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Periodic Information Asymmetry and Intraday Market Behaviour: An Empirical Analysis

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Abstract. The model of Foster-Viswanathan (1990, FV) predicts that information heterogeneity among market participants generates patterns in volume, trading costs and volatility. In the Italian Treasury bond market, periodic information asymmetry is related to the arrival of block orders from international investors, which cluster soon after the opening of the market and, respectively, of the US market. Our evidence is that volume is lower and trading costs are higher after the two openings, consistent with FV. We find only weak evidence that volatility behaves as implied by the model.

Keywords: Information asymmetry, Market microstructure, Intraday regularities, US macroeconomic news

JEL Classification: D82; G14

The game-theoretic models of dealership markets based on the asymmetric distribution of information among market players yield predictions for the behaviour of volume, trading costs and price volatility of financial securities during the trading day and the trading week. While the main results of the Admati and Pfleiderer (1988) model are obtained by allowing uninformed traders to have some discretion on the timing of their trades, the Foster and Viswanathan (1990, henceforth FV) model is based upon the additional assumption that information asymmetry follows a periodic pattern. The variety of theoretical approaches is not matched by the empirical literature in this area, which has focused mainly on one strand of investigation, i.e. testing the models' implications in the case of equity markets, for two reasons: the availability of data, and the implicit argument that the models' fundamental assumption, i.e. information heterogeneity on the asset's value, applies more to equity stocks than to e.g. Treasury bonds or foreign exchange currencies.

This paper examines the intraday behaviour of the cash market for Italian Treasury bonds, the *Mercato dei Titoli di Stato* (MTS), in the period from January

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1992 through June 1993. MTS is a screen-based dealership market which, thanks to its broad domestic and international participation, ensures high liquidity, speed of execution and fast information aggregation. We focus on the most common type of Treasury issue, the straight bonds known as *Buoni del Tesoro Poliennali* (BTP), with 10 years to maturity. The aim of the analysis is to test for the presence of regularities as implied by the model of periodic asymmetric information of Foster and Viswanathan (1990).

We believe that MTS lends itself to a test of the FV hypothesis, thus allowing an examination of the model's performance in a different setting from those considered in the literature. In its broadest interpretation, the FV model predicts that discretionary liquidity traders should refrain from trading when they perceive that the degree of information heterogeneity in the market is highest, and wait until this heterogeneity is eroded by the gradual release of information through trading and public announcements. In the case of BTPs, for which no inside information is available, the main form of information heterogeneity derives from the fact that some market members may have a superior knowledge of the order flow, particularly when they act as brokers for large institutional investors. We argue that the highest degree of information heterogeneity on MTS occurs during two periods of the day, i.e. soon after the market opens and, respectively, after the open of the US markets at 14:30 Italian time, and we check for the presence of patterns around those times of the day.

We also examine the effect of public information dissemination on MTS intraday activity. In the case of a bond market, the main sources of such information are the macroeconomic indicators for the country, which may affect expectations about future interest rates. However, in our case three considerations induced us to leave the analysis of the Italian news out of the picture: first, the main Italian economic indicators were released before or after the working hours of domestic financial markets; second, during our sample period these releases did not follow a regular calendar;[1] third, our interviews with market participants indicated that in 1992–1993 the market reaction to domestic indicators was weak, and that a genuine interest in forecasting these indicators and assessing their effects started to develop only in the following years, due mainly to the concern about Italy's convergence process towards the Maastricht Treaty criteria for monetary union. On the other hand, we gathered evidence that the market used to pay attention to the scheduled releases of other major countries, in the first place the US, which were seen as potential sources of 'world-wide shocks'. Based also on the empirical finding that the

[1] In particular, monthly CPI estimates based on data from the main cities were released before 9:00 between the 21st and the 25th of each month; the types and amounts of Treasury securities on offer at the fortnightly auctions were released after 17:00 about five days before each auction; the results of the Treasury auctions were released after 17:00 on auction day. Apart from these regularities, none of the above mentioned releases followed a regular calendar indicating the exact day and time of publication. For all other monthly economic indicators, such as the monetary aggregates and the balance of payments, the time window within each month was more vague and the release time during the day was random.

release of US macroeconomic announcements significantly increases volatility in financial markets, we then ask the question: 'To what extent do US news influence trading patterns on MTS?'. The question is relevant because we are interested in what happens on MTS around the opening of the US markets at 14:30 Italian time, when the major US macro announcements are usually made. Therefore, we would like to control our intraday tests for the effect of the US news.

The paper is organized as follows: Section 1 reviews theoretical predictions and evidence on the intraday behaviour of financial markets, and shows the implications of the FV model within an intraday setting; Section 2 is devoted to the organization on MTS; the data set is described in Section 3; Section 4 contains the results on the intraday regularities on MTS and discusses them in the light of the FV model's predictions; Section 5 summarizes.

1. Market Microstructure and Intraday Regularities

1.1. Information Asymmetry in Dealership Markets

The effect of information asymmetry on the intraday behaviour of markets has been examined by Admati and Pfleiderer (1988). Assuming that some liquidity traders have discretion on the timing of their trades and viewing the trading day as the sequence of several small time intervals, the model shows that liquidity traders prefer to trade at the time of the day when their transactions have little impact on prices. In equilibrium, this generates an incentive for liquidity trading to be concentrated. In those periods, informed traders also trade more actively, due to the desire to disguise their quality. This in turn implies that prices are more informative in periods of concentrated trading, and that the variance of price changes over low trading periods is lower than that during periods of concentrated trading.

The model of Foster and Viswanathan (1990) introduces a time framework that captures some features of real world stock markets. In particular, it is argued that the information advantage of the informed trader varies periodically over the week, being greatest on Mondays, which follow the longest period of market closure of the week. This pattern recognizes the fact that trading, along with public announcements, is in itself an important source of information for liquidity traders. To the extent that they may choose the timing of their trades, liquidity traders prefer to trade when the market maker is less sensitive to the order flow. Three predictions are derived from the model: in equilibrium (i) the market maker's sensitivity to changes in the order flow, λ, declines over the week, (ii) the variance of price changes also decreases over the week, and (iii) volume is lowest when the information asymmetry is largest, i.e. on Mondays.

The intraday behaviour of financial markets has also been analysed outside the conceptual framework of information asymmetry. Brock and Kleidon (1992), building on Merton's (1971) model of consumption and portfolio selection in continuous time, examine the implications of periodic closure on the dynamics of volume and the bid-ask spread in a dealership market. At the open of the market,

Table I. Predictions of intraday patterns

We summarise the regularities that hold in equilibrium according to each of the following models. For ease of reference, in the first row each prediction is labelled with the initials of the authors and a number.

	AP1	FV1	BK1
Periods with	High volume	High volume	High volume
are associated with	Low trading cost	Low trading cost	Large spread
and with *(when)*	High volatility	Low volatility	*Near market open and close*
	AP2	FV2	BK2
Periods with	Low volume	Low volume	Low volume
are associated with	High trading cost	High trading cost	Small spread
and with *(when)*	Low volatility	High volatility	*In middle of trading day*

the accumulation of orders after the overnight break is such that the demand for trading will be higher and less elastic than during the rest of the day. A similar phenomenon will occur before the market closes, when many traders will prefer to close their position without carrying overnight risk. The market maker will thus be able to charge a larger spread at those times of the day. The model has two implications: intraday volume and spread are both U-shaped.

Table I summarizes the predictions of the three models of Admati and Pfleiderer, FV, and Brock and Kleidon. For ease of reference and later use, we label each prediction with the initials of the authors and a number. Only the implications of Brock–Kleidon are precise as to the timing of events within the daily trading cycle. The Admati–Pfleiderer model predicts that in equilibrium a pattern such as AP1 should emerge *at some time of the day*, implying by difference that pattern AP2 should prevail during the rest of the day. The FV model was originally developed within a weekly time framework. However, relying on the model's application to the intraday setting made by the same authors (Foster and Viswanathan, 1993) and on the reasoning explained below, in Table I we compare the predictions of FV with those of the two other models at the *intraday* level. In particular, the FV model predicts that pattern FV1 should emerge at those times of the day when the degree of information asymmetry is lowest, whereas pattern FV2 should prevail in the opposite case, when liquidity traders perceive information asymmetry to be highest.

1.2. Empirical Regularities

A number of empirical studies, devoted mainly to the analysis of the US stock market, have documented daily seasonalities in volume, trading costs and return volatility, thus providing useful indications on the applicability of the asymmetric information theories. Comprehensive surveys of the empirical evidence can be found in Yadav and Pope (1992) and Goodhart and O'Hara (1995). The view that valuable private information is 'released' through trading and public announcements is supported by the finding that overnight and week-end return volatility is lower than during stock exchange trading hours (e.g. French and Roll, 1986), and that stock return variance declines steadily during the trading day (Gerety and Muhlerin, 1994). The studies on intraday patterns (e.g. Wood et al., 1985) find evidence of a U-shape in return volatility of NYSE stocks during the trading day, and the association of high volume with large price changes soon after the open of the market (Jain and Joh, 1988; Foster and Viswanathan, 1993), in accordance with pattern AP1 from Table I. Asian stock markets display a double U-shape in intraday volatility, related to the lunch break (Chang et al., 1993; Cheung et al., 1994). The finding of high trading costs after the open (Foster and Viswanathan, 1993) runs counter to a specific implication of the Admati and Pfleiderer model and to one of the tenets of the FV model (pattern FV1). On the other hand, this evidence is consistent with the explanation put forward by Brock and Kleidon (pattern BK1).

1.3. The Effects of Macroeconomic Announcements

A related strand of empirical investigation has shown the effects of public information arrival on the intraday behaviour of financial futures markets. The evidence is that the US-European foreign exchange futures are more volatile during US trading hours than during European trading hours (Harvey and Huang, 1991), and this is explained by the importance of public-information trading based on the release of US macroeconomic announcements (Becker et al., 1993). In the US futures markets, the volatility surrounding the announcements accounts for a large percentage of total close-to-close volatility (Ederington and Lee, 1993; 1995). In particular, a group of US announcements exerts a strong effect on volatility, and volatility on announcement days is significantly higher than on non-announcement days before the release time. In the absence of leakage, this phenomenon is related to uninformed trading generated by the upcoming news release.

1.4. Periodic Information Asymmetry in the Italian Treasury Bond Market

We note that the main empirical implications of FV depend on the assumption that information asymmetry follows a periodic pattern, whereby it is largest in one period and declines in later periods, but they *do not* depend on the number of periods in the model. In other words, the same conclusions would hold in the case of a 'dreamlike week' made of two working days only and a long-week end. More generally, the properties of the time framework that are required for the model to yield its empirical implications are that (i) there is a trading cycle, (ii) private information arrives at the beginning of each period in the cycle, (iii) public information arrives at the end of each period in the cycle and, finally, (iv) before a particular period in the cycle (Monday for FV) the informed trader receives a large private information shock, such that in the following period his information advantage is the largest of the cycle (for FV, this advantage derives from the fact that private information accrues also on Saturday and Sunday, while public information does not). Therefore, under the four above mentioned assumptions, the FV model can be applied to different time settings. This observation, together with the knowledge of some important features of the Italian Treasury bond market, suggested the usefulness of a new test of the FV model of periodic information asymmetry.

During the sample period, the average order size on MTS was slightly above the minimum value set by the managing board of the market, i.e. 5 billion ITL. This phenomenon is related to the rule that each market maker has to make a firm commitment to buy or sell a fixed amount of bonds at the bid or ask of his own choice, as published on the electronic page. Therefore, a plausible strategy for the category of market makers as a whole, in the face of adverse selection, is to make low quantity commitments, i.e. close or equal to the minimum. The 5 billion size regularity is well accepted by all market participants, who are accustomed to working large orders into a sequence of several small transactions.

The important point to note is that, as a matter of fact, there are two times of the day when large orders are clustered. These are soon after 9:00, coinciding with the open of MTS, and 14:30 Italian time, corresponding to the open of the US markets (8:30 US E.S.T.). A survey conducted among Italian bond dealers in Italy and London showed that the typical Italian bond 'ticket' from Far Eastern and US investors is generally in the region of 25–50 billion ITL (equivalent to roughly 15–30 million US dollars) and quite often reaches 100 billion ITL, compared with a modal trade size of 5 billion on MTS. The Far Eastern orders, that accumulate overnight (daytime in Asia and Australia), hit the Italian market at its open, while US orders typically arrive soon after 14:30. These block orders are placed with a limited number of dealers and executed gradually on MTS, either directly or indirectly. By indirectly we mean that an order may be filled on the over-the-counter market, sometimes through a broker. In any case, the institution which has accepted a large trade outside MTS will rely on MTS to offset its position. In both cases, the direct trade and the indirect trade, the knowledge of a block order for Italian bonds is a valuable piece of private information for any dealer who is also an MTS member, since he can revise his expectation of the bond's value based on this knowledge. We observe that this extension of the concept of private information to include the knowledge of the order flow, in the context of the asymmetric information models of financial markets, has also been invoked in other studies, e.g. Lyons (1995) in the case of the foreign exchange market.

We therefore propose to adapt the FV model to the pattern of periodic information asymmetry suggested by the microstructure of MTS. We partition the trading day into intervals of 30 minutes each. Then, if the FV model holds, we would expect to see relatively low volume, high volatility and high trading costs in the two

30 minute periods which follow the open of MTS and, respectively, 14:30, when the degree of information heterogeneity among market participants is highest. In other words, we expect pattern FV2 to hold.

2. The Market

MTS[2] was established in May 1988. Its aim was to provide liquidity and transparency for government bond transactions, which, due to their increasing volumes, in previous years had been migrating from the official stock exchanges, operated on a retail basis through a daily call auction, to the over-the-counter market. Since its inception, the screen-based market has enjoyed a rapid growth in trading volume and in the number of participants, both domestic and international. MTS is a dealers' market, supervised by the Treasury, through the Banca d'Italia. The market is managed by a board of members, incorporated under common law.

The securities listed on MTS include bills (*Buoni Ordinari del Tesoro* – BOT) over a range of maturities up to 1 year, floating-rate notes (*Certificati di Credito del Tesoro* – CCT) with up to 7 years to maturity, and straight bonds (*Buoni del Tesoro Poliennali* – BTP) with up to 30 years to maturity.

The market makers, known as *operatori principali* (primary dealers), are committed to quoting firm bid and ask prices for at least 10 listed securities of their choice, each for a minimum nominal value of 5 billion ITL, which is also the minimum trade size in the market.[3] In June 1993, the *operatori principali* included 29 major domestic and foreign financial institutions. Ordinary members, known as *operatori*, included 289 financial institutions, 29 of which were from abroad. All MTS members may trade on their own account or on behalf of clients.

Each member may work from any part of the country. Buy and sell orders transmitted through the screen are firm and the execution of orders is automatic. Ordinary members may trade with primary dealers only, at any of the outstanding quotes for a given security. Primary dealers may trade among themselves at the quoted prices, i.e., if a primary dealer initiates a trade, he has to 'hit' an available quote, just as any ordinary member would. The size and price of each trade are reported on the screen in real time. The name of the buyer/seller is known only to the primary dealer whose quote has been hit.

As in the official stock exchanges, where all outstanding Treasury issues continue to be traded on a retail basis, the securities are listed at their clean price, in percentage terms, with a minimum price increment of 0.01 per cent, and the settlement date is three working days after the trade day.

[2] In the professionals' jargon, MTS is sometimes referred to as 'the telematico', after the Italian *mercato telematico*, i.e. screen-based market.

[3] Primary dealers have stricter capital requirements than ordinary members, as well as some financing facilities with the Banca d'Italia. In 1994 a new category of 'top' primary dealers (*specialisti*) was introduced, as part of a general reform of the Italian bond market (see footnote 4).

The growth of foreign-driven transactions is an important phenomenon of our sample period. The Balance of payments data provide figures on BTP trades, including MTS and the over the counter market, where one counterpart was a foreign investor and the other domestic. The data show that, while from 1991 through 1993 BTP transactions as a whole grew steadily, in 1993 there was a surge in foreign-driven trading, to an amount in excess of the corresponding MTS total volume.[4]

Daily trading times on MTS changed during the sample period. We recall that Italian time is usually one hour ahead of British time and six hours ahead of US E.S.T. During 1992 the market was open from 9:30 to 16:30, with a break from 13:30 to 14:30. Since January 1993 market trading hours have been extended by one hour, with the new opening and closing times respectively at 9.00 and 17.00, and the mid-day break has been abolished.

3. The Data

3.1. 10-YEAR BTPs

The regular issue of 10-year BTPs, started in 1991, has significantly contributed to the development of MTS. These bonds have attracted the interest of international investors, and have become the benchmark for the longer end of the Italian bond market as a whole. Since they were first listed on MTS, trading volume in 10-year BTPs has accounted for over 50 per cent of total market turnover.

BTPs are straight bonds paying half-yearly coupons, and principal at a fixed redemption date. All securities are floated in tranches, at the beginning and in the middle of each month, through uniform price auctions.[5] The data sample employed in the empirical analysis includes all transactions on 10-year BTPs in the period from January 1992 through June 1993. During this period, eight such bonds were listed, with a residual life of between eight and a half and ten years.

Summary statistics of daily data, covering all 10-year BTPs, are given in Table II. In 1992 total daily volume reached a maximum of 4.8 trillion ITL in May, and remained high in the first half of 1993. Average close-to-close volatility was fairly low during the first five months of 1992, between 2.22 and 2.82 percentage

[4] The increasing role of London-based investors on the domestic market, observed from the second half of 1992, led the Italian authorities to respond in two ways, first by introducing a BTP futures contract on the MTS screen network in September 1992, and later with the reform of MTS itself in January 1994. The reform, aimed at reducing transaction costs and widening international participation, included three main measures: (i) the abolition of the 0.009 per cent transactions duty; (ii) the introduction of the category of top primary dealers, the 'specialists', with more stringent requirements, in terms of capital and market share, as well as benefits, in the form of selective access to financing facilities with the Banca d'Italia and to some of the Treasury's auctions; (iii) the possibility for ordinary market members to locate their trading screens outside Italy. Our sample period, starting in January 1992 and ending in June 1993, falls entirely in the pre-reform period.

[5] During the sample period, a 12.5 per cent withholding tax was levied on coupon income and, at redemption, on the difference between par value and the issue price, if positive.

Table II. Summary statistics of daily data

Period	Avg. daily volume – All BTPs (bln ITL)	Avg. close-to-close volatility (per cent, annualised)	Avg. closeing spread of on-the-run bond (as a percentage)
1992			
Jan.	2616	2.82	0.013
Feb.	3267	2.28	0.010
Mar.	4201	2.50	0.012
Apr.	4548	2.77	0.012
May	4795	2.22	0.011
June	4444	7.23	0.026
July	3432	9.23	0.025
Aug.	2540	8.22	0.032
Sept.	3443	14.09	0.051
Oct.	3380	14.71	0.039
Nov.	2973	5.43	0.013
Dec.	2088	8.20	0.030
1993			
Jan.	3348	5.59	0.046
Feb.	3120	7.97	0.044
Mar.	2719	6.59	0.030
Apr.	2858	9.35	0.040
May	3731	5.03	0.028
June	3382	6.03	0.020

points. June 1992 marked a rise in volatility to 7.23 per cent. Volatility remained high in the summer and peaked again during the currency crisis of September and October, at 14.71 per cent. Since November 1992 volatility declined, with values in the range of 5.03–9.35 per cent. The average spread of on-the-run bonds, made available only at the close of the market, shows a humped profile over time.

3.2. Structure of Intraday Data

We partition the data into three sub-samples: *period 1*, from January to the end of May, 1992; *period 2*, from June through the end of 1992; *period 3*, the first half of 1993. The starting date for period 2 is suggested by a specific event, the Danish rejection of the plan for European Union in the referendum of 2 June, 1992. This generated fears of a government deficit expansion in Italy and brought about a sudden fall in BTP prices and an increase in their volatility, which remained high throughout the rest of the year.

The data set employed in the analysis that follows includes all trades made on MTS during the sample periods. For each trade, the following information is recorded: the day and time, to the nearest second; the security code; price; trade size; an indicator variable saying whether the trade was initiated by a buyer (seller), i.e. whether it took place at the outstanding ask (bid) quote.

For each day we extract the data for the 10-year BTP which turned out to be the most liquid on the previous day. We divide each day into half-hour intervals, starting at 9:30 in periods 1 and 2, and at 9:00 in period 3. For a reason which will be soon made clear, we discard from our data set the trading days belonging to three sub-periods when, due to differences in the switch to and from Daylight Saving Time, the time lag between US E.S.T. and Italian time was different from 6 hours.[6]

3.3. The Monthly Release of US Macroeconomic Announcements

In order to analyse the effects on MTS of the release of the US macro announcements, we selected the monthly data releases that, according to Ederington and Lee (1993, 1995), affect the intraday behaviour of the futures contracts examined in their study *and* are made public at 8:30 US E.S.T.[7] Thanks to the filter criterion just described, this time always coincides with 14:30 Italian time in our data sample.

We keep a separate account of whether each day was an announcement day or a non-announcement day. This will enable us to perform tests of the differential impact of US news on the Italian market. Following Ederington and Lee and others, we do not use the content of the release, but simply record whether a release occurred or not. The announcements concern: unemployment, the PPI, the CPI, durable goods orders, the merchandise trade deficit, GNP and retail sales.

4. Empirical Results

This section describes the empirical results concerning the intraday behaviour of, respectively, MTS volume, trading costs and volatility. We recall that we consider separately the 'morning cycles' and the 'afternoon cycles'. The morning cycle is the sequence of half-hour intervals that runs from the open of the market until 14:30. The afternoon cycle is the sequence of half-hour intervals that runs from

[6] These periods are: (i) from 29 March through 5 April, 1992 when, due to the one-week lag of the US with respect to Europe in moving to Daylight Saving Time, the time lag between US and Italy was 7 hours; (ii) from 27 September through 25 October, 1992 when, due to the one-month lag of the US with respect to continental Europe in the move back to Standard Time, the time lag was 5 hours; (iii) from 28 March through 4 April, 1993 when, for the same reason as (i) above, the time lag was 7 hours.

[7] We ignore the following indicators, scheduled for release later in the day: industrial production and capacity utilization (released at 9:15 E.S.T.), construction spending and the National Association of Purchasing Managers survey (10:00 E.S.T.), the Federal budget (14:00 E.S.T.).

14:30 to the market close. Following e.g. Foster and Viswanathan (1993) and Ederington and Lee (1993), the presence of empirical patterns is checked by means of dummy variable regressions and tests on the restrictions implied by them.

4.1. Volume

We compute volume in relative terms, taking the ratio of trade volume in each interval to total daily volume for the relevant bond, as a percentage.[8]

Test I is aimed at detecting the presence of intraweek patterns in volume. We use the following OLS regression with dummy variables:

$$v_{d,i} = \alpha_0 + \sum_{k=2}^{I} \alpha_{1,k} u_{1,k} + \sum_{j=2}^{5} \sum_{k=1}^{I} \alpha_{j,k} u_{j,k} + \varepsilon_{d,i} \tag{1}$$

where $v_{d,i}$ is volume in week day $d = 1, \ldots, 5$, interval $i = 1, \ldots, I$. Considering the morning trading cycles, in periods 1 and 2 (period 3) of our sample $i = 1$ corresponds to the half-hour interval 9:30–10:00 (9:00–9:30 in period 3), while $i = I$ corresponds to 13:00–13:30 (14:00–14:30). In the afternoon trading cycles, $i = 1$ corresponds to 14:30–15:00, while $i = I$ corresponds to 16:00–16:30 (16:30–17:00 in period 3). The dummy variables $u_{j,k}$ are equal to 1 only where $j = d$ and $k = i$, and 0 otherwise. The α_0 coefficient measures the average volume in day 1 of the week, i.e. Monday, and in interval 1. All the other α coefficients measure the differential effect on volume related to being in a different day and interval.

We use Equation (1) to run the F test on the absence of intraweek patterns. The null hypothesis is:

$$\begin{aligned} H0: \ & \alpha_{j,1} = 0, & j = 2, \ldots, 5; \\ & \alpha_{1,k} = \alpha_{2,k} = \alpha_{3,k} = \alpha_{4,k} = \alpha_{5,k}, & k = 2, \ldots, I. \end{aligned} \tag{2}$$

The results of the F test are reported in Table III. The table shows the results for the morning in the upper half, and for the afternoon in the lower half. For example, the F statistic for period 1, morning is equal to 1.41, with a probability value of 0.69, thus indicating failure to reject the hypothesis of no intraweek patterns in volume. Examining all the other statistics for Test I, we reach the same conclusion, i.e. there is no evidence of intraweek effects on the behaviour of volume.

Test II checks for the differential effect of announcement days, based on the following regression:

$$v_{d,i} = \beta_1 + \sum_{k=2}^{I} \beta_k w_k + \sum_{k=1}^{I} \delta_k x_k + \zeta_{d,i}. \tag{3}$$

[8] Trade volume in the BTP market may vary widely from day to day. We performed a first run of tests on intraday regularities using absolute trade volume as the variable of interest and, for the above reason, found that the estimates were affected by a significant amount of heteroskedasticity. In order to avoid this problem, we therefore resorted to a relative volume measure.

Table III. Variations in volume – test results

We report the test results on variations in volume for each period and trading cycle. In Test 1, the null hypothesis implies that the restrictions (2) be imposed on Equation (1) in the text. In Test II, the null hypothesis implies that the restrictions (4) be imposed on Equation (3). In Test III, the null hypothesis implies that the restrictions (6) be imposed on Equation (5). The variance-covariance matrix of the underlying regressions is computed using the White heteroskedasticity consistent estimator.

	Period 1		Period 2		Period 3	
	F test	p-value	F test	p-value	F test	p-value
Morning						
Test I:						
H0: No intra-week regularities	1.41	0.69	0.77	0.82	0.98	0.51
Test II:						
H0: No efect of announcements	1.55	0.14	1.65	0.11	0.89	0.55
Test III:						
H0: No intra-cycle regularities	41.0	0.00	37.11	0.00	82.18	0.00
Afternoon						
Test I:						
H0: No intra-week regularities	0.97	0.49	0.53	0.94	1.07	0.38
Test II:						
H0: No efect of announcements	0.86	0.49	0.70	0.59	1.81	0.11
Test III:						
H0: No intra-cycle regularities	11.24	0.00	14.09	0.00	6.94	0.00

Here the dummy variables w_k are equal to 1 only where $k = i$ and day d is a non-announcement day, whereas the x_k are equal to 1 only where $k = i$ and day d is an announcement day. The null hypothesis, corresponding to the absence of any differential effect on volume related to US announcements, is:

$$\begin{aligned} H0:\ & \delta_1 = 0; \\ & \delta_k = \beta_k,\ \ k = 2, \ldots, I. \end{aligned} \tag{4}$$

The F test results are reported in Table III. The table shows that in period 1, morning cycle the test fails to reject, with a probability value of 0.14. The same result is obtained with all other pairs of period and cycle: we fail to reject the hypothesis of absence of differential effects on volume related to US macro announcements. Besides, we find no evidence of a rise in volume after 14:30 on US announcement days compared with non-announcement days, which could be hypothesised on the basis of the argument that US announcements should decrease the scope for information heterogeneity.

Test III is on the absence of regularities within each trading cycle, morning or afternoon. This is based on the following OLS equation:

$$v_{d,i} = \eta_1 + \sum_{k=2}^{I} \eta_k z_k + \psi_{d,i} \tag{5}$$

where the z's are dummy variables equal to 1 when $k = i$, with the null hypothesis being:

$$H0: \quad \eta_2 = \eta_3 = \cdots = \eta_1 = 0. \tag{6}$$

Test III results in Table III indicate that the hypothesis of no regularities within the morning or afternoon is always rejected. The full regression results of Equation (5) are given in Table IV. In all periods and cycles, almost all the η_k coefficients are significantly different from zero, implying the existence of patterns within each trading cycle.

The intracycle patterns are best illustrated in Figure 1. Panels a–b of the figure show the behaviour of volume in period 1, respectively during the morning and afternoon cycles. Each histogram after the first one is given by $\eta_1 + \eta_k$. The histograms show the average volume figure for each interval. In period 1 there is evidence of a reverse-J intraday pattern. Volume is highest in the first two half hours, at around 13 per cent of the total daily figure and then declines until the last morning interval. In the afternoon volume remains relatively low during 14:30–15:00 and rises again in the last part of the day. It is interesting to observe how the intraday picture changes as we move from period 1 to period 2 and, particularly, period 3. In period 2, volume in the first interval, with an average 10.3 per cent, is lower than in the second interval, at 11.7 per cent. In the afternoon it is confirmed that volume in the first interval following 14:30 is lower than in later intervals. Panels e–f show the intraday behaviour of volume in period 3, when the role of foreign-driven transactions in the market was highest. There is clear evidence that volume in the opening interval, at an average 7.4 per cent, declines further than in the same interval of period 2, falling well below the figure for interval 2, at 11.1 per cent, and also of interval 3, at 10 per cent. The afternoon profile is similar to those of periods 1 and 2.

4.2. Trading Costs

Two types of trading costs are usually examined in empirical studies on intraday regularities: a fixed cost related to the bid-ask spread, and a variable cost, the sensitivity parameter λ, associated with the adverse selection faced by the market maker (see Section 1.1). The latter cost component is directly relevant for our test of intraday patterns; in analogy with previous studies, we also wish to investigate the patterns of the fixed cost component. Since neither of these trading costs is

Table IV. Variations in volume – results of regression (5)

We report the results of regression (5) applied to volume for each period and trading cycle. Equation (5) is

$$v_{d,i} = \eta_1 + \sum_{k=2}^{I} \eta_k z_k + \psi_{d,i}$$

where $v_{d,i}$ is volume in day $d = 1, \ldots, 5$, interval $i = 1, \ldots, I$, and the z's are dummy variables equal to 1 when $k = i$. We recall that trading hours are longer in Period 3 than in Periods 1 and 2. One (two) asterisk(s) denote significance at the 5% (1%) level. The variance-covariance matrix is computed using the White heteroskedasticity consistent estimator.

Interval	Period 1 (η est.)	Period 2 (η est.)	Period 3 (η est.)
Morning			
9:00–9:30			7.36**
9:30–10:00	12.77**	10.31**	3.72**
10:00–10:30	−0.07	1.43*	2.62**
10:30–11:00	−2.71**	−0.63	−0.17
11:00–11:30	−4.87**	−1.02	0.04
11:30–12:00	−5.37**	−1.16*	−0.22
12:00–12:30	−5.83**	−2.58**	−0.86
12:30–13:00	−6.65**	−3.69**	−2.74**
13:00–13:30	−7.29**	−4.67**	−3.55**
13:30–14:00			−5.07**
14:00–14:30			−4.26**
Adj. R sq.	0.25	0.18	0.38
DW test	1.76	1.73	1.74
RMSE	4.55	3.95	3.34
No. of obs.	720	992	1199
Afternoon			
14:30–15:00	5.76**	6.04**	4.89**
15:00–15:30	2.17**	1.73**	1.57**
15:30–16:00	1.73**	1.63**	1.29**
16:00–16:30	3.16**	2.31**	1.41**
16:30–17:00			0.83*
Adj. R sq.	0.05	0.05	0.03
DW test	1.80	1.71	1.74
RMSE	4.58	3.60	2.89
No. of obs.	360	496	545

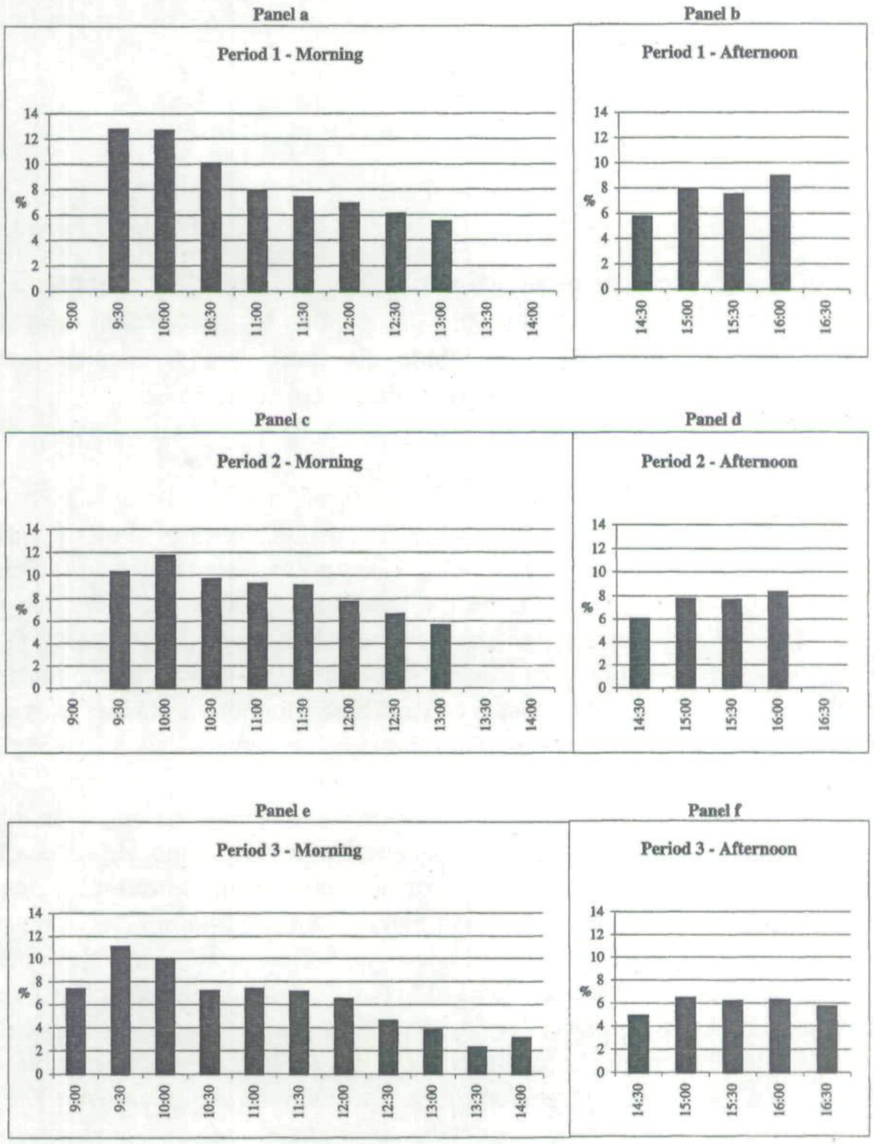

Figure 1. Variations in volume. Averages of relative intraday volume by interval and period.

directly observable,[9] in order to obtain estimates for them we use the empirical model developed by Hasbrouck (1991a; 1991b), which characterises the market maker's price setting behaviour, and can be applied to trade-to-trade data within each interval (see also Foster and Viswanathan, 1993).[10] The first part of the market maker's rule is an equation that yields an estimate of the unexpected component of the order flow. The second part, a price adjustment rule, takes the unexpected

[9] Simultaneous bid and ask quotes, and hence the spread, are published by the market only as of the close of the trading day (see also Table II).

[10] Similar approaches have also been used in other studies, e.g. Neuberger (1992).

component of the order flow as one of the inputs and yields a measure of both the bid-ask spread and the adverse selection cost λ.

In our context, the order flow equation is:

$$q_t = \theta + \sum_{l=1}^{3} t_l q_{t-l} \sum_{l=1}^{3} \varphi_l dp_{t-l} + \tau_t \tag{7}$$

where q_t denotes the signed transaction size and dp_{t-}, $l = 1, 2, 3$, are the lagged transaction price changes. The purpose of Equation (7) is to obtain the residual τ_t, i.e. the unexpected fraction of each order after taking into account the previous three orders and price changes. The price adjustment equation is:

$$dp_t = \mu + c(1_{q_t>0} - 1_{q_{t-1}>0}) + \lambda\tau_t + \xi_t. \tag{8}$$

In Equation (8), the regressor in brackets is an order-reversal dummy variable, equal to 1 (-1) when the previous order was a public sale (buy) and the current order is a public buy (sale), and 0 when the two orders are on the same side of the market. Therefore, c measures the effect of the bid-ask spread on transaction price changes, whereas the estimate of λ enables us to measure how much the trade price varies in response to an unanticipated order. These parameter estimates provide our measures of, respectively, the fixed and the variable components of trading costs within each interval.

We should add a qualification to the definition of the q_t variable. The natural choice would be to set it equal to the actual (signed) trade volume. However, only in a very small number of cases (3 per cent of the total) does trade volume differ from the minimum size of the exchange, i.e. (plus or minus) 5 billion ITL. Corresponding to those outliers, a first run of regressions yielded extremely large residuals. The above choice thus introduces a source of heteroskedasticity in Equation (7), while reducing its explanatory power. To overcome this problem, we set our q_t variable equal to +1 in the case of a public buy and to -1 in the case of a public sale. This choice affects the interpretation of λ and the way we should measure the price impact of a fully unanticipated order, which is ultimately what we are interested in. To see how, let us assume for simplicity that all orders are equal to plus or minus 5 (billion ITL). Equation (7) tries to model the process whereby the next incoming order will be a buy or a sale, on the basis of the previous record of orders and prices. By normalising order size to plus or minus 1, we can forget about *size* itself in the problem at hand, and can think of the endogenous variable as the *decision* on the side of the order. Now, the τ_t term says which 'fraction' of the decision is explained by the past order flow. If the explanatory variables in Equation (7) are such as to yield a 100 per cent exact prediction of the decision at time t, we would expect τ_t to be equal to 0. If, on the other hand, the explanatory variables are such as to yield a totally incorrect prediction, i.e. buy (+1) when the endogenous is actually sell (-1) or vice-versa, this implies that τ_t will be equal to 2 in absolute value. For the price formation Equation (8), the interpretation of λ follows accordingly. Since we are interested in the price impact of a fully unanticipated order (assuming all orders are of the same size), to measure this price impact *we should multiply* λ *by* 2, i.e. by the 'value' of a fully unanticipated decision in Equation (7).

The estimation of Equations (7)–(8) for each interval and day was carried out by least squares, consistent for the presence of an AR(2) component in the residuals. In order to improve the efficiency of the estimates, we discarded the intervals with less than fifteen transactions. This selection left us with a small number of intraday cost estimates in the intervals with a thin market, particularly towards the end of the morning cycle and in period 3 (see Figure 1).[11]

Also in the case of trading costs we run the tests described previously for volume: we apply Test I on the absence of intraweek effects, as under hypothesis (2), using an equation identical to Equation (1), where the volume variable is replaced by the c variable and, respectively, the λ variable as defined above. In Test II, we examine the presence of US announcement effects on trading costs using the modified version of Equation (3) and hypothesis (4). Finally, in Test III we look at patterns within the same trading cycle using Equation (5) and hypothesis (6).

As shown in Table V, Test I indicates the absence of intraweek effects across all periods and cycles. The Test II results indicate that the hypothesis on the absence of US announcement effects is never rejected, except in the morning of period 3. Test III on the absence of intraday regularities always shows rejection of the null hypothesis.

Table VI gives the regression results of Equations (5) and (3), the latter in the case of period 3, morning cycle, due to the US announcement effect. The evidence of the regressions is summarised in Figure 2. Panels a and b, which refer to period 1, show that the average value of c remains low and stable throughout the day, at around one basis point. In periods 2 and 3 there is evidence first, that c increases compared with period 1 and, second, that it significantly declines from the initial to the following intervals within each trading cycle. This finding is consistent with the FV hypothesis that trading costs decline as information asymmetry is reduced. Finally, there is evidence that c is largest in the hour that precedes the release of the US monthly indicators during period 3, rising to 4–6 basis points. An account of the selection procedure described earlier, we observe that the latter finding is based on a relatively small number of observations and, as such, is not as powerful as the regularity observed at the beginning of the day.[12]

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[11] In particular, looking at the half-hour intervals in period 1 (where the number of days is 95), the 'good' intervals are in the range of 27 and 76 per cent of the total. In period 2 (142 days) the corresponding figures are 50 per cent and 89 per cent. In period 3 (114 days) the figures are 11 per cent and 84 per cent.

[12] In particular, in the 13:30–14:00 interval we have 12 observations, 3 of which are on an announcement day. In the 14:00–14:30 interval we have 18 observations, 5 of which are on an announcement day.

Table V. Variations in fixed trading cost c – test results

	Period 1		Period 2		Period 3	
	F test	p-value	F test	p-value	F test	p-value
Morning						
Test I:						
H0: No intra-week regularities	1.07	0.37	0.92	0.59	1.38	0.06
Test II:						
H0: No effect of announcements	1.09	0.37	0.17	0.99	4.87	0.00
Test III:						
H0: No intra-cycle regularities	2.43	0.03	2.74	0.01	9.61	0.00
Afternoon						
Test I:						
H0: No intra-week regularities	0.75	0.74	1.19	0.28	0.90	0.59
Test II:						
H0: No effect of announcements	1.50	0.21	0.36	0.83	0.60	0.70
Test III:						
H0: No intra-cycle regularities	5.52	0.00	15.66	0.00	5.32	0.00

A comparison may be established between our c estimates and the actual bid-ask spread observed at the close of the day and reported in Table II. From Figure 2, in period 1 we estimate a c value of around 1 basis point in the last half hour of trading, while the actual closing spread is in the range of 1–1.3 basis points; in period 2 our figure for c is 2 basis points, compared with a spread in the range of 1.3–5.1 basis points; finally, in period 3 we estimate a c value of around 2 basis points, whereas the closing spread is in the range of 2–4.6 basis points.

Next, we turn to the evidence on λ. The Test I results in Table VII show no evidence of intraweek patterns; Test II indicates that in period 3, morning cycle there is a differential effect on λ related to the arrival of US macroeconomic indicators, whereas Test III shows that intraday patterns in adverse selection trading costs are present, except during the afternoons of periods 1 and 3. The regression results of Equations (5) and (3) as applied to λ are given in Table VIII. These are best illustrated in Figure 3 which, for the sake of simplicity, reports the estimated price impact of a fully unanticipated order, i.e. 2λ, within each trading interval. The main facts that emerge from the regressions and Figure 3 are, first, the decline in this cost component between the initial and the following intervals within most cycles; second, the increase in cost before the close; third, the relative increase in cost associated with the upcoming US news release in the mornings of period 3, when the estimate of 2λ is equal to around 3.5 basis points (from panel e), at a time

Table VI. Variations in fixed trading cost c – results of regressions (5) and (3)

We report the results of regression (5) applied to fixed cost c for each period and trading cycle. For period 3, Morning cycle, we give the results of regression (3) due to the presence of a significant effect related to announcement days. The most general equation is (3), i.e.

$$c_{d,i} = \beta_1 + \sum_{k=2}^{I} \beta_k w_k + \sum_{k=1}^{I} \delta_k x_k + \zeta_{d,i}$$

where $c_{d,i}$ is the trading cost measure in day $d = 1, \ldots, 5$, interval $i = 1, \ldots, I$, the w's are dummy variables equal to 1 when d is a non-announcement day and $k = i$, and the x's are dummy variables equal to 1 when d is an announcement day and $k = i$. We recall that trading hours are longer in Period 3 than in Periods 1 and 2. One (two) asterisk(s) denote significance at the 5% (1%) level. The variance-covariance matrix is computed using the White heteroskedasticity consistent estimator. The regressions are consistent for the presence of an AR(1) component of the residuals (coefficient $\rho(1)$), wher applicable.

Interval	Period 1 (η est.)	Period 2 (η est.)	Period 3 (β est.)	Period 3 (δ est.)
Morning				
9:00–9:30			0.0185**	0.0076
9:30–10:00	0.0104**	0.0205**	−0.0093**	−0.0056
10:00–10:30	−0.0001	−0.0054**	−0.0074*	−0.0071
10:30–11:00	−0.0018	−0.0057**	−0.0059	−0.0079
11:00–11:30	−0.0024*	−0.0074**	−0.0075*	−0.0069
11:30–12:00	−0.0031	−0.0064*	−0.0063	−0.0072
12:00–12:30	−0.0036*	−0.0075**	−0.0055	−0.0031
12:30–13:00	−0.0023	−0.0057	−0.0033	−0.0053
13:00–13:30	−0.0037	−0.0029*	−0.0052	−0.0029
13:30–14:00			−0.0013	0.0388**
14:00–14:30			0.0058	0.0242*
$\rho(1)$		0.12**	0.19**	
Adj. R sq.	0.01	0.01	0.19	
DW test	2.00	2.04	2.02	
RMSE	0.004	0.008	0.007	
No. of obs.	245	554	550	
Afternoon				
14:30–15:00	0.0120**	0.0204**	0.0165**	
15:00–15:30	−0.0034	−0.0075*	−0.0022	
15:30–16:00	0.0004	−0.0060*	−0.0033	
16:00–16:30	−0.0038*	−0.001	−0.0023	
16:30–17:00			0.0059	
$\rho(1)$	0.23**	0.25**	0.15*	
Adj. R sq.	0.07	0.09	0.04	
DW test	1.93	2.05	2.04	
RMSE	0.004	0.008	0.008	
No. of obs.	132	263	243	

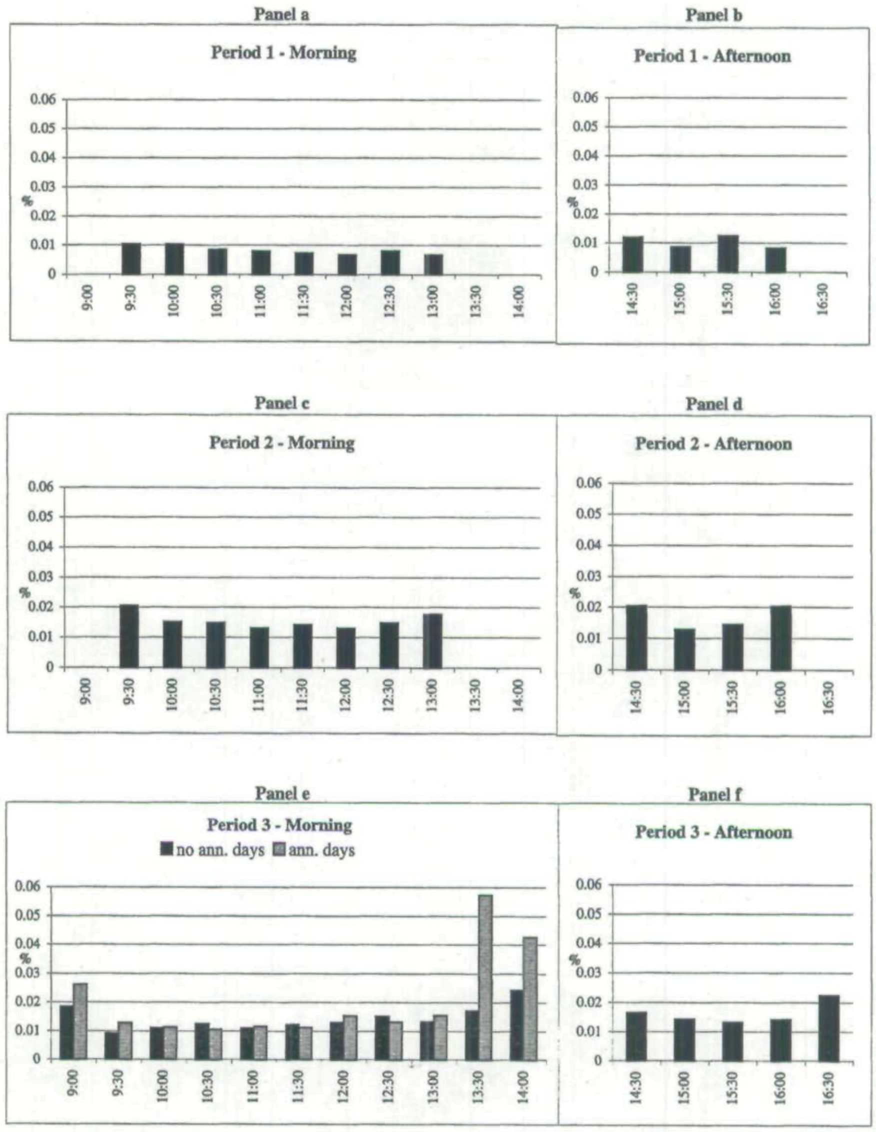

Figure 2. Variations in fixed trading cost c. Averages of intraday trading cost c by interval and period.

when the fixed cost component c also rises to 4-6 basis points. Again, we point out that the latter finding is obtained with a relativaly small number of observations.

4.3. VOLATILITY

In order to examine price volatility at the intraday level, we set the volatility measure equal to the squared return over each interval i, computed between the first trade of interval i and the first trade of interval $i + 1$ (the last trade of interval i

Table VII. Variations in adverse selection trading cost λ – test results

	Period 1		Period 2		Period 3	
	F test	p-value	F test	p-value	F test	p-value
Morning						
Test I:						
H0: No intra-week regularities	0.90	0.63	1.07	0.37	1.37	0.06
Test II:						
H0: No effect of announcements	0.98	0.45	0.65	0.73	2.16	0.02
Test III:						
H0: No intra-cycle regularities	2.28	0.04	2.28	0.03	5.64	0.02
Afternoon						
Test I:						
H0: No intra-week regularities	0.29	0.99	0.82	0.66	0.80	0.72
Test II:						
H0: No effect of announcements	0.42	0.80	0.22	0.93	0.35	0.88
Test III:						
H0: No intra-cycle regularities	0.64	0.53	5.47	0.00	1.43	0.23

if this is the end of a cycle). Table IX gives the results of Tests I to III. Intraday volatility shows no day-of-the-week effect. Test II shows that no significant effect is related to US announcements. Test III shows that intraday patterns are present, except for the afternoons of periods 2 and 3.

Table X reports the regression results of Equation (5), while Figure 4 illustrates our volatility estimates within each interval. The table shows that volatility declines between the initial and the following one or two intervals in the mornings of all periods, while this pattern is absent in the afternoon. Perhaps the most important phenomenon is the rise in volatility in the afternoons of period 2, when the figure for the last half hour of trading (0.027) is over four times larger than that for the first half hour (0.006). The peak in volatility in the final half hour of trading shows similarities with empirical evidence for other markets (see Section 1.2). In our case, this phenomenon could be explained by the extraordinary crisis which hit the lira and Italian T-bonds in September and October 1992. In that period massive sales from the US and other foreign countries caused large downward shocks to prices. According to market reports, these sales not infrequently took place towards the close of the Italian market.

We checked these results using a different measure of volatility, given by the standard error of the price change regression (8) for each interval. The results for this definition of volatility, not reported for simplicity, confirm weak support for hypothesis FV2 and the rise in volatility at the end of the day in period 2. In

Table VIII. Variations in adverse selection trading cost – results of regressions (5) and (3)

We report the results of regression (5) applied to adverse selection trading cost λ, for each period and trading cycle. For Period 3, Morning cycle, we give the results of regression (3) due to the presence of a significant effect related to announcement days. The most general equation is (3), i.e.

$$\lambda_{d,i} = \beta_1 + \sum_{k=2}^{I} \beta_k w_k + \sum_{k=1}^{I} \delta_k x_k + \zeta_{d,i}$$

where $\lambda_{d,i}$ is the trading cost measure in day $i = 1, \ldots, I$, the w's are dummy variables equal to 1 when the day is a nonannouncement day and $k = i$, and the x's are dummy variables equal to 1 when the day is an announcement day and $k = i$. We recall that trading hours are longer in Period 3 than in Periods 1 and 2. One (two) asterisk(s) denote significance at 5% (1%) level. The variance-covariance matrix is computed using the White heteroskedasticity consistent estimator. The regressions are consistent for the presence of an AR(1) component of the residuals (coefficient $\rho(1)$), where applicable.

Interval	Period 1 (η est.)	Period 2 (η est.)	Period 3 (β est.)	Period 3 (δ est.)
Morning				
9:00–9:30			0.0098**	−0.0028
9:30–10:00	0.0044**	0.0089**	−0.0022	0.0020
10:00–10:30	−0.0007*	−0.0023	−0.0021	0.0022
10:30–11:00	−0.0008	−0.0022*	−0.0033*	0.0049
11:00–11:30	−0.0007	−0.0011	−0.0024	0.0031
11:30–12:00	−0.0009	0.0010	−0.0023	0.0019
12:00–12:30	−0.0008	0.0007	−0.0014	0.0016
12:30–13:00	−0.0014	0.0001	−0.0004	0.0026
13:00–13:30	−0.0011	0.0039	0.0022	0.0025
13:30–14:00			0.0024	0.0041**
14:00–14:30			0.0059*	0.0068
$\rho(1)$	0.18**		0.28**	
Adj. R sq.	0.02	0.01	0.14	
DW test	2.01	1.89	1.99	
RMSE	0.004	0.011	0.007	
No. of obs.	245	554	550	
Afternoon				
14:30–15:00	0.0041**	0.0125**	0.0096**	
15:00–15:30	−0.0006	−0.0045*	0.0002	
15:30–16:00	−0.0008	−0.0040	−0.0003	
16:00–16:30	0.0019	0.0024	0.0047	
16:30–17:00			0.0012	
$\rho(1)$				
Adj. R sq.	0.01	0.03	0.01	
DW test	1.93	1.92	2.07	
RMSE	0.012	0.014	0.015	
No. of obs.	132	263	243	

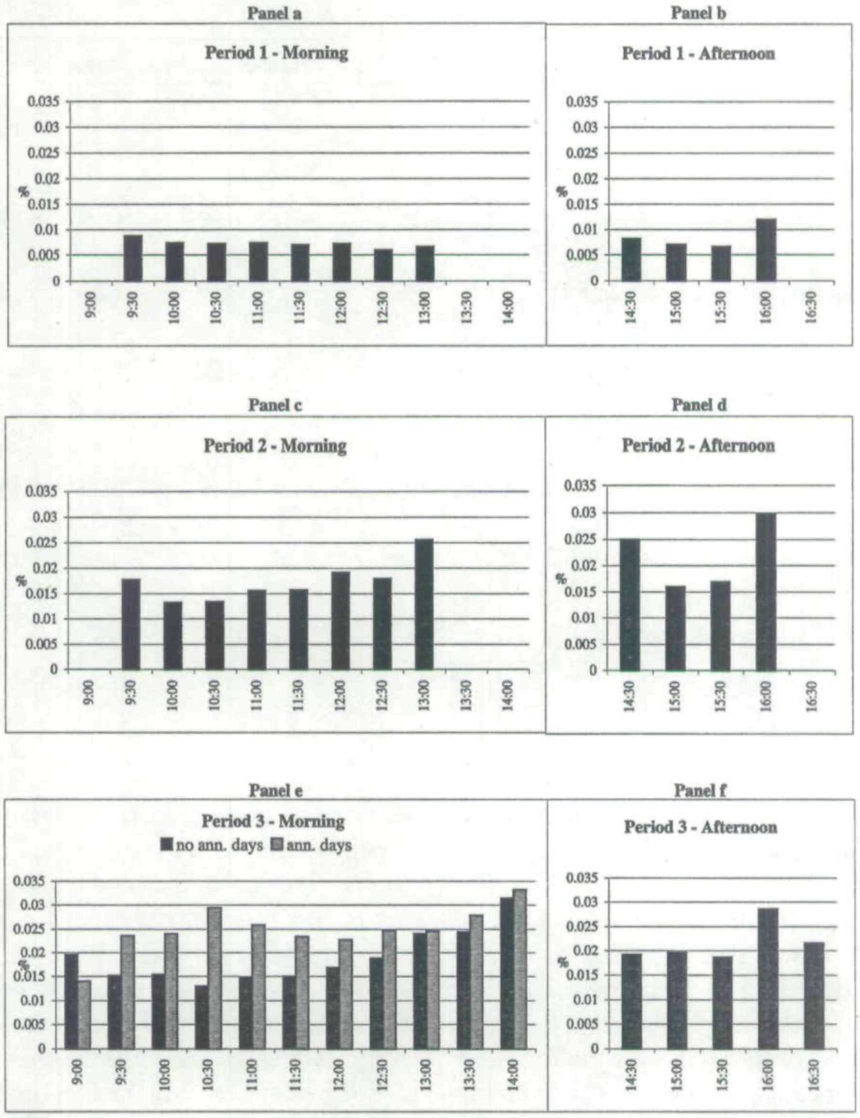

Figure 3. Variations in cost of a fully unanticipated order, 2λ. Averages of intraday cost by interval and period.

addition, the new volatility measure significantly increases prior to the release of US announcements.

4.4. Discussion

We focused on the intervals of the trading day in which the degree of information asymmetry should be highest, i.e. the initial intervals in the morning and afternoon. Prediction FV2 states that when information asymmetry is high, volume should be low, whereas trading cost and volatility should be high.

Table IX. Variations in volatility – test results

	Period 1		Period 2		Period 3	
	F test	*p*-value	*F* test	*p*-value	*F* test	*p*-value
Morning						
Test I:						
H0: No intra-week regularities	1.27	0.15	0.54	0.98	1.06	0.37
Test II:						
H0: No effect of announcements	0.62	0.76	1.05	0.40	1.29	0.22
Test III:						
H0: No intra-cycle regularities	9.06	0.00	18.99	0.00	7.15	0.00
Afternoon						
Test I:						
H0: No intra-week regularities	1.50	0.10	0.74	0.75	0.90	0.59
Test II:						
H0: No effect of announcements	0.71	0.59	1.21	0.31	0.98	0.43
Test III:						
H0: No intra-cycle regularities	31.31	0.00	1.89	0.15	1.85	0.14

Our evidence for volume and both measures of trading costs, related to the bid-ask spread and adverse selection, seems consistent with the prediction of the Foster-Viswanathan model, since these variables change in the predicted fashion between the initial interval and the following interval(s), with the exception of the mornings of period 1 (Figures 1–3). This finding lends support to the view that the clustering of block orders from international investors increases the adverse selection faced by the market makers on the Italian Treasury bond market, inducing them to raise the cost of trading. The liquidity traders that have discretion on the timing of their trades wait for some time after the initial interval, and let the block trades be worked by the informed traders. The initial intervals are thus the times of the day when a large fraction of private knowledge on the order flow becomes public through trading.

The behaviour of volatility (Figure 4) in the morning trading cycles is mildly consistent with FV2, since we observe a declining trend as we move from the early trading intervals to the middle of the day. However, the rising pattern in the afternoon suggests that information asymmetry is not the only factor responsible for volatility.

In the initial intervals of the mornings in period 3 volatility is high when trade volume is also high. This finding appears more in line with the view of the Admati-Pfleiderer model, that volatility and trade volume are both positively affected by the arrival of private information in the market. We recall that AP obtain this

Table X. Variations in volatility – results of regression (5)

We report the results of regression (5) applied to volatility s^2 for each period and trading cycle. The regression equation (5) is

$$s^2_{d,i} = \eta_1 + \sum_{k=2}^{I} \eta_k z_k + \psi_{d,i}$$

where $s^2_{d,i}$ is volatility measure in day $d = 1, \ldots, 5$, interval $i = 1, \ldots, I$, the z_k's are dummy variables equal to 1 when $k = i$. We recall that trading hours are longer in Period 3 than in Periods 1 and 2. One (two) asterisk(s) denote significance at the 5% (1%) level. The variance-covariance matrix is computed using the White heteroskedasticity consistent estimator. The regressions are consistent for the presence of an AR(1) component of the residuals (coefficient $\rho(1)$) where applicable.

Interval	Period 1 (η est.)	Period 2 (η est.)	Period 3 (η est.)
Morning			
9:00–9:30			0.011**
9:30–10:00	0.003**	0.017**	0.001
10:00–10:30	−0.002**	−0.003	−0.005*
10:30–11:00	−0.002**	−0.006*	−0.007**
11:00–11:30	−0.003**	−0.010	−0.007**
11:30–12:00	−0.002**	−0.003	−0.005*
12:00–12:30	−0.002**	−0.008*	−0.006*
12:30–13:00	−0.003**	−0.007*	−0.008**
13:00–13:30	−0.002**	−0.008	−0.005*
13:30–14:00			−0.008**
14:00–14:30			−0.008**
$\rho(1)$		0.33**	0.11**
Adj. R sq.	0.08	0.11	0.05
DW test	2.00	2.09	2.01
RMSE	0.003	0.031	0.013
No. of obs.	720	992	1199
Afternoon			
14:30–15:00	0.001	0.006**	0.006**
15:00–15:30	0.002	0.006	0.000
15:30–16:00	0.001	0.009	−0.001
16:00–16:30	0.001	0.020**	0.001
16:30–17:00			0.003
$\rho(1)$	0.43**		
Adj. R sq.	0.18	0.01	0.01
DW test	1.95	2.00	1.99
RMSE	0.008	0.081	0.012
No. of obs.	360	496	545

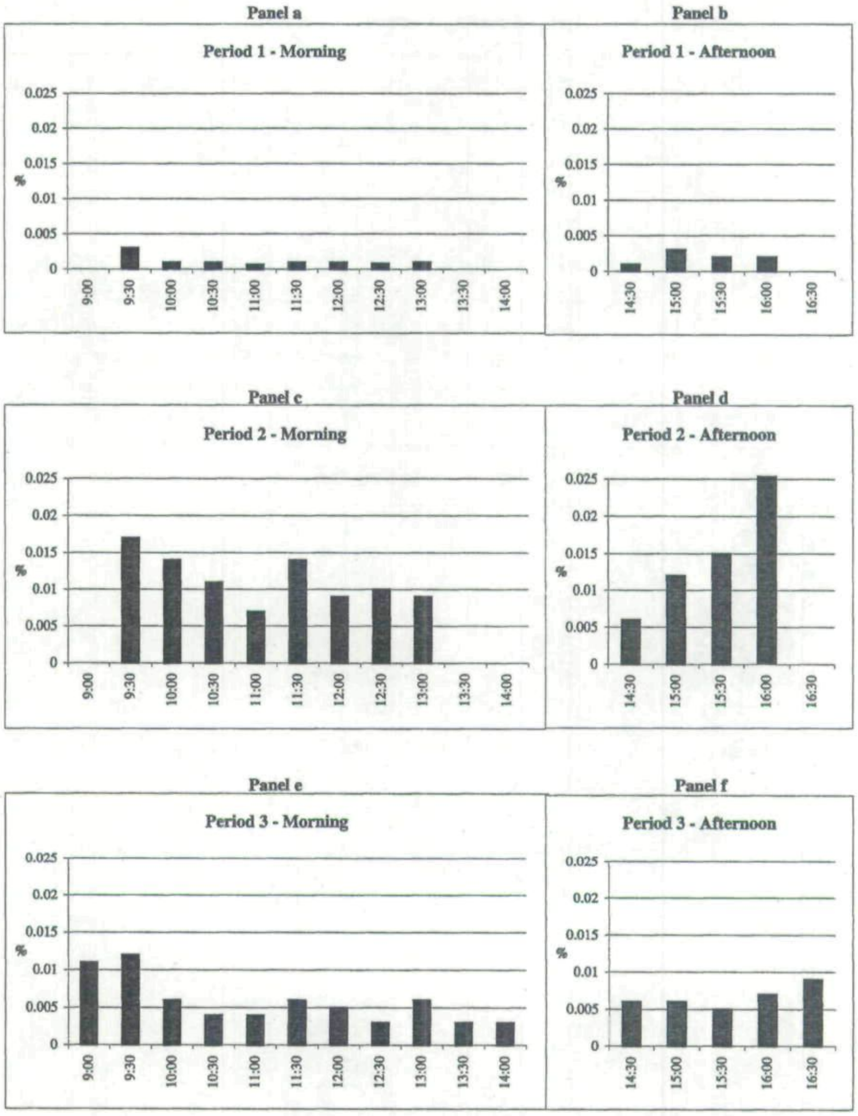

Figure 4. Variation in volatility. Averages of intraday volatility by interval and period.

prediction by allowing the acquisition of costly endogenous information in the model. However, in our environment we find it difficult to give empirical content to the hypothesis of endogenous information acquisition, and relate our finding to the AP model. On the other hand, it seems highly intuitive that a pattern of periodic private information exists in the Italian Treasury bond market, and this circumstance induced us to focus on the FV model from the start. It was thanks to the latter that we were able to formulate a prediction on the daily timing of events, namely pattern FV2. This increases the power of a test of the FV model compared

Table XI. Correlations of intraday variables

		All sample	Mean of intraday correlations
Period 1	Volume/fixed cost	0.06	0.17
	Volume/adverse sel. cost	−0.05	−0.08
	Volume/volatility	0.08	0.34
	Fixed cost/adverse sel. cost	−0.010	−0.29
	Fixed cost/volatility	0.20	0.23
	Adverse sel. cost/volatility	0.04	−0.01
Period 2	Volume/fixed cost	0.07	0.11
	Volume/adverse sel. cost	−0.03	−0.11
	Volume/volatility	0.04	0.29
	Fixed cost/adverse sel. cost	0.00	−0.41
	Fixed cost/volatility	0.12	0.21
	Adverse sel. cost/volatility	0.00	0.01
Period 3	Volume/fixed cost	−0.06	0.03
	Volume/adverse sel. cost	0.00	−0.08
	Volume/volatility	0.21	0.36
	Fixed cost/adverse sel. cost	−0.29	−0.48
	Fixed cost/volatility	0.25	0.25
	Adverse sel. cost/volatility	−0.03	−0.03

with an analogous test of the Admati-Pfleiderer model, which remains intrinsically more generic as to when events AP1 and AP2 should happen.

To gain more intuition on this issue, we computed the intraday correlation coefficients between volume, costs and volatility, given in Table XI. We first pooled all our estimates through different periods and computed the overall correlations, which are reported in the first column of the table; besides, we computed the average of the day-by-day correlations between our variables, reported in the second column. Our main findings are: (i) the correlation between volume and volatility is positive and relatively high, up to 0.36 in period 3 if we look at the average day-by-day correlation; (ii) the correlation between the two cost measures is negative and large, down to −0.48 on average in period 3; (iii) fixed cost and volatility are positively associated, with average correlations in the range of 0.21–0.25; (iv) all other correlations are weak. In particular, the average correlations between volume and adverse selection trading cost are negative, as implied by FV, though relatively small, and in the range of −0.08 and −0.11. We observe that these low estimates are obtained using all the intervals of the day, i.e. the initial and later intervals of both cycles.

5. Conclusion

We analysed the intraday behaviour of the Italian Treasury bond market using transactions data in the period from January 1992 through June 1993. We hypothesised that the two trading intervals following respectively the market open and the open of the US markets at 14:30 Italian time should be marked by the largest degree of information heterogeneity among market members. In accordance with the Foster-Viswanathan model, we expected to find relatively low volume, high trading costs, and high price volatility at those times of the day. The picture that we obtained for volume and trading costs seems consistent with the predictions of FV. However, we found only weak evidence that volatility behaves as implied by the model. In the second half of 1992, in conjunction with the currency crises, volatility increased remarkably before the market close. In the first half of 1993, trading costs showed a tendency to rise prior to the release of US monthly macro announcements.

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