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Trading structure and overnight information: A natural experiment from the Tel-Aviv Stock Exchange

Tavy Ronen [1]

Rutgers University, 81 New Street, Newark, NJ 07102, USA

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Abstract

A unique data set from the Tel-Aviv Stock Exchange (TASE) is used to study the effect of trading mechanisms on stock return volatility. The TASE represents a *natural experiment* which allows separation of the overnight information effect from the trading mechanism effect. The data span a time period in which the order of the trading mechanisms (a sequential continuous mechanism and a call auction) was switched. Since overnight information should impact opening prices equally across periods, this affords an unparalleled opportunity to examine the trading mechanism effect without the confounding effect of the non-trading period. This paper finds that the null, that opening variances equal closing variances, cannot be rejected for either period. Further, the tests cannot reject null that the ratio of opening to closing return variances is equal across periods. This suggests that the trading mechanisms on the TASE do not differ in their effect upon return volatility.

JEL classification: G10; G14; G15; C53; C40

Keywords: Microstructure; Trading mechanisms; Non-trading periods; Transitory volatility; Variance ratios

[1] Tel.: 973 353 5272.

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1. Introduction

Recent microstructure studies have focused on two related issues. The first pertains to the relative merits of different trading mechanisms and their effect on stock return behavior. The second concerns transitory volatility at different times of the day, and the effect of non-trading periods on opening prices. These two issues are especially related in light of recent evidence from the NYSE and other exchanges, that 24-hour returns based on opening prices are on average 20% more volatile than those based on closing prices. See for example, Amihud and Mendelson (1987), French (1991) and Stoll and Whaley (1990). This difference in variances is typically attributed to the *trading mechanism* used at the open, and presumably implies that call auctions produce noisier prices than do continuous trading mechanisms. [2] Similar evidence from other exchanges which do not open with a call auction produces an alternative explanation for the noisier opening prices: the overnight non-trading hours may cause excess volatility at the open, since the trading halt may cloud the price formation process provided by continuous trading. [3] Finally, Ronen (1997) shows that the use of variance ratios in the comparison of intradaily volatilities may be subject to testing difficulties. Ronen shows that when standard error corrections are introduced, there is no significant difference between opening and closing return variances for a sample of NYSE stocks. Notwithstanding the results of this last study, an identification problem remains involving the empirical separation of the trading mechanism effect from the overnight information effect. For example, even if there is no significant difference between opening and closing return variances, both effects may exist, but they may offset each other.

This paper disentangles the *trading mechanism effect* from the *overnight information effect*, using a unique data set from the Tel-Aviv Stock Exchange,

[2] Trade on the New York Stock Exchange opens with a *call* auction, where buy and sell orders are accumulated overnight and are then executed simultaneously at a single price that matches aggregate supply and demand of market participants. Trade continues throughout the day and at the close in a specialist driven *continuous* trading mechanism. See Schwartz (1986) for institutional details.

[3] See for example, Masulis and Ng (1991), who find that the average variance ratio is 1.127 for a sample of Financial Times 100 stocks trading on the London Stock Exchange. These stocks trade continuously throughout the day. Similar evidence is provided by Amihud and Mendelson (1989, 1991), Amihud et al. (1990) and Choe and Shin (1993), for Tokyo, Milan, and Korea. Cao et al. (1994), Forster and George (1993) and Gerety and Mulherin (1994) examine the hypothesis that long periods of non-trading preceding the open may affect opening volatility by using international cross-listings, the Dow Jones Index, and NASDAQ stocks, respectively. Finally, price formation models supporting the hypothesis that noisier opening prices are produced by trade interruptions include Dow and Gorton (1993), Leach and Madhavan (1993) and Romer (1993).

which represents a *natural experiment*, facilitating experimental control previously unavailable. The data set is unique in that it spans a time period (1987–1990) over which the order of the trading mechanisms on the TASE was switched. While in 1987 the continuous trading rounds preceded the call, the order of the mechanisms was reversed in 1988. The existence of both trading mechanisms along with the reversed sequence provides a setting wherein each mechanism serves as experimental control for the other. Assuming that overnight information affects opening prices in the same way in both periods, any comparative results can be attributed to the trading structure, as opposed to the overnight information effect. Further, in contrast to earlier studies of foreign markets, multivariate tests are used to overcome the difficulties otherwise associated with the testing of variance ratios in this context.

The multivariate variance ratio tests conducted here account for the strong positive autocorrelations observed in the return series, as well as for cross stock correlation, serial correlation, heteroskedasticity, and the overlap between the opening and closing returns. This paper finds that there is no significant difference between opening and closing return variances within either period. Given the strong experimental control made possible by the aforementioned sequence reversal, this result implies that the order of the trading mechanisms does not significantly affect return volatility. This result is confirmed by testing the null that the ratio of opening versus closing return variances is equal across periods. Again the null cannot be rejected.

Since some of the conclusions in this paper are in contrast to others in the literature, a relevant concern is whether the non-rejections obtained here are the result of poor statistical properties of the multivariate test used. The size and power of the multivariate variance ratio test statistic are therefore investigated in detail, and power is found to be reasonable in most cases. It is therefore concluded that the test results obtained in this paper are not mere artifacts of low power.

When studying international markets, it is often the case that the specific institutional environment is likely to affect the results, and to limit the generality of the conclusions that may be reached. However, the *natural* control of the TASE data contributes to the resolution of the trading mechanism issue. Since this study disentangles the overnight information effect from the trading mechanism effect, it suggests that call auctions do not produce noisier opening prices than continuous markets, and is thereby consistent with the predictions of Amihud and Mendelson (1987), and Madhavan (1992) (that call markets do not produce more volatility than continuous markets).

The organization of the paper is as follows. Section 2 describes the method of trade on the TASE, in both the pre- and post-1988 periods. The data are described in Section 3. Section 4 presents preliminary variance ratios, autocorrelation patterns, and multivariate variance ratio test results. Section 5 examines the statistical properties of the variance ratio test employed. Section 6 summarizes. Appendix A provides detailed information regarding the trading rules on the TASE.

2. Trade on the Tel-Aviv Stock Exchange

Trading methods on the Tel-Aviv Stock Exchange (TASE) have changed significantly in the last decade. [4] Prior to 1987, all trade on the TASE was carried out through a sequential call procedure. On 23 April 1987 the exchange introduced a new continuous bilateral trading mechanism for the 30 stocks (*Mishtanim* stocks) with the highest trading volume. Together, these stocks accounted for 40–50% of the total trading volume on the TASE. In 1989–1990 the exchange increased the number of stocks to 40, as volume in the new continuous rounds rose to comprise up to 60% of daily volume. Initially, trade opened each day with the new continuous bilateral trading rounds (*Mishtanim rounds*), and closed with the call auction. However, in March 1988 the order was reversed, with the continuous rounds placed after the call auction.

The *Meretz* is a clearinghouse, or call mechanism, that aggregates and clears orders at a single price for each security. Each member submits to the TASE a 'leader' (compilation) of orders which includes every customer order received by the member. These orders may be market or limit orders, and may be submitted at any time during the previous trading day's continuous rounds and up until a few hours preceding the call auction. An excess supply or demand determines the direction in which the price will move from the base price, which is determined by the previous afternoon's close. Both large and small traders rely on the call mechanism.

In the Mishtanim rounds of trade, stocks trade in a sequential fashion, with the assistance of a caller. There are usually three complete trading rounds. A round consists of each stock in the group being called once, sequentially. Each time a stock is called, its base price is announced (see Appendix A) and members are free to announce their orders. Bilateral trades are set among the exchange members, and trade in a security continues until there are no more willing buyers or sellers. Most orders submitted to these rounds are limit orders. Price priority and then time priority rules are enforced. The caller

[4] The most notable change of these changes is probably the 1991 introduction of the KEREM. This electronic trading system through which a large number of less active securities now trade is similar to the recent efforts of other exchanges to move towards electronic systems. Since this paper focuses on the 1987 introduction of continuous rounds of trade, the rules and regulations outlined involve those trading mechanisms in place in 1987 and up until 1990. Subsequent changes in the TASE are not studied here. See Appendix A also for more information regarding the trading mechanisms.

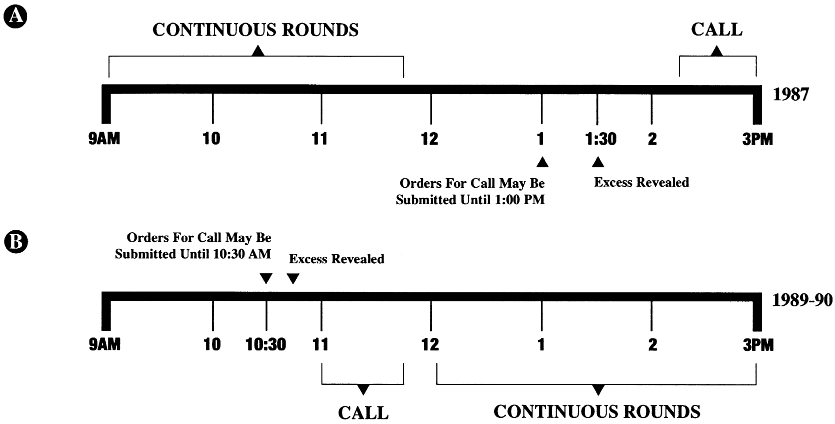

Fig. 1. Trading mechanisms on TASE – time-line.

occasionally adjusts the base price depending upon the excess supply or demand, to clear the market and facilitate limit orders. Orders not executed in one round are automatically transferred to the next. Since several different prices may be determined for each security in any one trading round, and since orders may be continuously entered for execution, these rounds are referred to as continuous rounds of trade. Since each transaction may occur at a different price, customers' orders may be filled in several smaller chunks, at different prices. A minimum trading requirement bars small trades from being executed in the continuous rounds (in 1987, this was only $3000). Appendix A provides more detailed information on trading rules on the TASE.

3. The data

The data consist of opening and closing prices and volume for the securities comprising the Mishtanim stocks. [5] Two subgroups are formed according to time periods. Period A consists of the seven months (150 trading days) from

[5] The majority of the data was obtained from Y. Nitzani, the Director of the TASE during the sample period. I am indebted to him and to the TASE for providing me with data at a time when it was otherwise unavailable in computerized form. I hand collected the remainder of the data from documents in the TASE Library. Specifically, opening prices for the 1987 period were hand collected, in order to capture the first price of the day, as opposed to the closing price of the first continuous round, which was only 'opening' price provided electronically. Ex-dividend and stock dividend dates were also hand collected from TASE documents.

Table 1
Mishtanim stocks – Basic information

	Cusip	Stock	$Size_A$	$Size_B$	μ_A	μ_B	σ_A	σ_B
1	593038	First Int'l Bank	85,395.43	150,489.23	0.0009	0.0008	0.024	0.023
2	608018	Clal Industries	42,979.43	137,272.47	−0.0008	0.0021	0.028	0.026
3	612010	Land Development	33,745.14	53,036.77	−0.0015	0.0002	0.030	0.026
4	629014	Teva	158,921.14	267,196.31	−0.0024	0.0004	0.029	0.022
5	631051	Dead Sea	262,253.79	350,929.99	−0.0008	0.0000	0.022	0.022
6	632018	A.I. Paper Mills	42,979.47	66,134.47	−0.0025	0.0017	0.026	0.024
7	636019	Delek	74,127.43	138,814.29	−0.0014	0.0006	0.027	0.023
8	639013	Discount Invsts.	95,504.57	154,704.06	−0.0031	0.0016	0.030	0.023
9	699017	Property and Bdng.	52,009.26	123,427.16	−0.0018	0.0018	0.030	0.023
10	728014	Clal Israel	114,758.28	212,039.31	−0.0005	0.0019	0.031	0.026
11	746016	Elite	36,181.30	26,099.10	−0.0022	0.0028	0.028	0.029
12	754010	Clal Real Estate Inv.	11,576.52	26,696.02	0.0005	0.0013	0.027	0.027
13	756015	Petrochemical	70,477.15	63,682.07	0.0006	−0.0007	0.032	0.030
14	777037	Super-Sal	25,341.24	42,500.08	−0.0013	0.0017	0.028	0.021
15	798017	IDB Development	19,545.72	275,177.66	−0.0020	0.0019	0.027	0.023
Average					−0.0013	0.0012	0.028	0.025

This table documents basic trading information for the 15 Mishtanim stocks trading on the TASE from 25 May 1987 to 31 December 1987 (period A), and from 27 June 1989 to 29 November 1990 (period B). Size is the market capitalization, in thousands of dollars. μ is the daily mean return, based on closing prices, and σ is the daily standard deviation of return, based on closing prices.

25 May 1987 until 31 December 1987. During this time period, the call (Meretz) followed the continuous (Mishtanim) trading rounds. Period B consists of the 17 months (350 trading days) between 27 June 1989 and 29 November 1990. [6] Since the order of trading mechanisms was reversed in 1988, Period B spans a period in which the continuous rounds followed the call mechanism. Fig. 1 indicates the time frame for trade in each period.

Although 27 stocks were found to trade in both periods, only 15 of these stocks are included in the sample. Stock selection is based upon a minimum trading day requirement (150 trading days), as well as an additional requirement that the trading days in each period must coincide, so that contemporaneous correlation across stocks can be adjusted for. Table 1 provides basic information for these securities.

[6] There was a two week stock exchange strike in 1990, that ended on 3 March 1990. This was adjusted for by removing the two week return from the sample. Likewise, the last two weeks of October 1997 were removed from the sample to account for possible impacts of the October 1997 crash. I than an anonymous referee for this suggestion.

4. Ratio analysis and autocorrelation patterns

To determine whether trading mechanisms affect return volatility, researchers typically compare variances of 24-hour returns based on prices determined in different mechanisms, by computing the ratio of variances: [7]

$$\Upsilon = \frac{V^{\mathrm{o}}}{V^{\mathrm{c}}} = \frac{\mathrm{Var}(R_t^{\mathrm{o}})}{\mathrm{Var}(R_t^{\mathrm{c}})}, \tag{1}$$

where R_t^{o} is the 24-hour continuously compounded return based on opening prices, and R_t^{c} is the 24-hour continuously compounded return based on closing prices. The motivation for using the variance ratio hinges upon the following argument: each 24-hour return should reflect innovations in the ‘true price’ and other disturbances, such as due to the particular trading mechanism employed. Since the opening and closing return variances are both computed over a 24-hour period, they should be equal if the two trading mechanisms are of the same quality, and if the true price follows a random walk. In the spirit of these studies, the variance ratio, Υ, is therefore estimated for each stock in each period: In 1989–1990, when the call preceded the continuous rounds of trade, Υ is on average 1.21, and is greater than 1 for all 15 stocks (Table 2). In 1987, the average variance ratio is 1.07, and is greater than 1 in 11 of the 15 cases. Thus, the variance ratio estimates are greater than 1 (on average) in both periods. These preliminary results are similar to those found for US data by Amihud and Mendelson (1987), and Stoll and Whaley (1990), who also find average variance ratio estimates greater than 1. Based upon the average variance ratio estimates and their dispersion, these studies conclude that opening return variances are significantly greater than closing return variances. Similarly, the results found for the TASE seem to imply that opening variances are significantly greater than closing variances in each period. However, Ronen (1997) shows that results based on such statistical analysis are difficult to interpret, due to the difficulties associated with testing for departures of the variance ratios from one. First, the numerator and denominator of the 24-hour variance ratio are correlated (their returns overlap). Second, heteroskedasticity and serial correlation can affect the variance ratio estimates. Third, when testing the behavior of multiple stocks, it is necessary to account for the correlation across the stocks and across the resulting variance ratio estimates. For these reasons, inferences based upon standard tests statistics can be misleading,

[7] See for example, Amihud and Mendelson (1987, 1989), Amihud et al. (1990), Masulis and Ng (1991) and Stoll and Whaley (1990), who compare the variances of 24-hour returns based upon opening and closing prices for US, Japan, Italy, and London exchanges.

Table 2
24-hour variance ratio estimates and autocorrelations

	Stock	Υ_a	Υ_b	ρ_a^{oo}	ρ_a^{cc}	ρ_b^{oo}	ρ_b^{cc}
1	First Int'l Bank	1.15	1.14	−0.069	0.054	−0.087	0.056
2	Clal Industries	1.07	1.21	−0.094	0.009	−0.072	0.093
3	Land Development	1.13	1.14	−0.103	0.120	0.000	0.063
4	Teva	0.99	1.24	−0.011	0.103	0.040	0.126
5	Dead Sea	1.10	1.12	0.013	0.035	−0.017	0.039
6	A.I. Paper Mills	1.11	1.14	0.031	0.139	−0.007	0.117
7	Delek	1.03	1.23	0.098	0.016	−0.096	0.057
8	Discount Invsts.	1.09	1.35	0.003	0.138	−0.104	0.086
9	Property and Bdng.	0.97	1.11	0.156	0.230	0.097	0.161
10	Clal Israel	1.26	1.34	−0.046	0.091	−0.074	0.092
11	Elite	0.98	1.23	0.035	0.106	0.080	0.167
12	Clal Real Estate Inv.	0.89	1.23	−0.035	0.091	0.073	0.198
13	Petrochemical	1.08	1.23	0.036	0.007	0.017	0.081
14	Super-Sal	1.00	1.09	0.208	0.068	0.036	0.152
15	IDB Development	1.10	1.30	−0.007	0.108	−0.080	0.143
	Average	1.07	1.21	0.011	0.087	−0.013	0.109
	Cross sectional std. dev.	0.09	0.08	0.092	0.072	0.067	0.046
	Cross sectional std. err.	0.02	0.02	0.023	0.018	0.017	0.012

This table documents daily (24-hour) variance ratios and autocorrelations based on open and close prices for both periods. Daily returns are calculated using daily data (open and close prices) of Mishtanim stocks trading on the TASE from 25 May 1987 to 31 December 1987 (period a), and from 27 June 1989 to 29 November 1990 (period b). Υ_a is the variance ratio calculated for the 1987 period, Υ_b is the variance ratio calculated for the 1989–1990 period, ρ_a^{oo} is the correlation between R_t^o and R_{t-1}^o in period a (1987 data). ρ_a^{cc} is the correlation between R_t^c and R_{t-1}^c in period a. ρ_b^{oo} is the correlation between R_t^o and R_{t-1}^o in period b (1989–1990 data). ρ_b^{cc} is the correlation between R_t^c and R_{t-1}^c in period b.

and joint tests which account for the various correlations may be more appropriate.

4.1. Autocorrelations

Since variance ratios may also be difficult to interpret if return autocorrelations are not zero, serial correlation and intertemporal variations in autocorrelation patterns are tested for. [8] Table 2 reports the first order autocorrelations

[8] Previous studies have found that daily first order serial correlation varies for return series calculated at different times of the day. Specifically, Wood et al. (1985), and Richardson and Smith (1988) find (for NYSE stocks) that first order autocorrelations are more pronounced at the beginning and end of day than at other times throughout the trading day. End of day returns tend to exhibit positive autocorrelation, while morning returns exhibit negative autocorrelations. Amihud and Mendelson (1987) find similar results for Tokyo.

of the daily return series. In the 1989–1990 period, the serial correlation in open-to-open (call-to-call) returns is on average −0.013, with seven stocks exhibiting positive autocorrelations (values range from −0.104 to 0.080). All of the closing returns exhibit positive autocorrelations, and are on average 0.109. [9] During 1987, the average autocorrelation for both opening and closing returns is positive, on average 0.011 and 0.087, respectively. Thus, opening call prices in 1989–1990 seem to be least (positively) autocorrelated, while closing price returns for that period are the most autocorrelated.

The covariance between intradaily and overnight returns can also be useful in gaining insights regarding the trading structure mechanisms. In fact, a direct relationship exists between the intradaily covariances and the deviations of Υ from one: Rewriting the variance ratio in Eq. (1), we have:

$$\Upsilon = \frac{\mathrm{Var}(R_t^{\mathrm{oc}}) + \mathrm{Var}(R_{t+1}^{\mathrm{co}}) + 2\,\mathrm{Cov}(R_t^{\mathrm{oc}}, R_{t+1}^{\mathrm{co}})}{\mathrm{Var}(R_t^{\mathrm{co}}) + \mathrm{Var}(R_t^{\mathrm{oc}}) + 2\,\mathrm{Cov}(R_t^{\mathrm{co}}, R_t^{\mathrm{oc}})}$$

(see Stoll and Whaley (1990) for a similar interpretation). Any deviations of Υ from 1 imply that $\mathrm{Cov}(R_t^{\mathrm{oc}}, R_{t+1}^{\mathrm{co}}) \neq \mathrm{Cov}(R_t^{\mathrm{co}}, R_t^{\mathrm{oc}})$. Table 3 documents the correlations between the intraday returns and the overnight returns.

In the 1989–1990 period, the correlation between the daytime and subsequent overnight return is positive in all 15 cases, ranging from 0.05 to 0.22, with an average of 0.15. The correlation between the daytime and the previous overnight return is positive in four cases, with an average across stocks of −0.05 (ranging from −0.13 to 0.07). This combination may be interpreted as an 'underadjustment' in closing (continuous) prices accompanied by an 'overadjustment' in opening (call) prices. In 1987, the correlation between trading day and subsequent overnight returns is on average 0.15, and positive for all stocks. The correlation between trading day and previous overnight returns is on average 0.08, and positive for 13 of the 15 stocks, indicating that both closing and opening prices in 1987 may imply underadjustment to information. In most cases, the closing prices underadjust by more than the opening prices.

In conclusion, closing prices underadjust in both periods. Since closing prices are determined by *different* mechanisms in the two periods, the underadjustment is unlikely to be trading-mechanism specific. Rather, this behavior is

[9] One possible source of the positive correlation exhibited by the closing returns is the structure of the data – the closing prices are in fact averages of the last three transaction prices of the day. An indirect test is conducted, to determine whether averaging has an effect on the magnitude of the autocorrelations. The autocorrelations of the closing prices in 1987 are estimated, and found to be similarly high to those in 1989–1990. Second, the volume weighted autocorrelations are estimated, and found to be much lower than the non-weighted autocorrelations. By weighting more heavily those returns which correspond to higher volume, the averaging problem is somewhat mitigated. Non-synchronous trade may also induce positive autocorrelations.

Table 3
Correlations between overnight and trading day returns

	Stock	$\rho_{\mathrm{a}}^{\mathrm{occo}}$	$\rho_{\mathrm{a}}^{\mathrm{cooc}}$	$\rho_{\mathrm{b}}^{\mathrm{occo}}$	$\rho_{\mathrm{b}}^{\mathrm{cooc}}$
1	First Int'l Bank	0.152	0.021	−0.072	0.108
2	Clal Industries	0.003	0.069	−0.055	0.171
3	Land Development	0.081	0.190	−0.126	0.049
4	Teva	0.150	0.090	0.012	0.181
5	Dead Sea	−0.121	0.139	0.021	0.108
6	A.I. Paper Mills	−0.009	0.143	−0.064	0.146
7	Delek	0.076	0.092	−0.066	0.145
8	Discount Invsts.	0.185	0.272	−0.066	0.199
9	Property and Bdng.	0.140	0.196	0.003	0.156
10	Clal Israel	0.092	0.148	−0.112	0.195
11	Elite	0.083	0.196	0.072	0.105
12	Clal Real Estate Inv.	0.091	0.121	−0.128	0.144
13	Petrochemical	0.043	0.167	−0.028	0.187
14	Super-Sal	0.137	0.136	−0.004	0.131
15	IDB Development	0.065	0.312	−0.095	0.223
	Average	0.078	0.153	−0.047	0.150
	Cross sectional std. dev.	0.077	0.075	0.059	0.048
	Cross sectional std. err.	0.020	0.019	0.015	0.012

This table documents correlations between daily and overnight returns for period a (1987) and period b (1989–1990). $\rho_{\mathrm{a}}^{\mathrm{occo}}$ is the correlation between the daily return and the preceding overnight returns in period a. $\rho_{\mathrm{a}}^{\mathrm{cooc}}$ is the correlation between overnight returns and the preceding trading day return in period a. $\rho_{\mathrm{b}}^{\mathrm{occo}}$ is the correlation between the daily return and the preceding overnight returns in period b. ρ^{cooc} is the correlation between overnight returns and the preceding trading day return in period b.

more readily explained by institutional factors specific to the TASE, such as the timing of information, and the barriers imposed upon mutual funds. Mutual funds, through which most of the public is invested can be sold only until 11 a.m. (and in some cases until 2 p.m.). The autocorrelations *do*, however, support the notion that the continuous mechanism contributes to the underadjustments, since prices determined in continuous trade tend to underadjust regardless of the time of day. This may again be due to institutional design: the minimum volume requirements, and lack of anonymity of the continuous rounds may be sufficient to support the observed correlations. In what follows, these autocorrelations are accounted for directly in the estimation of the variances.

4.2. The GMM approach

In this section, the joint hypothesis that each of the variance ratios equals one is tested, for each period, using a method proposed in Ronen (1997). The GMM of Hansen (1982) is used to overcome the difficulties associated with intradaily variance ratio analysis. The joint tests account for the correlation between the open and closing returns (the overlap between the numerator and the denominator), the correlation across the variance ratio estimates, as well as for serial correlation and heteroskedasticity in the return series. [10] The test results indicate that the null, that the variance ratio equals one, is not rejected for *either* period. Finally, a multivariate test is conducted to test the null that the variance ratios are equal across periods. Indeed, the results indicate that this null cannot be rejected, implying that the trading mechanisms used at the open and close do not effect transitory volatility.

Although the methodology is basically that found in Ronen (1997), an autocorrelation correction is specified here. A brief review of the test follows. To test the null hypothesis that each of the variance ratios estimated from a sample of stocks equals one jointly, both the Wald and Lagrange Multiplier-Type (LM) test statistics are considered. [11] For any stock i, the matrix of sample moments can be written,

$$g(\theta_i) \equiv g(\mu_i^{\mathrm{c}}, \Upsilon_i, V_i^{\mathrm{c}}) = \frac{1}{T}\sum_{t=1}^{T} \begin{pmatrix} (R_{i,t}^{\mathrm{c}} - \mu_{i,t}^{\mathrm{c}}) \\ (R_{i,t}^{\mathrm{o}} - \mu_i^{\mathrm{c}})^2 - \Upsilon_i V_i^{\mathrm{c}} \\ (R_{i,t}^{\mathrm{c}} - \mu_i^{\mathrm{c}})^2 - V_i^{\mathrm{c}} \end{pmatrix},$$

where θ_i is the vector of parameters, $R_{i,t}^{\mathrm{o}}$ and $R_{i,t}^{\mathrm{c}}$ are the 24-hour returns based on opening and closing returns, respectively, V_i^{c} is the variance of the 24-hour return based on closing prices, and $\Upsilon_i = V_i^{\mathrm{o}}/V_i^{\mathrm{c}}$ is the ratio of the opening variance to the closing variance, and where $\mu_t^{\mathrm{c}} \equiv \mathrm{E}[R_t^{\mathrm{c}} \mid \Phi_{t-1}^{\mathrm{c}}]$, the conditional expectation of the closing return using information available prior to the close of date t. [12] An autocorrelation correction is easily incorporated: $\mu_t^{\mathrm{c}} = \sum_{j=1}^{J} \rho_j R_{t-j}^{\mathrm{c}}$, where ρ_j is the jth order partial serial correlation of the returns. To account for the correlation across variance ratio estimates, the system is estimated jointly across stocks. For N stocks, the specification results in an exactly identified (unrestricted) system, and to test the null hypothesis, H_0: $\underline{\Upsilon} = [1, \ldots, 1]'$, the Wald test statistic is used:

$$T \times \underbrace{(\underline{\hat{\Upsilon}} - 1)'}_{1\times N} \underbrace{\hat{\Sigma}_{\Upsilon}^{-1}}_{N\times N} \underbrace{(\underline{\hat{\Upsilon}} - 1)}_{N\times 1} \overset{asy}{\sim} \chi^2(N),$$

[10] The Hansen and Singleton (1982) two-step procedure is used for estimation, producing serial correlation and heteroskedasticity consistent standard errors.

[11] Although the LM test is found to exhibit better small sample properties, the Wald test is more appealing in that it involves the estimation of each variance ratio explicitly.

[12] Since the means (μ^{o} and μ^{c}) are assumed to be time invariant, they are equal in large samples. Therefore, in order to maintain an identified system, the condition $\mu^{\mathrm{o}} = \mu^{\mathrm{c}}$ is imposed, and only μ^{c} is estimated.

Table 4
Joint test results, 1987

	Stock	V^c	a_o	b_o	a_c	b_c
1	First Int'l Bank	0.00052	0.00085	−0.07461	0.00070	0.08514
2	Clal Industries	0.00069	0.00210	−0.00492	0.00174	0.17739
3	Land Development	0.00065	0.00013	0.01736	0.00012	0.10207
4	Teva	0.00046	0.00063	0.03623	0.00030	0.15182
5	Dead Sea	0.00049	0.00000	−0.01705	0.00000	0.06435
6	A.I. Paper Mills	0.00057	0.00171	0.00816	−0.00144	0.18909
7	Delek	0.00053	0.00063	−0.01497	0.00016	0.09085
8	Discount Invsts.	0.00053	0.00171	−0.07913	0.00050	0.14706
9	Property and Bdng.	0.00056	0.00063	0.08846	0.00136	0.21230
10	Clal Israel	0.00067	0.00171	−0.04949	0.00146	0.15643
11	Elite	0.00089	0.00170	0.092666	0.00172	0.19821
12	Clal Real Estate Inv.	0.00073	0.00200	−0.00887	0.00224	0.24144
13	Petrochemical	0.00092	0.00253	0.10998	0.00103	0.14937
14	Super-Sal	0.00046	0.00115	0.03726	−0.00058	0.17079
15	IDB Development	0.00053	−0.00163	0.03726	0.00152	0.21172
	LM	p-value				
	12.86	0.61				
	$b_o, b_c = 0$	p-value				
	100.34	0.00				
	Wald	p-value				
	21.67	0.12				

This table documents the results for the joint tests for the period a (1987) data set. V^c is the closing return variance estimate, a_o, b_o, a_c, b_c are the coefficient estimates for the autocorrelation parameters for opening and closing returns.

where Σ_Υ is the variance–covariance matrix of the variance ratio estimates. [13] As an alternative to the Wald test, the LM test imposes the null (H_0: $\underline{\Upsilon} = [1, \ldots, 1]'$), in estimation. The resulting N-overidentifying restrictions yield a $\chi^2(N)$ specification test.

Results for the two periods are documented in Tables 4 and 5. The LM test statistic for the 1989–1990 period is 19.24, distributed asymptotically $\chi^2(15)$, and the p-value is 0.20. Similarly, the LM test statistic for the 1987 period is 12.86, with a p-value of 0.61, and the null cannot be rejected for either period. The Wald test results (Table 3) for the 1987 period are similar. The test statistic is 21.67, with a p-value of 0.12. For the 1989–1990 period the Wald statistic is 22.82, with a p-value of 0.09. Hence, both the LM test and the Wald tests indicate that for the 1987 period, the null, that the variance ratios jointly equal one, cannot be rejected. In the later period, when the call precedes the

[13] Estimation is carried out using the Hansen and Singleton (1982) two-step procedure, and the Newey and West (1987) corrections.

Table 5
Joint test results, 1989–90

	Stock	V^c	a_o	b_o	a_c	b_c
1	First Int'l Bank	0.00052	0.00146	−0.01251	0.00187	0.05473
2	Clal Industries	0.00069	0.00386	−0.01034	0.00323	0.06503
3	Land Development	0.00066	−0.00013	0.03531	0.00084	−0.01126
4	Teva	0.00050	0.00035	0.02938	0.00040	0.04855
5	Dead Sea	0.00049	0.00047	0.03365	−0.00019	−0.01270
6	A.I. Paper Mills	0.00062	0.00327	0.02281	0.00329	0.06104
7	Delek	0.00060	0.00281	−0.08565	0.00225	−0.05761
8	Discount Invsts.	0.00057	0.00269	−0.10130	0.00236	0.00011
9	Property and Bdng.	0.00055	0.00108	0.04483	0.00180	0.04156
10	Clal Israel	0.00068	0.00276	−0.05408	0.00227	0.00368
11	Elite	0.00078	0.00353	0.17720	0.00416	0.12507
12	Clal Real Estate Inv.	0.00072	0.00133	0.10943	0.00127	0.15075
13	Petrochemical	0.00111	0.00079	0.08363	0.00114	0.10055
14	Super-Sal	0.00043	0.00267	0.02038	0.00279	0.05852
15	IDB Development	0.00057	0.00376	−0.02355	0.00340	0.07871
	LM	p-value				
	19.24	0.20				
	$b_o, b_c = 0$	p-value				
	75.32	0.00				
	Wald	p-value				
	22.82	0.09				

This table documents the results for the joint tests for the period b (1989–1990) data set. V^c is the closing return variance estimate, a_o, b_o, a_c, b_c are the coefficient estimates for the autocorrelation parameters for opening and closing returns.

continuous rounds, the null cannot be rejected with the LM test, but can be marginally rejected (at the 10% level) by the Wald test. [14] In conclusion, no rejections are obtained for either period at the 5% level, using either joint test.

While these results are consistent with the hypothesis that the trading mechanism employed at the open does not induce transitory volatility in either regime, a direct test of the null hypothesis that the variance ratios are equal across periods is conducted to allow for direct inferences to be drawn. [15]

[14] Wald and LM tests are also conducted on raw returns (not-demeaned). Although autocorrelation in the zero-mean assumption may be inappropriate for the TASE data, Merton (1980) shows that return variances based on high frequency data will have smaller estimation errors if they are centered around zero, rather than on the sample mean return. These results are qualitatively consistent with the results in Table 3. Neither the LM or the Wald test statistics imply rejections of the null for the earlier period, and a marginal rejection (p-value of 0.088) is obtained for the later period with the Wald test.

[15] I thank an anonymous referee for suggesting that a direct test be conducted, thereby greatly enhancing this analysis.

The specification of this test is a further extension of Ronen (1997), in that it allows for comparison across regimes. To test the joint null hypothesis that each variance ratio in Period A equals each variance ratio in Period B (H_0: $\underline{\Upsilon_{\mathrm{A}}} = \underline{\Upsilon_{\mathrm{B}}}$), the Wald test statistic is used:

$$T \times \underbrace{(\underline{\hat{\Upsilon}_A} - \underline{\hat{\Upsilon}_B})'}_{1\times N} \underbrace{\hat{\Sigma}^{-1}_{\Delta\Upsilon}}_{N\times N} \underbrace{(\underline{\hat{\Upsilon}_A} - \underline{\hat{\Upsilon}_B})}_{N\times 1} \overset{asy}{\sim} \chi^2(N),$$

where $\Sigma_{\Delta\Upsilon}$ is the variance–covariance matrix of the difference in variance ratio estimates across periods, and therefore accounts for the correlation across the variance ratio estimates in each period. [16] The test statistic obtained is 8.64, distributed asymptotically $\chi^2(15)$(p-value of 0.23), implying that the null cannot be rejected. [17]

The combined results of the multivariate tests conducted in this section allow for direct inferences to be drawn regarding the impact of trading structures on transitory volatility. Specifically, since the results indicate that: (1) the null, that opening return variances equal closing return variances in each period cannot be rejected, and that further (2) the null, that the variance ratios are equal across periods cannot be rejected, this implies that the order of the trading mechanisms does not impact the return volatilities on the TASE. Finally, since the overnight information effect is essentially controlled for across periods (through the unique nature of the data), the empirical tests suggest that call auctions do *not* induce excess volatility.

5. Alternative price processes and interpretation

Before conclusive arguments can be made regarding the effects of trading mechanisms, the statistical properties of the multivariate variance ratio test must be explored in detail, since the non-rejections may be attributable to low statistical power. The size and power of the multivariate ratio test

[16] Again, estimation is carried out using the Hansen and Singleton (1982) two-step procedure, and the Newey and West (1987) corrections. Variance ratios are estimated as before, with the appropriate autocorrelation adjustments and standard error corrections.

[17] A similar test is conducted to test the null that the ratio of variance ratios equals one. Again, the test results indicate that the null cannot be rejected. Furthermore, tests are conducted on subsamples of Period B, to match the time series length of the two periods. The results are qualitatively similar-the null cannot be rejected at any reasonable level of significance.

are therefore examined, by means of a Monte Carlo simulation experiment. [18]

As is usually the case in power studies, there is no single alternative against which the test can be benchmarked. The model for the evolution of stock prices, which is used for the different simulation experiments, combines a number of prevalent assumptions about the possible origins of observable properties of price changes. The assumptions regarding the cross correlation properties of returns and trading errors are quite general. To begin, the strong positive autocorrelations exhibited in the data are interpreted as representative of a lagged (partial) adjustment effect: The autocorrelations documented in Table 2 indicate that the correlation between trading day and subsequent overnight returns ($\rho_{(R_t^{\mathrm{oc}},R_{t+1}^{\mathrm{co}})}$) is on average 0.15, and is positive in all cases. The other correlation term, $\rho_{(R_t^{\mathrm{co}},R_t^{\mathrm{oc}})}$, is negative in 11 of the 15 cases, with an average across stocks of −0.047. These values were interpreted in Section 4 as mainly due to an under-adjustment in closing prices, emanating from market frictions. The partial adjustment model is of particular interest if we wish to maintain the random walk assumption for true price movements, but at the same time, support positive return autocorrelations.

Assume that the observed log cum-dividend prices are the sum of two components,

$$p_t^{\mathrm{o}} = p_t^{\mathrm{o}*} + E_t^{\mathrm{o}}, \tag{2}$$
$$p_t^{\mathrm{c}} = p_t^{\mathrm{c}*} + E_t^{\mathrm{c}}, \tag{3}$$

where p_t^{o} and p_t^{c} are the log of the observed opening and closing prices of day t, $p_t^{\mathrm{o}*}$ and $p_t^{\mathrm{c}*}$ are the log of the true prices (defined as the expectation of the final value of the security conditional on all public information at time t). E_t^{o} and E_t^{c} are the pricing errors. Assume also that the true prices evolve as

$$p_t^{\mathrm{o}*} = p_{t-1}^{\mathrm{c}*} + w_t^{\mathrm{co}}, \tag{4}$$
$$p_t^{\mathrm{c}*} = p_t^{\mathrm{o}*} + w_t^{\mathrm{oc}}, \tag{5}$$

where w_t^{co}, and w_t^{oc} are the innovations in the true price overnight and during the trading day, respectively.

The pricing errors, E_t^{o} and E_t^{c} are in general assumed to be driven by either (*i*) a fraction of the last period's news, and/or (*ii*) an unrelated shock: [19]

[18] The Monte Carlo simulation approach is commonly used when the closed form solution does not necessarily exist under the particular alternatives considered. See for example, Poterba and Summers (1988), Lo and MacKinlay (1989), and Faust (1992) which examine the power of the multiperiod variance ratio test against alternatives to the random walk.

[19] The pricing error decomposition is based on the analysis in Hasbrouck (1993), but opening and closing price processes are allowed to differ.

$$E_t^{\mathrm{o}} = \lambda^{\mathrm{o}} w_t^{\mathrm{co}} + z_t^{\mathrm{o}}, \tag{6}$$

$$E_t^{\mathrm{c}} = \lambda^{\mathrm{c}} w_t^{\mathrm{oc}} + z_t^{\mathrm{c}}, \tag{7}$$

where λw_t is the information-related term, and z_t is the information-unrelated term. Both terms may impound trading structure effects. The first term arises from asymmetric information, and from partial (lagged) adjustment, or overreaction of prices to information. [20] The second term, z_t, is assumed to be determined by the trading mechanism, and other microstructure effects, such as price discreteness, inventory control, 'noise trading' and transient liquidity effects. Under these assumptions, the variance ratio can be shown to equal

$$\Upsilon = \frac{(1 + 2\lambda^{\mathrm{o}} + 2(\lambda^{\mathrm{o}})^2)\sigma_{\mathrm{n}}^2 + \sigma_{\mathrm{d}}^2 + 2\sigma_{z\mathrm{o}}^2}{(1 + 2\lambda^{\mathrm{c}} + 2(\lambda^{\mathrm{c}})^2)\sigma_{\mathrm{d}}^2 + \sigma_{\mathrm{n}}^2 + 2\sigma_{z\mathrm{c}}^2},$$

where $\sigma_{\mathrm{d}}^2 = \mathrm{Var}(\eta^{\mathrm{oc}})$, and $\sigma_{\mathrm{n}}^2 = \mathrm{Var}(\eta^{\mathrm{co}})$.

The empirical performance of the variance ratio test is now examined. [21] The specific alternative that $\Upsilon = 1.2$ is considered in each case. This alternative is of special interest in the light of the empirical evidence that exists for the 24-hour variance ratios calculated for samples of stocks trading on the New York Stock Exchange. See for example, Amihud and Mendelson (1987), who find that returns based on opening prices are on average 20% more volatile than those based on closing prices. Table 6 provides simulation results for the partial adjustment case described above. Eight variants of the null ($\Upsilon = 1.0$) are considered, along with the corresponding alternative ($\Upsilon = 1.2$). One thousand replications are conducted for each specification, for 15 stocks and 260 days (corresponding to 1 year of trading days). The true price trading day variances, σ_{d}^2 and σ_{n}^2 are standardized to equal 1. The closing error variance, $\sigma_{z\mathrm{c}}^2$, is set to equal zero, allowing for the variance of the trading error to be smaller than the variance of the true price. The variance of the opening error, $\sigma_{z\mathrm{o}}^2$, is the free parameter. Contemporaneous correlations are assumed to affect both true prices and errors (to capture differences in trading structures, measurement error introduced by bid ask bounce, and non-synchronous trade). These coefficients,

[20] In this model, λ is assumed to be negative, reflecting partial adjustment to information arising from trade barriers and other transactions costs particular to the TASE. The daily and intradaily autocorrelation patterns suggest that the close is always characterized by partial adjustment to information (underadjust), and therefore imply negative values for λ^{c}. It is important to note that λ here is assumed to be independent of trading structure effects, although the information-related component should probably rise as trading mechanisms become more costly (more inferior).

[21] In particular, the statistical properties of the Wald test are examined here. Although the test statistics satisfy $\xi_{\mathrm{Wald}} \geqslant \xi_{\mathrm{LM}}$ (see Savin, 1976; Berndt and Savin, 1977; Breusch, 1979), Engle (1984) shows that when sizes are corrected to be equal, the inequality disappears.

Table 6
Power of the variance ratio test (information related pricing errors)

	λ_o	λ_c	ρ_w	ρ_e	σ^2_{zo}	Υ	95th	α_5	$(1-\beta)_5$
1	−0.5	−0.5	0.00	0.00	0.000	1.0	16.42	0.000	–
	−0.5	−0.5	0.00	0.00	0.050	1.2	35.80	–	0.972
2	−0.5	−0.5	0.00	0.15	0.000	1.0	16.48	0.000	–
	−0.5	−0.5	0.00	0.15	0.050	1.2	36.87	–	0.958
3	−0.5	−0.5	0.15	0.00	0.000	1.0	16.57	0.000	–
	−0.5	−0.5	0.15	0.00	0.050	1.2	30.42	–	0.805
4	−0.5	−0.5	0.15	0.15	0.000	1.0	17.12	0.000	–
	−0.5	−0.5	0.15	0.15	0.050	1.2	29.28	–	0.733
5	−0.5	−0.8	0.00	0.00	0.090	1.0	33.97	0.003	–
	−0.5	−0.8	0.00	0.00	0.158	1.2	64.42	–	0.914
6	−0.5	−0.8	0.00	0.15	0.090	1.0	32.32	0.002	–
	−0.5	−0.8	0.00	0.15	0.158	1.2	66.23	–	0.939
7	−0.5	−0.8	0.15	0.00	0.090	1.0	32.67	0.004	–
	−0.5	−0.8	0.15	0.00	0.158	1.2	56.72	–	0.769
8	−0.5	−0.8	0.15	0.15	0.090	1.0	33.50	0.003	–
	−0.5	−0.8	0.15	0.15	0.158	1.2	53.45	–	0.663

This table provides Monte Carlo simulation results for the power of the 24-hour variance ratio test against the alternative that $\Upsilon = 1.2$. I assume that the errors at the open and close are correlated with efficient price increments. Each set of rows represents an independent simulation experiment based on 1000 replications for 15 stocks and 260 days. ρ_w is the coefficient of contemporaneous correlation in the true price increments across the stocks in the sample, ρ_e is the coefficient of contemporaneous correlation in the pricing errors, σ^2_{zo} is the opening pricing error variance, Υ is the variance ratio. It is set to equal either 1.2, or 1.0 for each set of parameters. The null ($\Upsilon = 1.0$) is considered in order to determine the size of the test. 95th is the 95th percentile of the empirical distribution of the Wald test statistic (asymptotically distributed $\chi^2(15)$ under the null). α_5 is the size of the test at the 5% level (probability of a type I error). $(1-\beta)_5$ is the power of the test at the 5% level (probability of a type II error). For these simulations, the true price variances during the trading day and overnight periods (σ_d and σ_n), are both standardized to one. λ_o and λ_c are the partial adjustment parameters at the open and at the close, respectively.

ρ_w and ρ_e are each allowed to equal 0.00 or 0.15. [22] The partial adjustment parameters in the opening and closing price errors, λ_c and λ_o, are assumed to be negative ($\lambda_o = -0.5$ and $\lambda_c = [-0.5, -0.8]$), as opposed to positive, as in Glosten (1987), and represent observed prices which cannot adjust (at least at the close) immediately to the information innovation. [23] The size of the test (reported as the percentage of the simulated distribution generated under the null, for

[22] The parameter choice of 0.15 is based upon evidence on average stock return covariances. For example, in Elton and Gruber (1992), an average (monthly) correlation across NYSE stocks of 0.15 is implied.

[23] The information adjustment parameters are chosen such as to support the autocorrelations found in the TASE data, but also such that no negative implied volatilities for the opening price error variances are obtained.

which the corresponding test statistic leads to rejection using the critical regions corresponding to the asymptotic distribution), ranges from 0.000 to 0.004. Size improves as the difference between the opening price variance and the closing price variance increases, and as the degree of partial adjustment decreases. The power, defined as the probability of rejecting the null when the alternative is true, ranges from 0.663 to 0.972, and is above 0.914 in 50% of the cases. Power is lowest when both the degrees of contemporaneous correlation and of partial adjustment are highest. These results suggest that the multivariate ratio test used here exhibits both reasonable size and power in most cases.

Thus, while interpretation of the test results must be carried out with caution, it seems likely that the results obtained in this paper are *not* mere artifacts of poor statistical properties of the joint tests, and that the null, that opening variances equal closing variances, cannot be rejected. However, the power study conducted here depends on the assumption that true prices follow a random walk and that the pricing errors are correlated. An alternative explanation for the strong autocorrelation patterns observed in the data is that true price innovations follow an autoregressive process: $w_t^{\mathrm{oc}} = aw_t^{\mathrm{co}} + \mu^{\mathrm{oc}} + \eta_t^{\mathrm{oc}}$, and $w_{t+1}^{\mathrm{co}} = bw_t^{\mathrm{oc}} + \mu^{\mathrm{co}} + \eta_{t+1}^{\mathrm{co}}$, where μ is the mean of the process, η is the mean zero error, and a and b are the autoregressive components of the trading day and overnight true price increments.

However, the evidence in Section 4 implies that the AR1 process assumption is less reasonable for the TASE than the partial adjustment model. Careful interpretation of the autocorrelations suggests that the strong positive autocorrelations observed between trading day and subsequent overnight returns imply underreactions in closing prices in both periods. [24] The evidence suggests that trading frictions are the most probable culprits for the serial correlations. Institutional barriers, such as barriers placed upon mutual fund traders restrict trade in the afternoon, regardless of the trading mechanism employed. This pattern is more reflective of partial adjustment in pricing errors at the close (and a random walk in true prices) than of autoregression in true prices.

6. Concluding remarks

This paper studies the efficiency of trading mechanisms using data from the TASE. This exchange exhibits unique features not common to any other exchange, representing a *natural experiment* which allows separation of the trading mechanism effect from the overnight information effect. In particular, the TASE features both a sequential continuous mechanism and an auction

[24] Mech (1993) finds that portfolio autocorrelations for smaller stocks in the US are most probably caused by partial adjustment. Similar arguments may be used for the data here.

mechanism. The data set spans a time period over which the order of the trading mechanisms was reversed. Employing the assumption that overnight information impacts opening prices equally in both periods allows the measurement of the trading mechanism effect separately from the non-trading period effect. Multivariate variance ratio tests are conducted to test the hypothesis that opening return variances equal closing return variances in each period. The results indicate that the null, that each of the variance ratios equals one, cannot be rejected in either period. Since these two periods are characterized by a reversal in trading order mechanisms, this implies that the order of the trading mechanisms does not affect return volatility. A direct multivariate test, of the null that each of the variance ratios (for each stock) in the early period equals the variance ratio (for that stock) in the latter period is conducted and confirms these results. Further, there is no support for the notion that call auctions produce more volatility than continuous trade (consistent with the results of Amihud and Mendelson (1987), Madhavan (1992) and Ronen (1997).)

Heretofore, the evidence regarding the effects of trading mechanisms on opening return volatility has been mixed. Several studies concluded that opening returns are more volatile than closing returns (see for example, Amihud and Mendelson, 1987; French, 1991; Stoll and Whaley, 1990), and attribute this difference to the trading mechanism employed at the open (a call auction). Additionally, studies of markets that do not open with a call auction suggest that the overnight non-trading hours preceding the open may cause excess volatility at the open, regardless of the opening mechanism (see for example, Amihud and Mendelson, 1989; Amihud et al., 1990; Choe and Shin, 1993). Finally, Ronen (1997) shows that statistical testing problems inherent in estimating intradaily variance ratios renders some of the previous results in the literature difficult to interpret. This paper not only incorporates the appropriate standard error corrections in the variance ratio tests, but it also addresses the economic issue of separating the potentially confounding effects of the overnight non-trading period from the trading mechanism used at the open (on return volatility).

In general, these results are specific to the TASE. The institutional barriers of this market may confound the interpretation of the results, and generalizations to other markets may be inappropriate. Nonetheless, the *natural control* supplied by this market affords a few generalizations regarding the *relative* effects of call and continuous markets on return volatility.

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Appendix A. Additional information on TASE trading rules

A.1. Meretz

The aggregate order information (specifically, excess demand or excess supply for each of the stocks) is made public 15 min before the call procedure begins. The actual call procedure is managed by a 'caller', who calls each of the stocks sequentially. The order in which stocks trade is predetermined and is identical to the order employed in the continuous rounds. In the case of an excess, the caller announces it orally, and the members may call out offsetting orders (these include both orders that they receive before the leader is compiled and orders they receive after the excesses become public). [25] These orders must be 'against the trend'. If the offsetting orders exactly match the excess supply or demand for a stock, that day's Meretz transaction price will equal the base price. Otherwise, the caller must move the price until the excess is cleared. All new orders must be submitted 'against the trend'. The Meretz price determined for each security is the single transaction price at which all trades in that stock occur for the round (day).

A.2. Mishtanim rounds of trade

The public obtains trade information during the trading rounds via the electronic system to which the brokerage firms and the majority of bank branches throughout the country are connected. Orders submitted during one trading round may be executed during that same round, or during subsequent ones. Public orders are subject to a minimum volume requirement in the Mishtanim rounds. [26] A base price is specified for each security that trades in both the

[25] Today, the excess is announced enough time before trading begins such that customers may submit offsetting orders before and even during trade. These may be in the form of either market or limit orders.

[26] This was about 3000 dollars when the rounds were implemented in 1987.

Mishtanim and Meretz rounds of trade, and is calculated as the last trading day's 'determining price' adjusted for dividends and splits.[27, 28]

A.3. Price limits on the TASE

The TASE implements price limits to dampen volatility. The appendix outlines the rules for the price limits applicable for each subperiod. These price limits are not observed frequently in the stocks that comprise the sample. [29] Additionally, 'partial execution' may take place in the *Meretz* round, but is rare for securities as frequently traded as those included here. [30] Therefore, neither price limits, nor partial execution should significantly affect the empirical results. Nonetheless, the rules for both are outlined here for completion.

For the later subperiod, 1989–1990, the price limits in the Meretz rounds are as follows: If at a 10% price movement (from the base price), the excess demand (supply) is not cleared, then 'buyers only' ('sellers only') is declared, and the price is artificially moved (there is no trade in that security in the Meretz round on that day) up 7% (−7%). [31] If on the next trading day, excess demand (supply) still remains and is not cleared even at a movement of +15% (−15%) from the base price, then 'buyers only' ('sellers only') is again declared, and the price will again be artificially moved up 7% (−5%) and there will be no trade. On the third consecutive day, the price movement is unlimited. In the instance of three consecutive days of mixed 'buyers only' or 'sellers only' (the excess directions may switch), then on the fourth day the price movement is unlimited in either direction.

The maximum daily price movement permitted in the Mishtanim is 12% from the base price. In the case of 'buyers only' ('sellers only'), the price will be automatically adjusted by 12%. An unlimited price movement in a security

[27] The 'determining price' is measured as the (volume) weighted average of the last three prices in the Mishtanim rounds whose dollar volume is greater than a certain minimum (usually 10,000 dollars). The base price is automatically translated such that it is set to 100, and all incoming orders are given in terms of 100, at increments of 0.25. The limit price of all limit buy (sell) orders is rounded down (up) to the next 0.25%. Thus, the minimal possible deviation in transactions prices is 0.25%.

[28] Occasionally an 'additional round' (Sivuv Nosaf) of the Mishtanim is held after the last Mishtanim regular round. The stocks are traded sequentially, and transactions occur only at the last price determined for the stock. These transactions are included in the 'determining price' calculations, which explains why the determining price is often the same as the last price observed. Time priority is used to determine allotment of shares. Since most transactions will typically be on the same side, this round is usually short and somewhat insignificant.

[29] When I remove days in which limits are hit, I do not find significant changes in the results.

[30] Again, see the appendix for specific rules. The incidence of partial execution in *Mishtanim* stocks is quoted to be extremely rare by the exchange.

[31] Today, an additional requirement is that the excess demand (supply) be greater than 50%.

in either the Meretz or the Mishtanim rounds is allowed only if 'buyers' or 'sellers only' has been determined for two consecutive days in the Mishtanim rounds (the determination of buyers or sellers only in the Meretz round alone is not a sufficient condition for an unlimited price move to be permitted).

For the time period between 23 April 1987 until 31 December 1987, the price limit rules were as follows: The price limits in the Mishtanim were ±7% from the base price, and ±5% in the Meretz. After one day of 'buyers only', the price limits the next day in the Mishtanim were −7% and +15%, and after one day of sellers only the price limits in the Mishtanim rounds were +7% and −15%. After two continuous days of 'buyers only' or sellers only, there are no price limits on the third day.

In addition to these price limits, there are also implicit price movements in the form of partial execution. In cases in which it appears that there will be sufficient excess demand (supply) to trigger buyers only (sellers only), the trade manager may opt to declare partial execution, in which the Meretz price will be set 'early', in terms of where it would be driven by demand or supply conditions. For example, assume there is excess demand for security A, and that in order to clear the excess, the price would have to rise by 11%. This of course would not occur, as 'buyers only' would be declared. However, the trade manager observes that if the price is moved up by only 6%, then 85% of the demand will be cleared. If partial execution is declared at +6%, 100% of the customers who had submitted orders will each have 85% of their order filled. Thus, the trade manager can prevent buyers only (sellers only) and hence a situation in which no trade takes place. Since cases of partial execution dampen volatility, they constitute implicit price limits which are the result of judgment calls on the part of the trade manager, and which are unobservable.

A.4. Time frame for trade

During the 1989–1990 period, the call (Meretz) began at 11:00 a.m. and ended at approximately 11:45 a.m. A 15 min break separated the call auction from the continuous rounds, which lasted from (approximately) 12:00 noon until 3:00 p.m. Orders for the call auction could be submitted until 10:30 a.m., and the leader excess was shown to the public at 10:45 p.m.

During the 1987 period, the continuous (Mishtanim) rounds began at 9:00 a.m. and ended at approximately 11:45 a.m. The call (Meretz) began at 2:15 and ended approximately at 3:00 p.m. Orders could be submitted to the call (including before and during the continuous rounds) until 1:00 p.m., and included limits, all market orders that had not been executed at the best, new market orders, or limits that had not been executed in the Mishtanim. The base price was determined by the determining price of the continuous rounds preceding the call. The leader excess was shown to the public at 1:30 p.m.

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