Journal of Financial Economics 16 (1986) 99–117. North-Holland

A TRANSACTION DATA STUDY OF WEEKLY AND INTRADAILY PATTERNS IN STOCK RETURNS

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Received April 1984, final version received September 1985

Weekly and intradaily patterns in common stock prices are examined using transaction data. For large firms, negative Monday close-to-close returns accrue between the Friday close and the Monday open; for smaller firms they accrue primarily during the Monday trading day. For all firms, significant weekday differences in intraday returns accrue during the first 45 minutes after the market opens. On Monday mornings, prices drop, while on the other weekday mornings, they rise. Otherwise the pattern of intraday returns is similar on all weekdays. Most notable is an increase in prices on the last trade of the day.

1. Introduction

Evidence of the day-of-the-week effect in stock prices has generally been obtained from studies of daily close-to-close returns in broad market indices [Cross (1973), French (1980), Gibbons and Hess (1981), and Lakonishok and Levi (1982)]. Although these studies conclusively identify systematic return patterns – in particular, negative Monday returns – they are unable to fully explain their cause. In an effort to shed additional light on the phenomenon, studies of midday-to-midday daily returns, time disaggregated returns, and firm disaggregated returns have been undertaken:

Prince (1982) examined daily returns in the Dow Jones 65 Stock Composite Index (January 1960 to December 1964) which were computed from hourly values of that index as well as from closing values. The negative Monday effect appears primarily in the close-to-close returns, and only to a lessor extent in returns measured from intraday prices. Although Prince concludes that the effect may be caused at least partly by systematically high Friday closing prices, he fails to interpret the fact that Friday-open-to-Monday-open returns appear normal while Monday-open-to-Tuesday-open returns are negative. This

*I am grateful to Truman Clark, Doug Joines, Marc Reinganum, Henry Schloss, and Mark Weinstein for helpful discussions and encouragement. The extensive comments of the referee, Donald Keim, were very helpful in preparing the final draft. The University of Southern California School of Business provided financial support through a Summer Research Grant.

0304-405X/86/$3.50

evidence suggests that the negative Monday close-to-close return accrues during the Monday trading day.

Rogalski (1984) decomposed daily close-to-close returns in the S&P500 Index (January 1979 to April 1984) and the DJIA (October 1974 to April 1984) into overnight returns and trading-day returns. In contrast to the evidence in Prince's paper, he found that negative Monday close-to-close returns accrued primarily from Friday-close-to-Monday-open and that the mean Monday open-to-close return is statistically indistinguishable from mean trading-day returns on the other weekdays. He concluded that the chronological time hypothesis (prices evolve at uniform rates through time) is supported within the trading day but not over non-trading periods.

Smirlock and Starks (1984) analyzed hourly returns in the DJIA (January 1963 to December 1983). They found that intraday patterns related to the day-of-the-week effect have changed over time. In the first third of their sample, Monday returns in the first hour of trading are positive while returns accruing later in the day are negative. In the last third of their sample, this pattern is reversed. There are negative returns early in the day on Monday and positive returns later. The latter results are very similar to those first reported in Harris (1984).

Keim (1983), Keim and Stambaugh (1984), and Rogalski (1984) examined the daily close-to-close returns of ten market value decile portfolios. They found that day-of-the-week effects characterize the returns of all size portfolios, and that the effects may be more pronounced for small firms. In particular, Keim and Stambaugh showed that close-to-close returns (over 1962 to 1976) are large for small firms on Fridays. Although this fact suggests that negative Monday returns may be caused by abnormally high Friday closing prices, their tests fail to support this hypothesis.

Although these studies of disaggregated returns are unable to provide a satisfactory explanation of the day-of-the-week effect, they are important. Use of cross-sectionally and temporally disaggregated data has permitted more complete characterizations of the phenomenon, and has made possible new tests of various hypotheses concerning the effect. Results from these studies have helped focus the search for an explanation of the day-of-the-week effect.

The purpose of this study is to more fully characterize the day-of-the-week effect by studying transaction-by-transaction data for NYSE stocks. These data make possible simultaneous analyses of both cross-sectional and intratemporal characteristics of the effect. Previous studies have established the value of both types of analyses, yet none has determined whether cross-sectional and intratemporal effects interact. This study shows that patterns in time-decomposed returns vary by firm size. Use of transaction data also allows a more precise characterization of the timing of systematic return patterns within the trading day. This study examines intraday returns measured over 15-minute intervals and shows they differ by weekday.

Several new observations emerge. Decomposition of close-to-close returns into trading- and non-trading-period returns indicates that for large firms, the negative Monday close-to-close return accrues before the market opens, while for smaller firms most of it accrues during the day on Monday. Further decomposition of the trading-period return into a series of 15-minute intraday returns reveals that there are only significant differences among weekdays during the first 45 minutes of trading. On Monday mornings, prices tend to drop, while on the other weekday mornings, they rise. Otherwise, price patterns are similar on all weekdays. The most striking similarity is a strong tendency for prices to rise on the last trade of the day.

The remainder of the paper is organized into six sections. Section 2 briefly describes the data set and shows that previous results are replicated. Section 3 describes the cross-sectional analysis of the decomposition of the daily close-to-close return into trading- and non-trading-period returns. Sections 4 and 5 discuss weekday differences and similarities in 15-minute intraday returns, respectively. Section 6 presents new evidence from the transaction data concerning the Friday-closing-price hypothesis. Finally, a summary is provided in section 7.

2. Replication of previous results

The stock transaction data, obtained from Francis Emory Fitch, Inc., consist of a time-ordered record of every common stock transaction made at the NYSE for the fourteen months between December 1, 1981 and January 31, 1983. For each of the approximately 15 million transactions, the date, time, price, and number of shares traded are available.

There are 296 different trading days in the sample period. Data for the nine days which followed trading holidays are excluded from the analyses to insure that no post-holiday trading effects influence the results. When necessary, daily and overnight returns are adjusted for splits and dividends.[1]

The weekdays pattern of close-to-close returns in this sample period is similar to that observed in all previous studies [such as French (1980) and

[1] Some additional details concerning the sample:

Although the Fitch data are relatively free of errors, some do exist. To ensure that the results are not severely biased by errors in the data, only data for which returns (transaction, open-to-close, close-to-open, or close-to-close) are less than 25% in absolute value are analyzed. This filter is narrow enough to exclude large errors in the prices but not so wide that it excludes large percentage changes that often result from trading low-priced stocks on discrete 'ticks'.

Multi-day returns were excluded from the analyses of close-to-close returns.

If a security traded only once on a given day, both the opening price and the closing price were set equal to the one transaction price and that day was excluded from the analyses of the open-to-close returns.

Split and dividend adjustments were made using the same procedure used by the Center for Research in Security Prices. The distributions data were obtained from the CRSP Daily Master File.

Gibbons and Hess (1981)]. The mean Monday close-to-close return of the equal-weighted NYSE portfolio is negative, in contrast to the other mean weekday returns, which are positive (table 1, panel A, line 1). Although an F-test of the equivalence of the weekday means (F_5) cannot reject equivalence at the 5% significance level [$F(4;281) = 1.86$], an F-test of whether the Monday mean is equal to the average of the other weekday means (F_{Mon}) does reject equality at this level [$F(1;281) = 7.30$].[2] These results are qualitatively and quantitatively similar to all previous results concerning close-to-close returns; the failure to reject equivalence of the weekday means is a consequence of the short time-series sample.

Keim (1983), Keim and Stambaugh (1984), and Rogalski (1984) all observe that stocks of all sizes have negative Monday close-to-close returns. The evidence from this sample is very similar. Each of the ten size decile portfolios of the NYSE sample (based on market value capitalization) exhibit the same weekday pattern of returns as does the market as a whole (table 1, panel A). In this short time-series sample, the Monday mean is significantly different at the 5% level from the other weekday means for all but the largest of the size portfolios (table 1, panel A, column 7).

The cross-sectional distribution of close-to-close returns displays a pattern similar to that observed by Keim (1983) and by Keim and Stambaugh (1984). Smaller firms have greater mean returns on Friday than do larger firms. To rigorously test whether this cross-sectional difference is statistically significant, an analysis of variance was conducted. Friday returns for the various portfolios were regressed on a set of size dummies and on a set of date dummies. The latter set consists of a dummy for each different date in the sample on which a Friday fell. These dummies are included to control for the substantial cross-sectional covariation which exists among the portfolio returns on any given day. The results (table 1, panel A, last row) indicate that Friday mean close-to-close returns are significantly different in cross-section. Similar tests for the other weekdays indicate that Wednesday returns are also significantly different. The cross-sectional pattern of returns on Friday appears to be related to the well-known small firm effect identified by Banz (1981) and Reinganum (1981). The pattern on Wednesday is not immediately identifiable.

Rogalski (1984) analyzed the decomposition of daily close-to-close returns in the S&P500 and DJIA indices into a previous close-to-open return and an open-to-close return. In his sample the negative Monday close-to-close return accrues primarily between the Friday close and the Monday open. He was unable to reject equality of the weekday open-to-close returns and therefore

[2]All F-tests in this study are computed from analysis of variance regressions. Returns are regressed on a set of dummies, one for each level of a classification variable (for example, weekday). The equality of means test determines whether the regression coefficients associated with the set of dummies are equal. The equality of the Monday mean with the average of the other weekday means test determines whether that linear restriction on the parameter estimates can be rejected.

Table 1

Mean portfolio close-to-close, close-to-open, and open-to-close returns by weekday and market value capitalization. F-tests of whether the five weekday means are equal (F_5), of whether the Monday mean is equal to the other weekday means (F_{Mon}), and of whether the Tuesday through Friday means are equal (F_4). F-tests of whether the mean returns on a given weekday are equal for all market value decile portfolios (F_{MV}).[a] F-statistics with corresponding tail areas between 0.05 and 0.10 are marked with an asterisk. Those with tail areas of less than 0.05 are marked by a double asterisk. All 1616 NYSE common stocks, all 296 trading days, December 1, 1981 to January 31, 1983, except 9 days which followed a holiday.

Market value decile	Means in percent							
	Mon (1)	Tue (2)	Wed (3)	Thu (4)	Fri (5)	F_5 (6)	F_{Mon} (7)	F_4 (8)
Panel A: Close-to-close-returns								
All firms[b]	−0.202	0.138	0.146	0.170	0.195	1.86	7.30**	0.06
(std. error)	(0.154)	(0.117)	(0.118)	(0.095)	(0.100)			
Smallest	−0.117	0.177	0.096	0.136	0.304	1.95*	5.74**	0.82
2	−0.211	0.085	0.211	0.175	0.262	3.23**	11.33**	0.62
3	−0.227	0.112	0.174	0.223	0.234	2.79**	10.41**	0.29
4	−0.220	0.137	0.197	0.155	0.208	2.30*	8.91**	0.10
5	−0.202	0.130	0.203	0.166	0.250	2.19*	8.19**	0.21
6	−0.208	0.125	0.166	0.194	0.160	1.96*	7.62**	0.07
7	−0.205	0.138	0.167	0.191	0.150	1.51	5.92**	0.04
8	−0.204	0.131	0.115	0.143	0.144	1.28	5.11**	0.01
9	−0.229	0.191	0.070	0.166	0.118	1.48	5.46**	0.18
Largest	−0.196	0.156	0.060	0.149	0.124	0.82	3.05*	0.09
F_{MV}	0.48	0.53	2.16**	0.55	2.12**			
N	53	56	61	60	56			
Panel B: Previous close-to-open returns								
All firms[b]	−0.095	0.001	0.052	0.018	0.066	1.63	5.40**	0.44
(std. error)	(0.065)	(0.049)	(0.045)	(0.041)	(0.040)			
Smallest	−0.029	−0.045	−0.054	−0.027	0.042	0.46	0.02	0.66
2	−0.074	−0.032	0.037	0.005	0.056	1.31	3.08*	0.82
3	−0.029	0.040	0.061	0.051	0.081	0.83	2.87*	0.18
4	−0.096	−0.001	0.051	0.011	0.047	1.61	5.42**	0.36
5	−0.108	−0.018	0.060	0.026	0.076	2.15*	6.47**	0.81
6	−0.072	0.015	0.064	0.001	0.045	1.36	4.13**	0.50
7	−0.101	0.005	0.073	0.029	0.066	1.70	5.66**	0.42
8	−0.139	−0.008	0.048	0.015	0.047	2.22*	7.97**	0.34
9	−0121	0.023	0.072	0.027	0.084	2.09*	7.41**	0.37
Largest	−0.177	0.034	0.105	0.047	0.114	2.87**	10.39**	0.44
F_{MV}	4.09**	2.47**	5.85**	1.43	1.43			
N	53	56	61	60	56			

Table 1 (continued)

Market value decile	Means in percent Mon (1)	Tue (2)	Wed (3)	Thu (4)	Fri (5)	F_5 (6)	F_{Mon} (7)	F_4 (8)
			Panel C: Open-to-close-returns					
All firms[b]	−0.105	0.140	0.098	0.157	0.136	1.12	4.29**	0.07
(std. error)	(0.124)	(0.106)	(0.105)	(0.080)	(0.081)			
Smallest	−0.064	0.249	0.173	0.193	0.288	2.26*	8.06**	0.38
2	−0.144	0.119	0.182	0.182	0.218	2.85**	10.70**	0.27
3	−0.205	0.074	0.111	0.175	0.158	2.55**	9.49**	0.27
4	−0.123	0.139	0.53	0.147	0.167	1.55	6.16**	0.02
5	−0.090	0.148	0.145	0.143	0.177	0.16	4.57**	0.03
6	−0.135	0.111	0.103	0.197	0.117	1.59	5.72**	0.23
7	−0.102	0.134	0.095	0.164	0.085	0.81	2.89*	0.12
8	−0.063	0.136	0.067	0.131	0.100	0.50	1.76	0.09
9	−0.110	0.167	−0.000	0.141	0.037	0.84	2.01	0.50
Largest	−0.018	0.122	−0.045	0.101	0.012	0.27	0.16	0.34
F_{MV}	1.39	1.39	3.83**	0.92	5.34**			
N	53	57	61	60	56			

[a]The F-statistics are obtained from analysis of variance regressions on dummies. F_5 and F_{Mon} are obtained from the regression of the returns on five weekday dummies. F_4 is obtained from the regression of only the Tuesday through Friday returns on four weekday dummies. The degrees of freedom associated with these F-statistics are F_5, 4,281; F_{Mon}, 1,281; and F_4, 3,229. The corresponding 10%, 5%, and 1% points are 1.94, 2.37, 3.32; 2.71, 3.84, 6.63; and 2.08, 2.60, 3.78.

F_{MV} is obtained from the regression of the returns for a given weekday on dummies for each of the market value decile portfolios and on dummies for each of the dates in the sample corresponding to that weekday. The latter set of dummies are used to control for the cross-sectional covariation among the various size portfolio returns on a given day. The degrees of freedom associated with these F-tests are 9,468 on Monday; 9,495 on Tuesday; 9,540 on Wednesday; 9,531 on Thursday; and 9,495 on Friday. The corresponding 10%, 5%, and 1% points of these F-statistics are all 1.63, 1.88, and 2.41.

[b]NYSE equal-weighted portfolio.

did not reject the hypothesis that stock prices evolve at uniform rates in chronological time during the trading day. In this sample, the same analysis for the equal-weighted NYSE portfolio yields somewhat different results (table 1, panels B and C, line 1, column 5). Only half of the negative Monday close-to-close return accrues between the Friday close and the Monday open, while the rest accrues during the Monday trading period. Although F-tests of the equivalence of the weekday means cannot reject equivalence at the 5% significance level for either the close-to-open weekday means [$F(4;281) = 1.63$] or the open-to-close weekday means [$F(4;281) = 1.12$], F-tests of whether the Monday mean is equal to the average of the other weekday means do reject equality in both cases [$F(1;281) = 5.4$, 4.29, respectively]. The next section shows that Rogalski's results may differ from these because of cross-sectional differences in the day-of-the-week effect.

3. Cross-sectional differences in trading- and non-trading-period returns

Unlike previous research, this paper analyzes trading- and non-trading-period returns by firm size. The results (table 1, panels B and C) show that although the mean Monday close-to-open return and the mean Monday open-to-close return are both negative for all size decile portfolios, their magnitudes vary by firm size. For large firms, the close-to-open return is greater in absolute value than the open-to-close return, and for small firms, just the opposite. This cross-sectional difference in Monday returns is clearly identified in tests of the equivalence of the mean Monday return with the average of the other weekday means. These F-tests (table 1, panels B and C, column 7) reject equivalence at the 5% significance level for all size portfolios larger than the third when the non-trading-period returns are examined and they reject for all size portfolios smaller than the seventh when the trading-period returns are examined.

To rigorously test for cross-sectional differences among the various portfolio trading- and non-trading-period mean returns, an analysis of variance, similar to that used to analyze the close-to-close returns, was conducted. The F-tests (table 1, panels B and C, last row) indicate that the Monday close-to-open means are significantly different in cross-section [$F(9,468) = 4.09$] but that the open-to-close means are not [$F(9,468) = 1.39$]. The cross-sectional differences in the time of accrual of the negative Monday close-to-close return are due primarily to significant differences in the non-trading-period returns and only to a lesser extent to differences in the open-to-close returns.

The size differences in the decomposition of the Monday close-to-close returns can explain the differences noted above among Rogalski's results (concerning the S&P500 and DJIA indices) and those presented in this study (concerning the NYSE equal-weighted portfolio). Since Rogalski analyzes indices that are heavily weighted towards large firms, his results are very similar to the results presented here for the largest decile portfolio. The S&P500, the DJIA, and the largest NYSE size decile portfolio all have Monday open-to-close returns which are positive, or in the case of the largest size portfolio, nearly zero. The equal-weighted NYSE portfolio is more heavily weighted towards small firms. It has significantly negative Monday open-to-close returns because small firms have large negative Monday open-to-close returns.

Size differences in the decomposition of the negative Monday close-to-close return may have implications for theories which try to relate negative Monday returns to macroeconomic information. If macroeconomic information generated over the weekend were the cause of the negative Monday close-to-close returns, why would that information be fully incorporated into the prices of large firms when they open trading on Monday, but not fully incorporated into the opening prices of small firms (especially since small firms typically first trade after large firm prices are observed)? If markets were not completely

Table 2

Mean accrued intraday returns over 15-minute intervals, by weekday. The accrued return is the average rate of return experienced by common stocks in the NYSE equal-weighted portfolio within a given 15-minute interval.[a] F-tests of whether the five weekday means are equal (F_5), of whether the Monday mean is equal to the other weekday means (F_{Mon}), and of whether the Tuesday through Friday means are equal (F_4). F-tests of whether the mean returns on a given weekday are equal within each 15-minute intervals (F_{24}), of whether the mean of the first three 15-minute returns is different from the last twenty-one (F_{Open}), of whether the mean of the last 15-minute accrued return is different from the other 15-minute accrued returns (F_{Close}), and of whether the means of the inner twenty 15-minute returns (10:45–15:35) are equal (F_{Inner})[b]. F-statistics with corresponding tail areas of less than 0.05 are marked by a double asterisk. All 1616 NYSE common stocks, all 296 trading days, December 1, 1981 to January 31, 1983, except 9 days which followed a holiday.

	Means in percent								
15-minute interval	Mon (1)	Tue (2)	Wed (3)	Thu (4)	Fri (5)	STD[c] (6)	F_5 (7)	F_{Mon} (8)	F_4 (9)
10:00–10:15	−0.038	0.063	0.084	0.067	0.066	0.183	3.94**	15.2**	0.18
10:15–10:30	−0.059	0.024	0.045	0.041	0.026	0.127	6.26**	23.7**	0.47
10:30–10:45	−0.035	0.004	0.013	0.013	0.010	0.088	2.90**	11.2**	0.14
10:45–11:00	−0.012	−0.008	0.000	−0.001	−0.009	0.071	0.34	0.50	0.29
11:00–11:15	−0.003	−0.011	−0.005	−0.008	−0.007	0.061	0.14	0.28	0.10
11:15–11:30	−0.002	−0.015	−0.012	−0.005	−0.001	0.058	0.062	0.46	0.65
11:30–11:45	−0.007	−0.006	−0.003	−0.002	0.002	0.055	0.25	0.36	0.21
11:45–12:00	−0.011	−0.007	−0.001	0.009	0.007	0.057	1.36	2.32	0.98
12:00–12:15	−0.006	−0.001	−0.002	0.009	0.005	0.055	0.68	1.20	0.47
12:15–12:30	0.002	−0.001	0.003	0.007	0.004	0.049	0.18	0.04	0.22
12:30–12:45	0.006	0.010	0.005	0.004	0.012	0.049	0.25	0.07	0.30
12:45–13:00	0.005	0.015	0.007	0.004	0.012	0.046	0.53	0.42	0.53

13:00–13:15	0.003	0.011	0.005	0.006	0.003	0.043	0.32	0.34	0.30
13:15–13:30	0.003	0.008	0.003	0.004	−0.004	0.045	0.54	0.00	0.66
13:30–13:45	0.003	0.005	0.003	0.002	−0.003	0.050	0.20	0.01	0.25
13:45–14:00	0.005	0.000	0.004	−0.004	−0.005	0.055	0.37	0.59	0.29
14:00–14:15	0.007	−0.009	0.003	−0.007	−0.004	0.066	0.54	1.21	0.32
14:15–14:30	0.003	−0.003	−0.005	−0.004	0.001	0.072	0.13	0.31	0.07
14:30–14:45	−0.004	−0.008	−0.026	0.003	−0.010	0.076	1.13	0.27	1.46
14:45–15:00	−0.015	−0.009	−0.029	−0.004	−0.015	0.084	0.74	0.00	1.01
15:00–15:15	−0.028	−0.000	−0.020	−0.007	−0.010	0.095	0.73	1.65	0.42
15:15–15:30	−0.017	0.016	−0.013	−0.016	0.007	0.109	1.13	0.90	1.22
15:30–15:45	0.002	0.017	0.009	0.006	0.015	0.112	0.16	0.33	0.11
15:45–16:00	0.108	0.130	0.109	0.147	0.122	0.134	0.84	0.83	0,81
F_{24}	5.3**	6.1**	7.9**	10.7**	10.2**				
F_{Open}	35.1**	10.1**	44.0**	28.1**	26.0**				
F_{Close}	82 **	101 **	88 **	183 **	162 **				
F_{Inner}	0.5	0.6	1.0	0.4	0.8				
N	53	57	61	60	56				

[a] The appendix provides a full description of how the accrued means are computed.

[b] The F-statistics are obtained from analysis of variance regressions on dummies. F_5 and F_{Mon} are obtained from the regression of the returns on five weekday dummies. F_4 is obtained from the regression of only the Tuesday through Friday returns on four weekday dummies. The degrees of freedom associated with these F-statistics are F_5, 4,282; F_{Mon}, 1,282; and F_4, 3,230. The corresponding 10%, 5%, and 1% points are 1.94, 2.37, 3.32; 2.71, 3.84, 6.63; and 2.08, 2.60, 3.78.

F_{24}, F_{Open}, F_{Close}, and F_{Inner} are obtained from the regression of the returns for a given weekday on a set of 24 dummies which indicate each of the 15-minute time intervals. The numerator degrees of freedom for these test are 23, 1, 1, and 19, respectively. The denominator degrees of freedom associated with these F-statistics are 1248 on Monday, 1344 on Tuesday, 1440 on Wednesday, 1416 on Thursday, and 1320 on Friday. The corresponding 10%, 5%, and 1% points are 1.40, 1.55, 1.86 for F_{24}; 2.71, 3.84, 6.63 for F_{Open} and F_{Close}; and 1.46, 1.57, 1.79 for F_{Inner}.

[c] The weekday average standard deviation of the accrued returns in the given 15-minute time interval. Within each interval, the standard deviations are very similar on all weekdays.

efficient, perhaps there could be a lagged reaction to macroeconomic information among small firms. However, if small and large firm markets are informationally efficient, it appears unlikely that the day-of-the-week effect would be related to macroeconomic information. Further research will be necessary before strong conclusions can be made.

Tests for cross-sectional differences among the various portfolio trading- and non-trading-period mean returns also were conducted for the other weekdays. The results (table 1, panels B and C, last row) indicate that the close-to-open means are also significantly different in cross-section on Tuesday and Wednesday and that the open-to-close means are significantly different on Wednesdays and Fridays. An examination of the mean returns, by size decile, reveals that the Monday close-to-open returns and the Wednesday and Friday open-to-close returns may be related to the small-firm effect (small firms have greater returns than large firms). No easily identifiable pattern characterizes the close-to-open returns on Tuesday or Wednesday. These cross-sectional results show that the large Friday close-to-close returns observed in small firms portfolios by Keim (1983) and by Keim and Stambaugh (1984) accrue primarily during the trading day.

4. Weekday differences in intraday price patterns

To further investigate systematic weekday differences in open-to-close returns, means were computed, by 15-minute intervals, of the returns which accrue within the trading day. The results are presented in table 2 and cumulative means are plotted by weekday in fig. 1. The appendix describes the method used to compute the accrued means.

There is a striking difference between Monday and the other weekdays in the first 45 minutes of trading. The mean return in this interval for the NYSE equal-weighted portfolio is negative on Monday (-0.13%), while on the other weekdays it is positive (0.09%, 0.14%, 0.12%, and 0.10%). The difference is significant. An F-test of the equivalence of the weekday means and an F-test of the equivalence of the Monday mean to the average of the other weekday means both reject equality at the 5% significance level in each of the first three 15-minute intervals but in none of the following 21 intervals (table 2, columns 7 and 8). Only after the Monday returns are removed from the sample can equivalence of the remaining weekday means not be rejected in all the intraday intervals (table 2, column 9).

The weekday pattern of returns observed in the first 45 minutes of trading is pervasive both through time and throughout the cross-section. In 11 of the 14 months in the sample, the mean return realized by the NYSE equal-weighted portfolio over the first 45 minutes on Monday is negative, while in 39 of the 56

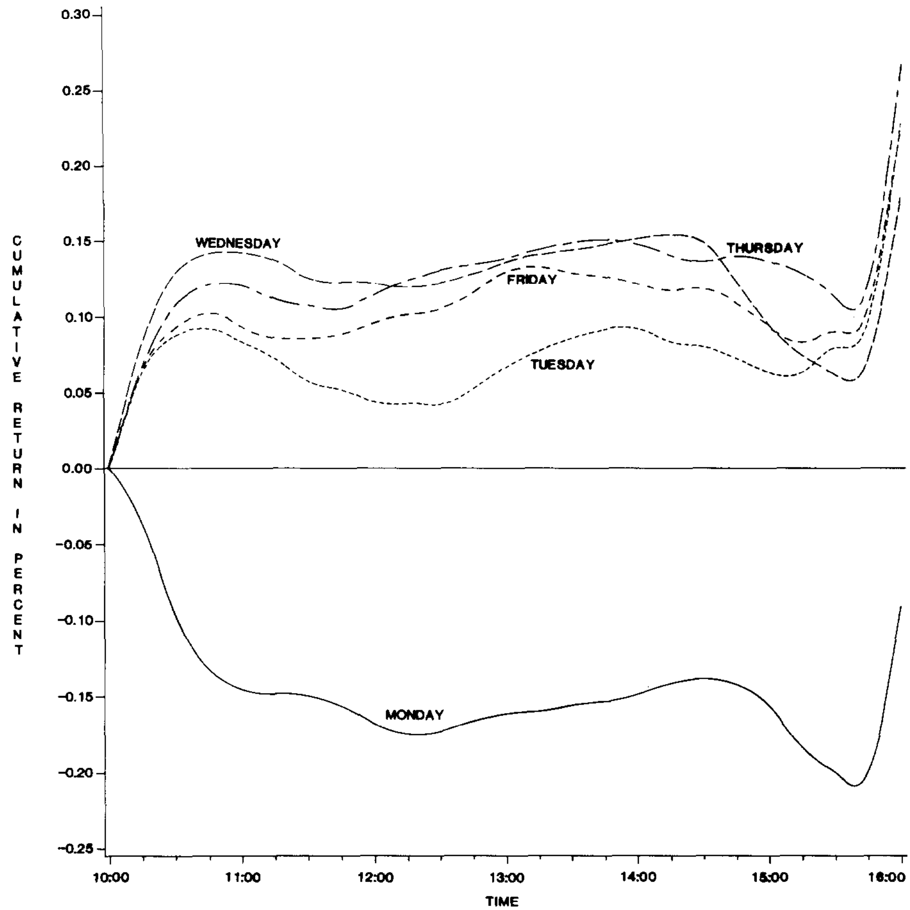

Fig. 1. Cumulated mean 15-minute intraday returns, by weekday, in percent. The accrued return is the average rate of return experienced by common stocks in the NYSE equal-weighted portfolio within a given 15-minute interval. All 1616 NYSE common stocks, all 296 trading days, December 1, 1981 to January 31, 1983, except 9 days which followed a holiday.

(4 × 14) other weekday-months, the mean return is positive (table 3).[3] If positive and negative values were equally likely, the probability of observing 11

[3]Rogalski (1984) observed that the mean Monday close-to-close return in January is positive in his 1974–1983 sample. In this sample, which includes two Januarys, this mean is negative, as are the mean Friday-close-to-Monday-open return and the mean Monday open-to-close return and the mean Monday return in the first 45 minutes of trading. The difference between Rogalski's close-to-close results and those presented here is probably due to the different sample periods (Rogalski studied data from 1963–1982) and to the fact that only two Januarys are present in this sample. It would be interesting to know whether negative Monday returns in the first 45 minutes also characterize Januarys for which mean Monday close-to-close returns are positive.

Table 3

The cumulated sum of the first three 15-minute mean accrued returns, by month and weekday, in percent. These means are of the average rate of return experienced by common stocks in the NYSE equal-weighted portfolio between 10:00 and 10:45. All 1616 NYSE common stocks, all 296 trading days, December 1, 1981 to January 31, 1983, except 9 days which followed a holiday.

Month	Mon	Tue	Wed	Thu	Fri
All months	−0.133	0.092	0.142	0.121	0.103
(std. error)	(0.066)	(0.044)	(0.045)	(0.039)	(0.041)
N	53	57	61	60	56
December, 1981	−0.230	−0.075	−0.003	0.071	0.178
January, 1982	−0.306	−0.051	0.088	0.258	0.233
February	−0.219	0.091	0.241	0.193	0.133
March	0.182	0.185	−0.052	0.157	−0.079
April	0.058	−0.094	0.005	0.097	0.235
May	−0.216	0.144	−0.016	0.091	0.125
June	−0.086	0.033	0.186	−0.003	0.086
July	0.132	−0.006	−0.021	−0.065	−0.026
August	−0.011	0.354	0.370	0.348	−0.000
September	−0.216	0.282	0.163	−0.015	0.123
October	−0.052	0.114	0.299	0.414	0.017
November	−0.501	0.051	0.753	−0.023	0.146
December	−0.076	0.275	−0.032	−0.041	0.232
January, 1983	−0.279	−0.030	0.114	0.320	0.052

or more negative values in a sample of 14 months would be 0.0287, and the probability of observing 39 or more positive values in a sample of 56 would be 0.0016. Similar results (not presented) are obtained for each of the decile portfolios. These statistics indicate that the beginning-of-day differences among weekday mean returns are common; they are not caused by a few large returns in only a few months or only a few firms.[4]

To summarize, there are weekday differences in the pattern of intraday returns within the first 45 minutes of trading only. Later in the day, no such weekday differences are apparent. The latter results might suggest that the chronological trading time hypothesis may be an adequate description of the evolution of returns after the market opening. The next section, however, shows that even this limited form of the hypothesis is not supported by the data. There are systematic patterns in the time-series of intraday returns which are common to all of the weekdays.

[4] It is also possible to establish that the intradaily return patterns in this sample are stable through time using analysis of variance methodology. F-tests were computed to determine whether the 14 vectors of monthly weekday mean returns are equal. These tests were conducted for each decile portfolio within each 15-minute period. Equality is rejected at the 5% significance level in only 7 of the 240 (24 intervals times 10 portfolios) tests. The rejections are not associated with any one time interval or decile portfolio.

5. Time-series patterns in intraday prices

A cursory examination of intraday means (table 2, fig. 1) for the equal-weighted NYSE portfolio reveals that the evolution of prices during the trading day is not uniform on any of the weekdays. Mean intraday returns at the beginning and end of of the trading day are five to ten times larger in absolute value than returns which accrue in the middle of the day. These casual observations are confirmed in F-tests (last rows of table 2) of the equivalence of the twenty-four 15-minute intraday return means (F_{24}), of the equivalence of the first three 15-minute means to the average of the following 15 means (F_{Open}), and of the equivalence of the last 15-minute mean to the average of the preceding 23 means (F_{Close}). On every weekday, these tests all can reject their respective null hypotheses at significance levels of less than 5%. Similar results (not shown) are found for each of the size decile portfolios. Equivalence

Table 4

Mean transaction returns (percentage change in price from one transaction to the next) at the beginning and end of the trading day, by weekday.[a] All 1616 NYSE common stocks, all 296 trading days, December 1, 1981 to January 31, 1983, except 9 days which followed a holiday. The standard errors of these means range between 0.0030 and 0.0033.

Transaction	Mon	Tue	Wed	Thu	Fri	All days
Panel A: The first ten transaction returns						
2[b]	−0.0313	0.0155	0.0254	0.0189	0.0271	0.0114
3	−0.0284	0.0071	0.0131	0.0194	0.0210	0.0066
4	−0.0222	0.0047	0.0093	0.0069	0.0075	0.0014
5	−0.0160	0.0026	0.0082	0.0175	0.0152	0.0055
6	−0.0063	0.0001	0.0084	0.0133	0.0067	0.0045
7	−0.0164	0.0073	0.0111	0.0181	0.0106	0.0062
8	−0.0094	0.0033	0.0052	0.0105	0.0103	0.0040
9	−0.0090	0.0033	0.0040	0.0097	0.0165	0.0048
10	−0.0034	0.0019	0.0112	0.0079	0.0050	0.0046
11	0.0017	0.0077	0.0063	0.0069	0.0087	0.0063
Panel B: The last ten transaction returns						
Last	0.0371	0.0527	0.0342	0.0574	0.0568	0.0476
2	−0.0091	0.0051	−0.0059	0.0038	0.0047	−0.0002
3	−0.0135	−0.0054	−0.0076	−0.0036	0.0038	−0.0053
4	−0.0186	−0.0023	−0.0131	−0.0043	−0.0022	−0.0081
5	−0.0062	−0.0003	−0.0064	0.0002	−0.0041	−0.0033
6	−0.0091	−0.0010	−0.0054	−0.0032	0.0106	−0.0018
7	−0.0069	0.0009	−0.0085	−0.0031	−0.0013	−0.0038
8	−0.0054	−0.0015	0.0011	0.0012	0.0041	−0.0001
9	−0.0048	0.0057	−0.0069	0.0034	−0.0011	−0.0007
10	−0.0037	0.0034	0.0012	−0.0006	0.0052	0.0011

[a] Since many securities did not trade 21 times each day, some transaction returns contribute to means found in both panels of this table.

[b] The transaction return associated with the first transaction of the day is the previous close-to-open return. Means for this return can be found in table 1.

among the intraday means is accepted only for the inner twenty (10:45–15:35) 15-minute means (F_{Inner}).

Transaction-by-transaction returns were examined to determine whether the large beginning-of-day returns and end-of-day returns observed in the 15-minute interval returns are related to the first and last transactions only. At the beginning of the day, the results do not support this view. The mean returns accruing between the first and second and between the second and third transactions are both large relative to later mean transaction returns (table 4, panel A). These two means rank first and second in absolute value among the first ten mean transaction returns on all weekdays.[5] At the end of the day, however, only the return accruing between the penultimate and last transactions is large (table 4, panel B). The mean of this transaction return is positive and approximately five to ten times larger in absolute value than each of the nine preceding mean transaction returns. The end-of-day phenomenon is pervasive through time – the mean of the last transaction return is positive in 65 of the 70 weekday-months in the sample, and it is pervasive in cross-section – all market-value groups experience end-of-day returns which are positive and significantly larger than earlier returns (results not shown). Apparently, the return-generating processes for the first few transactions and for the last transaction are different from those which generate the mid-day transaction returns.

In addition to the larger returns at the beginning and end of the trading day, there are other time-series patterns in the 15-minute intraday returns which are common to all weekdays and therefore worthy of note. These patterns appear to include a rise in prices between 12:30 and 1:30 and a fall between 2:30 and 3:15. To measure whether these observations are statistically significant, Spearman correlations were computed among all ten pairs of the five weekday time-series of mean 15-minute accrued returns. Since it is already known that there are weekday similarities at the beginning and end of the trading day, only the twenty mean 15-minute returns which accrued between 10:45 and 3:45 are used to compute the correlations. The results obtained for the equal-weighted

[5] The large early returns may partially explain Roll and French's (1984) surprising observation that trading-period variances on a per-hour basis are about twenty times as large as non-trading period variances. Since information flows are probably more uniformly distributed over trading and non-trading periods than their evidence suggests, Roll and French conjecture that trading may be self-generating rather than in response to information flows. However, if the large price changes seen in the first 45 minutes are in response to information that arrived while the market was closed, then perhaps these prices should be included in the computation of the non-trading variances and excluded from the computation of the trading variances. Doing so would increase the former variance and lower the latter. The long adjustment time to new information may be a consequence of regulations which require market specialists to maintain an orderly market. [See Lakonishok and Smidt (1983).]

Alternatively, note that the relation between the standard deviation of the 15-minute intraday returns and the time-of-day is U-shaped (table 2, column 6). This shape is the same which can be seen in the relation between numbers of transactions and time. The similarity does not necessarily support the Self-Generating Trade Hypothesis [the Mixture of Distributions Hypothesis can also explain such a relation – see Harris (1985) – but it is not inconsistent with it].

NYSE portfolio tend to confirm the casual observations. All ten of the correlations are positive (range 0.209 to 0.651) with four of them significantly different from zero at the 5% level and three others significantly different at the 10% level.[6]

The results indicate that there are systematic time-series patterns in mean intraday returns which are common to all of the weekdays. Even within weekday trading periods, prices do not evolve at equal rates. Further research will be necessary to identify the origin of these patterns and to determine whether traders can profit by considering time-of-day effects when planning their transactions.

6. New transaction data evidence concerning high Friday closing prices

Several authors [Gibbons and Hess (1981), Starks and Smirlock (1983), and Keim and Stambaugh (1984)] have suggested that abnormally high closing prices on Friday could account for high Friday close-to-close returns and negative Monday returns. These same studies, however, are able to reject this hypothesis using an F-test of whether the sum of the Friday and Monday mean close-to-close returns is equal to the average of the other weekday means. Using transaction data, at least three new tests of the high Friday closing price hypothesis are possible. These tests also reject the high closing price hypothesis.

If high closing prices on Friday were the result only of errors in the measurement of the last transaction price, then the mean of the last transaction return of the day would be greater on Friday than on the other weekdays, and the last Friday transaction return would be negatively correlated with the Friday-close-to-Monday-open return. The data, however, do not support either prediction. For all market value decile portfolios but the smallest, the mean Friday last-transaction return is not significantly larger than the average of the weekday means.[7] For six of the portfolios, the Friday mean is not even the maximum of the weekday means.

Two issues make the second prediction somewhat more difficult to test. Portfolio returns will not display negative serial autocorrelation due to measurement errors in security prices if those errors are non-systematic. Correlations must therefore be computed for each security separately. Secondly, normal price jumps from bid to ask can also cause the last Friday transaction

[6] The statistical tests are one-sided tests for positive correlation. Pearson correlations were also computed with similar results. The Spearman correlations are reported because they are more robust. Correlations were also computed for each market value decile separately. The results for each group are very similar to those reported for the equal-weighted NYSE index.

[7] The mean returns on the last transaction of the day for the smallest firms, by weekday, are 0.073% for Monday, and 0.133%, 0.092%, 0.138%, 0.185% for the other weekdays. The Friday mean return is significantly different from the average of the other weekday means [$F(1,281) = 5.42$, p-value = 0.0207]. Large Friday returns at the end of the day for small firms may cause the large Friday open-to-close returns noted for these same firms.

return to be correlated with the weekend non-trading-period return. Therefore that correlation must be compared to similar correlations obtained for the other weekdays – there is no obvious reason why the bid–ask induced correlation should be any larger on Friday than on the other weekdays. If it is found that the correlation on Fridays is greater (in absolute value) than on the other weekdays, this would be evidence in favor of the high Friday closing price hypothesis. The data, however, do not favor this hypothesis. The mean across all securities of the Friday correlation is not significantly greater (at the 5% level, one-sided test) than the average of the other weekday means [$F(6627,1) = 3.12$.[8] To determine whether there might be cross-sectional differences in this result, the means were compared separately for the securities in each market value decile. The results are the same for all deciles.

The third transaction data test of the high Friday closing price hypothesis is based on the assumption that high Friday closing prices are artificially created by traders wishing to overstate shock prices over the weekend period. If so, it is likely that the price would be established in a small transaction as late as possible in the day in order to minimize the costs of trading at and maintaining an above-market price. The data, however, offer little evidence of such behavior. Not only is there little variance across weekdays in the end-of-day transaction return, there is also little weekday variance in the number of shares traded in the last transaction, or in the time of that transaction. Mean shares traded, by weekday, are 1016, 1135, 1192, 1113, and 1066 shares; mean times are 3:34, 3:33, 3:33, 3:32, and 3:33. For all size portfolios, F-tests (results not shown) reject the hypothesis that the Friday means of these variables are significantly different from the average of the other weekdays means. It is unlikely that the weekend effect seen in this sample is the result of manipulated Friday closing prices.

7. Summary

Fourteen months of the complete transaction record of the NYSE were examined to further characterize systematic weekly and intradaily price patterns. Several results were found:

* There are cross-sectional differences in weekday patterns found in both trading- and non-trading-period returns. For large firms the negative Monday close-to-close return accrues between the Friday close and the Monday open. For small firms it accrues during the Monday trading day.

[8] The cross-security mean correlation of the last Friday transaction return with the following non-trading-period return is -0.144. The means for Monday through Thursday are -0.130, -0.134, -0.130, and -0.150.

* There are significant weekday differences in intraday trading returns in the first 45 minutes of trading. On Monday, returns are negative, while on the other weekdays, returns in this interval are positive.

* There are systematic intraday return patterns which are common to all of the weekdays. Returns are very large at the beginning and at the end of the trading day. The beginning-of-day returns accrue over several transactions. The large positive end-of-day returns accrue only on the last transaction of the day.

* These patterns are pervasive over time and over market value groups.

* It is unlikely that the weekend effect in this sample is caused entirely by high Friday closing prices, caused either by systematic errors in the data or by deliberate price manipulation.

Trading strategies based only on these weekly and intradaily patterns would not be profitable because of transaction costs. However, profits may be made when there are other reasons to trade. Purchasers of stock may wish to avoid transacting early on Monday morning and sellers may wish to avoid early transactions on Tuesday through Friday.

This study does not solve the day-of-the-week anomaly. It does, however, provide a more complete and detailed characterization of the effect. It is hoped that these results will help others to develop new hypotheses.

Further empirical work should be done to determine whether the intraday return patterns described in this study are stationary, non-stationary, or perhaps seasonal. The 14-month time-series sample analyzed here is too short to make such determinations with confidence. Replication of this study using a transaction data set which covers a longer (or different) period of time would be desirable.

Appendix: The computation of 15-minute intraday returns

The intraday analyses undertaken in this study require measurement of portfolio returns which accrue over 15-minute intervals. The method used estimates the average rate of return accrual in the given interval rather than the average realization of returns within that interval. The accrual method was used because it is less sensitive to problems associated with non-sychronous trading. These problems are serious since most securities do not trade within each 15-minute interval on every day (and therefore returns are not relized in each interval for all stocks), and when securities do trade, in general, the trade is not at the end of each interval. Despite these considerations, returns computed using the realization method yielded similar results.

The accrual method averages the rate of return per unit time experienced by the securities in a portfolio over a given 15-minute interval. The average is computed in several steps. First, for each of the portfolio securities, all pairs of successive transactions for which the time period between them (the transaction time period) overlaps at least part of the 15-minute interval are identified. Since an index of only intraday returns is desired, only pairs for which both transactions took place on the same day are used. Next, the return from the first to the second transaction in the pair is divided by the elapsed time between them to get the rate of price accrual per minute for the pair. Finally, the average 15-minute accrued return is computed as the weighted average of the rate of price accrual associated with each of the transaction pairs. The weights are proportional to the amount of time over which each transaction time period overlaps the 15-minute interval, and they are scaled so that they add up to 15.

Three details must be noted. Sometimes successive transactions occur during the same minute. The Fitch records, however, report only the minute (and not also the second) of each transaction. When two successive transactions appear within the same minute, the time between them is assumed to equal one-third of a minute. This figure is the expected time between the two transactions under the assumption that their times of arrival are independently and identically distributed uniformly over the minute. Second, the return between two successive transactions is computed as the difference in their prices

Table 5

An example illustrating the method used in this paper to estimate accrued portfolio returns over 15-minute intervals. The method, which is fully described in the appendix, computes a weighted average of the rates at which individual portfolio securities accrue returns in a given 15-minute interval. Assume that there are only two securities in the portfolio. On a given day, suppose that security A first traded for $50 at 10:00 and next for $53 at 10:45. Suppose also that security B traded for $20 at 10:10, for $21 at 10:20, and for $20 at 10:25, the last transaction of the day. The accrued return for the portfolio in the 15-minute interval from 10:15 to 10:29 is computed as shown.

Transaction return[a]		Time between transactions[b]		Duration time[c]		Accrued return, 10:15–10:29
(53 − 50)/50	÷	45	×	15	=	2%
(21 − 20)/20	÷	10	×	5	=	2.5%
(21 − 20)/20	÷	5	×	5	=	−5%
Summed portfolio duration time				25		
Summed accrued return						− 0.5%

The average portfolio accrued return, 10:15–10:29, is $-0.5\% \div 25 \times 15 = -0.3\%$

[a] The transaction return is computed as the difference in price between two successive transactions, divided by the initial transaction price of the day. This seemingly unusual denominator is used in lieu of the normal lagged price to control the upward bias in arithmetic mean returns which results when prices jump back and forth between bid and ask.

[b] The elapsed time between the two successive transactions.

[c] The total time over which the interval between the two successive transactions overlaps the 15-minute interval (10:15–10:29) for which the accrued return is being computed.

divided by the first price of the day. This seemingly unusual denominator is used in lieu of the normal lagged price to control the upward bias in arithmetic mean returns which results when prices jump back and forth between bid and ask [see Blume and Stambaugh (1983)]. Finally, it must be noted that the accrual method introduces autocorrelation into the series of average interval returns, making it appear to be more smooth than it actually is.

An example of the application of the procedure is presented in table 5.

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