the paired t-test comparing the mean presplit sample variance to the mean postsplit sample variance. z-stat is the result of the binomial z-statistic. $\Pr(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$ represents the proportion of observations for which $(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$, and $\Pr(\tilde{R}_2^2 > \tilde{R}_1^2)$ represents the proportion of observations for which $(\tilde{R}_2^2 > \tilde{R}_1^2)$. * denotes statistics significant at 5%, and ** denotes significance at 1%.

Table 8
Change in variance of weekly returns by ex-dividend price level

Ex-dividend price level	Mean presplit var. (%^{2})	Mean postsplit var. (%^{2})	F-stat	Paired t-stat	z-stat	$\Pr(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$	$\Pr(\tilde{R}_2^2 > \tilde{R}_1^2)$
			Closing transaction price returns				
$P \leq 15$	21.21	43.81	1.63**	1.37	0.24	0.649	0.510
$15 < P \leq 20$	22.17	34.46	1.77**	1.70	1.82	0.614	0.575
$20 < P \leq 25$	15.16	38.59	1.95**	2.70**	1.22	0.696	0.544
$25 < P \leq 30$	19.96	31.60	1.71**	1.99	2.90**	0.706	0.610
$30 < P \leq 40$	20.30	26.41	1.33*	0.71	−0.65	0.545	0.473
$40 < P$	14.63	24.37	1.82**	1.49	1.51	0.569	0.552
			Closing bid-to-bid returns				
$P \leq 15$	21.31	39.07	1.74**	1.18	2.29*	0.568	0.590
$15 < P \leq 20$	21.23	33.33	1.74**	1.65	0.92	0.595	0.538
$20 < P \leq 25$	16.30	41.39	1.97**	2.45*	1.71	0.644	0.561
$25 < P \leq 30$	16.71	29.50	1.82**	2.38*	3.28**	0.771	0.628
$30 < P \leq 40$	22.14	26.14	1.31	0.55	−0.49	0.558	0.480
$40 < P$	14.63	24.04	1.77**	1.90	0.69	0.600	0.524
			Closing ask-to-ask returns				
$P \leq 15$	20.94	38.24	1.68**	1.10	1.19	0.639	0.547
$15 < P \leq 20$	21.82	31.49	1.67**	1.40	0.85	0.595	0.536
$20 < P \leq 25$	15.31	40.49	2.05**	2.49*	2.09*	0.702	0.575
$25 < P \leq 30$	17.81	30.31	1.79**	2.14*	3.31**	0.755	0.627
$30 < P \leq 40$	21.52	25.34	1.31	0.57	0.88	0.568	0.535
$40 < P$	14.53	23.37	1.75**	1.94	0.96	0.600	0.533

Comparison of pre- and postsplit variance by ex-dividend price level. F-stat is the result of the pooled F-test of change in variances. Paired t-stat reports results of the paired t-test comparing the mean presplit sample variance to the mean postsplit sample variance. z-stat is the result of the binomial z-statistic. $\Pr(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$ represents the proportion of observations for which $(\tilde{\sigma}_2^2 > \tilde{\sigma}_1^2)$, and $\Pr(\tilde{R}_2^2 > \tilde{R}_1^2)$ represents the proportion of observations for which $(\tilde{R}_2^2 > \tilde{R}_1^2)$. * denotes statistics significant at 5%, and ** denotes significance at 1%.

increase in transaction price return volatility, then bid quote returns should eliminate the effect of the bid-ask spread, and a weekly return interval should mitigate the impact of other measurement effects on daily returns. Since weekly bid quote returns still show significant increases in volatility around splits, neither the bid-ask spread nor other measurement effects appear to explain the increase in volatility around splits.

5. Conclusions

It is important to distinguish between changes in return characteristics that are the result of the way stock prices are measured and fundamental changes in stock return distributions associated with the ex-dates of stock splits and stock dividends. The former results from an institutional feature of trading while the latter represents a potential violation of market efficiency. This article examines the relation between two institutional factors affecting stock price measurement—the bid-ask spread and price discreteness, and the variance of ex-stock split returns. Extensive bid and ask quotations data allow direct tests of the impact of measurement effects after stock distributions. There is some evidence that the bid-ask spread contributes partially to the increase in return volatility after splits. However, eliminating the bid-ask spread by computing bid quote returns or ask quote returns does not eliminate most of the volatility increase. Controlling for the bid-ask spread, the change in volatility is also not significantly correlated with the price level, suggesting that price discreteness is also not responsible for the volatility increases. The increase in volatility is associated with an increase in actual daily trading volume, but with a decrease in volume on a split-adjusted basis. Weekly returns also show significant increased volatility. This is further evidence that measurement effects do not generate the volatility increase. Variance ratio tests provide additional evidence that bid-ask errors are small for splitting stocks in the sample, and therefore could not explain the significant increase in variance after splits. The two measurement effects considered in this article are not the primary causes of changes in return variance around stock splits. The explanation for the increase in variance after stock distributions remains a topic for further research.

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