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THE EFFECTS OF MARKET DESIGN ON THE INFORMATIONAL EFFICIENCY AND MANIPULATION OF PRICES

Shmuel Hauser
Avraham Kamara
Itzik Shurki

Shmuel Hauser is from Ono Academic College, Israel. Avraham Kamara is from the University of Washington. Itzik Shurki is from the Israel Securities Authority. Opinions expressed in this paper do not necessarily reflect the position of the Israel Securities Authority. We thank Yakov Amihud, Batia Filo, Ronen Madar, Amir Rubin, Orly Sade, Sunil Wahal, and seminar participants at the University of Washington, the Pacific Northwest Finance 2006 Conference, and the WFA 2008 Annual Meeting for their helpful comments. A. Kamara thanks the CFO Forum and Global Business Center at the University of Washington for their financial support.

Corresponding author:
Professor Avraham Kamara, Michael G. Foster School of Business, University of Washington, Box 353200, Seattle, WA 98195-3200.
Tel. 206-543-0652. Fax: 206-543-7472. Email: kamara@u.washington.edu

Shmuel Hauser's email address: shauser@ono.ac.il

Itzik Shurki's email address: ItzikS@isa.gov.il

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ABSTRACT

Exchanges around the world are tackling challenges presented by extreme liquidity events like the expiration and cash-settlement of stock index derivatives using opening stock prices. Opening of trade systems are also important because they follow no-trading periods. Many exchanges open with a preopening period that ends with a call auction, and some have switched from fixed to random opening times. Our Tel Aviv Stock Exchange data offer an almost-perfect laboratory to study the effects of index derivatives and randomization of opening time on the informational efficiency of stock prices. Index options expiration is accompanied by tremendous increases in opening volume, but preopening and opening prices that are noisier, less informative, and distorted. Cash settlement encourages manipulation of stock prices. Randomization has significantly improved price discovery and reduced excess volatility and price distortion. It offers a simple and effective way to mitigate the stressful effects of extreme liquidity events. In the policy debate on self-regulation by exchanges versus government regulation, our evidence supports self regulation.

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1. Introduction

The manner in which asset prices incorporate information is a critical issue for financial markets. Opening of trade systems are especially important in facilitating efficient price discovery because they usually provide the first opportunity to trade after overnight and weekend trading halts.[1] As a result, many exchanges open (and often close) with special trading systems that differ from the trading system during the rest of the day. Though there is no single opening system that is "best" for all securities markets, the majority of theoretical and empirical studies advance call auction as the desired system.[2] The London Stock Exchange, for example, introduced fully automated opening and closing call auctions in 1997 and 2000, respectively, and NASDAQ introduced opening and closing call auctions in 2004. Moreover, facing fierce competition, exchanges continuously modify their call auctions to improve their ability to accommodate orders and incorporate information. Consequently, call markets are characterized by a variety of mechanisms and algorithms. Particularly relevant to our paper, Deutsche Börse (and other exchanges that use its Xetra trading system, e.g., the Irish Stock Exchange), Euronext,

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[1] Trading volumes at the opening are typically much larger than during the rest of the day (including the close). There is evidence that the price discovery process at the opening differs significantly from the price discovery process during the continuous trading period that follows. Amihud and Mendelson (1986) find that opening prices are more volatile than closing prices on the NYSE. Examining other markets in which call auctions are also held at other points in time in addition to the opening, Amihud, Mendelson and Murgia (1990) and Amihud and Mendelson (1991) advance that the greater volatility of opening prices reflects the fact that the market is closed overnight rather than inefficient opening mechanisms.

[2] See, for example, the review articles by Madhavan (2000), Schwartz (2001), and Biais Glosten and Spatt (2005). Hillion and Suominen (2004) find that closing prices on Paris Bourse were manipulated before the change to closing call auction, and that the change was successful at reducing the manipulation. Madhavan and Panchapagesan (2000) study the NYSE's opening system, which has many of the characteristics of a call market, but with an auctioneer (specialist). They advance that this opening mechanism increases the informational efficiency of prices relative to a pure call market. Ellul, Shin and Tonks (2005) investigate the performance of call markets at the open and close of the London Stock Exchange, where traders can choose between a call market and an off-exchange dealership system. They find that although the call market dominates in terms of price discovery, it may not be the optimal method for opening and closing trading of medium and small sized stocks. Amihud, Mendelson and Lauterbach (1997) find that the Tel Aviv Stock Exchange move from once-a-day call auction to opening call auction followed by continuous trading has improved its liquidity and informational efficiency.

London Stock Exchange and Tel Aviv Stock Exchange (TASE), among others, have modified their opening call auctions from a fixed opening time to a random opening time.[3] Investigating the effects of this modification on the performance of TASE is a major objective of our paper. As Madhavan (2000) emphasizes, the rules of any trading system play a key role because they determine the rules of the game for investors and liquidity suppliers, and how orders are translated into realized transactions and prices.

To improve the informational efficiency of the price discovery process, many exchanges (including, for example, Deutsche Börse and other exchanges that use its Xetra trading system, Euronext, NASDAQ, TASE and Toronto Stock Exchange) have combined the opening call auction with a preopening period. The preopening period is designed to give the market time to incorporate the overnight information into the opening prices and discover the new equilibrium when trading resumes. The preopening phase constitutes a particularly suitable framework for studying the price discovery, because the absence of trades enables researchers to distinguish between the information contained in the order flows and the confounding effects of dealer inventories and the quality and costs of trade execution. Indeed, as Biais, Hillion and Spatt (1999) note, the preopening trading system of the Paris Bourse motivated Walras to introduce the concept of tâtonnement, the trading system in which traders revise their buy and sell orders when they believe that the price is too low or too high, continuously driving the price up and down, until prices and quantities reach equilibrium. There is extensive literature that studies the price discovery process during trading hours, but considerably less is known about the process during the preopening period.[4]

[3] The Australian Securities Exchange and the Stock Exchange of Thailand also open at a random time. Domowitz and Madhavan (2001) analyze the different trading protocols used to open securities markets.
[4] Cao, Ghysels and Hatheway (2000) study the preopening period on NASDAQ in 1995-1996 when market makers submitted nonbinding bid and ask quotes, which were widely disseminated, along with the market maker‘s identity.

In this paper we examine unique data from the Tel Aviv Stock Exchange (TASE) which allow us to extend extant literature in important ways. The data include all the theoretical opening prices and volumes for each share, from the beginning of 2000 through July 2004, based on the order book, which TASE continuously calculates, and publishes, starting at 9:00 AM (about 45 minutes before the opening). The data also include all buy and sell orders, including cancellations and revisions during the preopening and opening phases. This enables us, for example, to estimate the preopening supply and demand curves and examine the impact of information generated by them on the price discovery process. Furthermore, our data also allow us to investigate how two important factors, index options expirations and market design, affect the price discovery process in the preopening period.

We exploit these two key features of our sample to gain important insights into the relation between market design, the expiration of stock index options, strategic trading in the underlying stocks, and the information and noise reflected in opening and preopening prices and supply and demand functions. The first feature is that all the stocks in our sample were always in the TA-25, which is the index of the 25 largest firms on TASE and the underlying asset for the TA-25 index options. The TA-25 options are cash-settled European options that expire once-a-month, and their settlement values are calculated using the opening stock prices on the expiration day. This puts the stock market under substantial stress on expiration days due to the enormous increase in trading volume. Moreover, it also creates incentives to submit manipulative orders, which

Market makers were able revise their quotes in response to the quotes of others, but there was no formal order matching or equilibrium mechanism. They find that the non binding quotes contained significant information. In the late 1990s investors began to actively trade during NASDAQ's per-opening period using electronic communication networks (ECN). Barclay and Hendershott (2005) find that this has improved the informational efficiency of opening prices. Stoll and Whaley (1990a) find that the lack of disclosure and inability to revise orders before NYSE's opening resulted in structurally-induced volatility in opening prices and price reversals after the opening. Biais, Hillion and Spatt (1999) and Davies (2003), which we discuss later in the paper, study the preopening periods in the Paris Bourse and Toronto Stock Exchange, respectively.

obstruct the price discovery process during the preopening session and distort opening stock prices away from their true values.[5]

The second feature is that in an attempt to alleviate the adverse effects of options expiration on the informational efficiency of preopening and opening prices, TASE modified its opening session. On December 20, 2000, TASE changed the time it sets opening prices from the fixed time of exactly 9:45 AM to a random time between 9:45 and 9:50 AM. According to officials of TASE and the Israeli Securities Authority (the government agency that regulates Israel's financial markets), the reason for the change was the tendency of options traders to submit last-minute (and last-second) stock orders in order to influence the settlement values of the expiring options. TASE reasoned that the modification will improve the ability of informed traders to react to these trades and hinder manipulation.[6]

Kumar and Seppi (1992) develop a model in which uniformed investors earn positive expected profits by establishing positions in cash-settled futures contracts and then, on the contracts' expiration, manipulate the spot price used to settle the futures contracts. Consistent with their predictions for the equity market, we find that options expiration leads to tremendous increases in the number of orders submitted in the preopening period and executed at the opening session, while making stock prices excessively volatile and less informative relative to other days. Options expiration also affects the timing of order submission, increasing the percent of orders submitted very close to the opening, yet opening prices are distorted and more likely to be followed by reversals.

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[5] Ni, Pearson and Poteshman (2005) find that the expiration of options on (individual) stocks in the US causes stock price manipulation by options writers. Notice that because options on individual stocks are settled by delivery of shares, owners of put and calls do not have an incentive to manipulate stock prices. In contrast, because stock index options settle in cash, both people with long and short positions in stock index options have an incentive to manipulate their settlement values.

[6] Several other exchanges also write that their open opening session ends at a random time in order to avoid price manipulation: The Deutsche Börse [Deutsche Börse (2004), p. 20], the Irish Stock Exchange [Irish Stock Exchange (2007), p. 21].

The good, and more important, news is that our evidence suggests very clearly that the modification of the opening session was successful. The modification has improved the ability of traders to react to orders submitted near the opening of trade and weakened the ability to manipulate opening prices. It improved considerably the informational efficiency of preopening and opening prices on options' expiration days, as well as reduced the excess volatility and distortion of opening prices.

Our findings have important implications for researchers, exchanges and practitioners around the world. Most exchanges and regulators around the world, including the US, are continuously tackling challenges presented by expiration of stock index derivatives contracts.[7] These challenges have likely increased in recent years because equity markets around the world have witnessed a tremendous growth in derivatives contracts on indices with much smaller market values and substantial less liquidity than, say, the Standard and Poor's 500. The effect of derivatives trading on their underlying assets is also a subject of considerable social and regulatory importance, and their impact on opening prices raises concerns about fairness and market efficiency. Though much smaller than US exchanges, TASE is comparable to many

[7] At the beginning of derivatives trading on the S&P 500 in the U.S., all the contracts (futures, options, and futures options) settled at the closing prices of the third Friday of the month. This created substantial order imbalances in the S&P 500 stocks, which led to significant stock price distortions (see, for example, Stoll and Whaley (1990b)). To reduce these problems, exchanges and regulator scattered the expiration times of index derivatives. The S&P 500 futures and futures options contracts now settle at the Friday's opening prices, whereas the S&P 500 options settle at the Friday's closing prices. In addition, to improve its ability to deal with the expiration of stock index futures contracts, in November 2004, NASDAQ added consolidated opening call auctions for its stocks. Although these changes has helped, Barclay, Hendershott and Jones (2008) report that on index derivatives expiration days, opening volume on NYSE and NASDAQ on index derivatives expiration days is about 5-7 times larger than normal, and opening prices are significantly more volatile than usual. Moreover, before November 2004, the effect on NASDAQ was much bigger than on NYSE. Following NYSE's difficulty in the 1980s, Amihud and Mendelson (1985, 1989) and Cohen and Schwartz (1989) proposed changes in its market design to accommodate the changing structure of US equity markets, and in particular, in manage the large volumes of derivatives related trading. Amihud and Mendelson (1985, 1989) propose an order execution subsystem that includes both an electronic call market and an electronic continuous-trading market. They suggest that the exchange should let market forces determine the exact mix of the two market structures for each security. Cohen and Schwartz (1989) recommended that the NYSE open (and close) using electronic call markets, in which all traders (including traders off the trading floor) have equal access to the order book and are allowed to revise their orders as the opening price is being established. They argue that this will improve the price discovery process and reduce the likelihood that stock index derivatives contracts will settle using temporarily distorted stock prices.

exchanges around the world.[8] Stock index derivatives contracts around the globe are typically settled in cash, based on the value of the underlying index at a predetermined time during the expiration day. Expiration of cash-settled derivatives can worsen the informational efficiency of underlying stock prices and lead to manipulation of stock prices.

Our data offer an almost-perfect laboratory to study the effects of a relatively simple and easy to implement change in the opening mechanism on the ability of exchanges to deal with an extreme liquidity event like the expiration of index options. Our study suggests that the TASE experiment offers a simple and effective way to reduce the adverse effects of the expiration of derivatives contracts and other extreme liquidity events.

Concerns about the adverse effects of derivatives trading on the underlying markets, and the possible use of derivatives contracts to manipulate the derivatives and spot markets have existed for many years (see Edwards and Edwards (1984)). The cash-settled stock index futures and options contracts, which began trading in the USA in the 1980s, were of particular Congressional concern in the 1980s and 1990s. One of the strongly debated policy issues is whether the exchanges have the proper incentives to address potential abuses and self-regulate their markets or whether additional government regulation is needed. Edwards and Edwards (1984), Easterbrook (1986) and Grossman (1986) are among the researchers advocating self regulation, whereas Pirrong (1995) presents the case for additional government regulation. Our evidence provides clear support for self-regulation.

Our paper is also related to Biais, Hillion and Spatt (1999) study of preopening prices on the Paris Bourse. They advance two hypotheses regarding the informational efficiency of preopening prices. The first is the full-information hypothesis, which postulates that preopening prices

[8] Based on publications of the Futures Industry Association in the USA, we estimate that during our sample period TASE was among the top 15 of all (stock, commodity, options, etc.) exchanges, and TA-25 options were among the top 7 stock index option contracts, around the world, in terms of the number of options contracts traded.

reflect full-information, rational expectations, equilibrium values. On the other hand, because there is no actual trading before the opening and orders can be canceled, preopening orders may fail to be serious and informative orders, or even produced by gaming strategies designed to obstruct price discovery. In line with this, they posit the pure-noise hypothesis, which postulates that preopening prices and orders do not contain any new information about the value of the security.[9] They cannot reject the pure-noise hypothesis until 10 minutes before the opening, and cannot reject the full-information hypothesis afterward. They find that the change in the results of the tests coincides with a strong increase in the order flow around 10 minutes before the opening. They also find that the preopening price discovery process is a learning process, in that the information content of prices increases monotonically as the opening time approaches. TASE's preopening system is similar to that of the Paris Bourse.[10] Yet, we always reject both the pure-noise and full-information hypothesis. That is, we find that prices throughout the preopening period always contain new information that helps predict opening prices, yet they also always contain a significant noise component.[11] We find that the price discovery process is a learning process on the days on which index options do no expire, and after the modification of the opening mechanism, on option expiration days as well.

The paper is organized as follows. The next section describes TASE's trading structure and how it sets the opening prices. Section 3 develops the informational efficiency hypotheses and test methodology, based on Biais, Hillion and Spatt (1998). In Section 4 we present the empirical evidence for the entire sample. Section 5 studies the effects of the expiration of index options on

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[9] See also the model of Medrano and Vives (2001). In game theory, the fact that those submitting orders are not obligated to execute them and can cancel them at any time prior to opening is called "cheap talk" (see Farrel and Rabin (1996)).

[10] The Tokyo Stock Exchange, the Toronto Stock Exchange and most European exchanges, among others, also have (with some differences) similar trading systems to the Paris Bourse and TASE.

[11] A critical difference between our study and Biais, Hillion and Spatt (1999) is that we test the ability of preopening prices to predict the opening prices, whereas, they study their ability to predict subsequent closing prices.

the preopening session, and Section 6 investigates the effects of the modification of the opening mechanism on the preopening session. Section 7 examines the effects of options expiration and the modification on the information efficiency and distortion of opening prices. In Section 8 we further investigate the evidence on manipulation. In section 9 we provide additional evidence by analyzing the price elasticities of the supply and demand curves emanating from the order book, based on the methodology in Kalay and Wohl (2004).[12] The results of the elasticity tests complement and validate our findings in the earlier sections. We conclude in Section 10.

2. The Market Structure of the Tel Aviv Stock Exchange

The Tel Aviv Stock Exchange (TASE), the only stock exchange in Israel, did not have designated market makers during the sample period. TASE trading system has three (fully computerized) trading phases each day: The opening session, the continuous trading phase, and the closing session.[13] The opening session involves multi-lateral auction trading in which opening shares prices are automatically calculated by an algorithm based on the order flow at the opening time. The opening session for shares in the 100 firms with largest market value (including the shares that we study) is currently between 9:45 to 9:50 AM. Before December 20, 2000 the opening prices were determined at exactly 9:45 AM, but since then the opening time is chosen randomly between 9:45 to 9:50 AM. The opening session for all other shares is at 10:30 AM. Buy and sell orders used to determine the opening prices are submitted starting at 8:30 AM. The second phase, the continuous trading phase, commences immediately after the conclusion of the opening session. During this phase, trade is bilateral, continual and simultaneous. Trading is generated by a fully computerized limit order book system. During this period, the best three bid

[12] See also Madhavan and Panchapagesan (2000), Cornelli and Goldreich (2001), Kalay, Sade and Wohl (2004) and Kaniel and Liu (2006).
[13] See Kalay, Wei and Wohl (2002) for detailed description of TASE's trading system.

(highest limits) and ask (lowest limits) prices are disclosed electronically to all investors. All matching orders are executed immediately. The priority for executing orders is determined by price (first priority) and the time of order submission (second priority). Similar continuous trading systems are used in Euronext (which includes the Paris Bourse), Tokyo Stock Exchange, Toronto Stock Exchange, and other exchanges. The third and final phase of trade is the closing session (4:45-5:00 PM), in which transactions are executed at the (single) closing price.

In this paper, we focus on the process of price discovery in the preopening period, which precedes the opening session, and the opening session. The preopening period, for the shares that we examine, begins at 8:30 AM, when traders can start to submit buy and sell orders,[14] and ends between 9:45 to 9:50 AM. At the conclusion of the preopening period, trade is conducted at the (single) opening price, which is a function of the supply and demand curves derived from the order book at the opening time. The opening price is the price in which the highest trading volume is achieved.[15] The time priority rule provides an incentive to traders to place their orders early and thus contribute to price discovery. If the opening mechanism results in more than one equilibrium price, the exchange chooses the price closest to previous day's closing price.

Starting at 9:00 AM, TASE continuously publishes the first three levels of the order book, which include the three best bid (highest limits) and the three best asking (lowest limits) prices submitted, as well as the volume of supply and demand at each price. The identity of the member posting an order is unknown. At any given point of time, TASE calculates and publishes theoretical opening price and volume for each share based on the order book at that moment.

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[14] Investors can submit two types of limit orders: LMO, which is only for the opening session, and LMT, which is for the opening session and the subsequent trading sessions. Unfortunately, we do not know the type of the orders.

[15] A ceiling on fluctuations from the previous day's closing price is applied, amounting to 15% prior to 11/2001 and 35% afterward. We do not take the ceilings into account because price fluctuations rarely exceed 10%. Kalay and Wohl (2004) found that in only 2 instances of 15,449 transactions studied by them, opening price fluctuations exceeded 10%. In addition, since 11/2001 it was forbidden to submit "best" orders for execution in the opening session. We do not explicitly take this change into account as well, since, for all intents, these orders function as orders limited to the maximal fluctuation of 35%.

This is designed to provide investors with real-time information until the opening of trade. The theoretical price is the price that would be set as the opening price if trade began at that particular moment.

Table 1 presents examples describing the principles governing the calculation of opening prices, as well as the theoretical preopening prices. In Part A we assume the following sell orders: (1) 200 shares with a NIS 55 limit; (2) 300 shares with a NIS 56 limit; (3) 100 shares with a NIS 57 limit; and (4) 200 shares with NIS 58 limit. In addition, we assume the following buy orders: (1) 200 shares with a NIS 55 limit; (2) 100 shares with a NIS 56 limit; (3) 200 shares with a NIS 57 limit; and (4) 200 shares with a NIS 58 limit. Based on these supply and demand curves, the highest trade volume is 500 shares, which is attained at NIS 56. Hence, this will be the opening price. Since allocation of shares is determined by price and time priority criteria all 500 shares will trade at NIS 56 and the allocated shares will be as follows: All the sellers with priorities 1 and 2 (orders to sell at 56 or lower) will sell all their shares at 56, as requested. All the buyers with priorities 1, 2 and 3 (orders to buy at 56 or higher) will buy all their shares at 56, as requested. If for example, the buyer with priority 3 would have asked to buy 200 shares instead of 100 shares at 56, the opening volume and price will remain 500 shares at NIS 56. But, because she is in the 3rd priority, she would have received only 100 of the 200 shares requested. There is also time priority. If, for example, an additional order to buy 100 shares at 56 was submitted later than the order reported in Part A of Table 1, it would not be filled.

The stocks studied in this paper were in the TA-25 index, which is the underlying asset of TASE’s index options. The options settle in cash using the opening prices of the constituent stocks on the options expiration day. This creates an incentive to manipulate the opening stock prices on options expiration days. Part B of Table 1 presents a simple example of successful manipulation. Suppose that an option trader wishes to increase the opening price. Observing the information in Part A, the trader will manipulate the price by submitting an order to buy 200 shares at NIS 57, an instant before the opening of trade. This will increase the opening price to NIS 57, in which the highest trade volume of 600 shares is achieved. The buyer in this example loses NIS 200, by buying 200 shares at one NIS above their “true” price, because he will gain more than NIS 200 from the increase in the settlement price of his options.

One of the critical features of preopening activity is the ability to cancel or revise orders. Each revision implies a change in the time-based priority ranking as well. Between 8:30-9:30 one can revise or cancel buy and sell orders without any restriction. Starting at 9:30, however, cancellations are not accepted, unless, they have absolutely no bearing on the theoretical price according to the status of the order book at the time.

Until December 20, 2000 the opening prices of the TA-25 shares were determined at exactly 9:45 AM. Starting on December 20, 2000, TASE modified the opening mechanism for the TA-25 shares, by changing the opening time from the fixed time of 9:45 to a randomly chosen time between 9:45-9:50 AM. This change was designed to curb alleged attempts to manipulate the opening prices of TA-25 stocks, particularly on the expiration days of the TA-25 options. TASE was concerned about the tendency of traders to delay the submission of “last round” orders to seconds before 9:45 in order to influence the opening index value. TASE’s view was that changing the opening time to a randomly chosen opening time between 9:45-9:50 AM will deter manipulative activity because it will: (i) improve the ability of other investors to respond to these last-minute orders; and (ii) introduce execution risk into any manipulative trading activity. We will investigate the effect of this modification on trading strategies and the information content of preopening and opening prices.

3. The Informational Efficiency Hypotheses and Test Methodology

The two alternative hypotheses that we test concerning the informational efficiency of preopening prices are developed in Biais, Hillion and Spatt (1998). The first hypothesis is that the preopening price process is only noise. The second hypothesis is that the preopening price process is fully informative.

The pure-noise hypothesis advances that the theoretical preopening share prices reflect noise only and do not convey any new information about the true values of the securities. The rationale is that preopening orders are not serious and informative orders because there is no actual trading before the opening and orders can be canceled. Formally, this hypothesis is expressed by the following equation:

$$P_t = E(V \mid I_0) + \varepsilon_t \qquad (1)$$

Where P_t represents the theoretical preopening price at time t, V is the true equilibrium price of the asset, I_0 is the information disclosed to the public at time *0*, which is *prior to the preopening phase* (i.e., the previous trading day), and ε_t is noise. Under this hypothesis, the preopening price, P_t represents only noise and does not incorporate any new information since the previous trading day's closing price.

In contrast, ***the full-information hypothesis*** advances that P_t, the theoretical preopening price at time *t;* can be expressed as:

$$P_t = E(V \mid I_t) \qquad (2)$$

Where I_t is the information disclosed to the public by the preopening order flows at time *t*. The full information hypothesis asserts that investors are rational, react correctly to all the information flowing to the market, and act accordingly.

To test the hypotheses above, we follow Biais, Hillion and Spatt (1998) and estimate the following regression:

$$\frac{V - E(V \mid I_0)}{E(V \mid I_0)} = \alpha_t + \beta_t [\frac{P_t - E(V \mid I_0)}{E(V \mid I_0)}] + Z_t \qquad (3)$$

Where Z_t is the error term. [16]

We estimate equation (3) under the assumptions that the opening price represents *V*; the true equilibrium price of the asset, and the previous trading day's closing price represents $E(V \mid I_0)$. The pure-noise hypothesis postulates that $\beta_t = 0$ because $[P_t - E(V \mid I_0)]$ does not provide any help in predicting the change in the value of the asset since yesterday's closing value. That is, the preopening theoretical prices do not convey any new information about the opening prices. In contrast, the full-information hypothesis postulates that $\beta_t = 1$ because the preopening theoretical price, $P_{t,}$ is the conditional (rational) expectations of *V*.

Biais, Hillion and Spatt (1999) find that the preopening price discovery process is a learning process, in that the estimated β_t of preopening prices increases monotonically towards one as the opening time approaches. We call this, ***the learning process hypothesis***. We test the learning process hypothesis by investigating if beta changes systematically as we approach the opening session. To estimate the price adjustment process, we run a cross-section analysis of the regression estimates for all the stocks each and every minute, starting at 9:00, over all the trading days in the sample. In addition, we will also examine the behavior of the volatility of betas and the volatility of returns. If the volatility of betas is relatively large (as we will clarify below), it

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[16] Following Biais, Hillion and Spatt (1999) we divide $[V - E(V \mid I_0)]$ and $[P_t - E(V \mid I_0)]$ by the previous day's closing price. Working with rates of returns rather than price changes also eliminates the heteroskedasticity induced by variations in price levels.

would suggest that the price discovery process, even if it is a learning process, also exhibits unaccountable volatility or noise.

Biais, Hillion and Spatt (1998) do not investigate the sources of the noise. We study the information and noise reflected in preopening prices by comparing different trading environments. First, we study the expiration days of index options versus all other days. The stock index options are European options that are cash-settled based on the value of the underlying index at the opening of trade on the expiration day. This creates incentives for trading strategies that influence, and even manipulate, preopening and opening stock prices. Second, we investigate the period until December 20, 2000 in which opening prices were set at exactly 9:45 AM versus the subsequent period in which opening prices were set randomly between 9:45 and 9:50 AM. TASE adopted this change to hinder manipulation and improve the ability of informed traders to react to trades submitted very close to the opening. We use this change to study the effects of the opening mechanism on trading strategies and the informational efficiency of orders and prices.

We also study the order flows during the preopening period as well as conduct tests on the opening prices. We study how option expiration and the modification of the opening session affect the degree to which opening prices are excessively volatile, distorted, followed by price reversals, and informative about subsequent prices.

Lastly, we also study the degree to which prices are informative by examining the elasticities of the supply and demand curves emanating from the order book. These tests are based on the thesis of Kandel, Sarig and Wohl (1999) and Kalay and Wohl (2004) that informed traders tend to condition their trade size on the transaction price, and thus have elastic supply and demand curves. In contrast, uninformed traders tend to have inelastic supply and demand curves. Hence, greater price elasticity indicates that current orders and prices are based on more accurate information and are less noisy. We will describe these tests and their theoretical rationale in more detail in Section 9.

4. An Analysis of the Entire Sample

4.1. The Data

Our sample includes preopening data from the beginning of 2000 through July 2004 for the 17 stocks that were included in the TA-25 index throughout our entire sample period. The TA-25 index represents the 25 firms with the highest market value on TASE, and is also the underlying asset for TASE's traded equity index options. The composition of the index is updated every six months and only 17 firms were included in it throughout our sample period. The data include all preopening buy and sell orders, all cancellations, all theoretical preopening prices, and the status of the order book at any given point for each of the stocks in the sample.

Table 2 summarizes the market values and trading volumes of the shares. The shares in the TA-25 account for approximately 62% of the market value of all shares traded on TASE, and for 74% of TASE's turnover. The 17 stocks in our sample represent Israel's largest publicly traded companies, and command 86% of the market value of the TA-25. They accounted for 79% and 96% of the trading volume of the TA-25 in dollar value and number of shares, respectively. Though TASE is much smaller than US markets, the data in Table 2 are comparable to many exchanges around the world, including some developed countries.

Our data also include opening prices for each of the shares as well as prices attained 15 minutes after the beginning of continuous trade, and the closing prices. For each day we collected data for each buy and sell order submitted, cancelled or revised, starting from 8:30 AM until the opening session. The majority of cancellations were submitted by 9:30, since in the final 15 minutes prior to opening it is possible to cancel only orders that are not instrumental in setting opening prices. We find that the volume of cancellations up to 9:30 is three times the volume between 9:30 and the opening of trade.

4.2. The Empirical Evidence

We estimated equation (3): $\frac{V - E(V \mid I_0)}{E(V \mid I_0)} = \alpha_t + \beta_t[\frac{P_t - E(V \mid I_0)}{E(V \mid I_0)}] + Z_t$ for each of the 17 stocks in the TA-25 index. Recall that V is the opening price for the day, P_t is the theoretical preopening price, and $E(V \mid I_0)$ is measured by the previous day's closing price. The pure-noise hypothesis postulates that $\beta_t = 0$, whereas the full-information hypothesis postulates that $\beta_t = 1$. The learning process hypothesis postulates that β_t approaches one as we approach the opening.

Table 3 reports the averages of the estimated betas for the 17 stocks in the TA-25 by minutes to opening, starting at 9:00 AM, at least 45 minutes before the opening session. Both the pure-noise and full-information hypotheses are always rejected at conventional levels. The average betas for the group are always significantly larger than zero and significantly smaller than one. These findings suggest that the preopening prices contain both noise and information. Preopening prices always contain information that is not contained in the previous day's closing price about the opening prices, but are never fully informative. Consequently, unlike Biais, Hillion and Spatt (1999) who cannot reject the hypothesis that preopening prices on the Paris Bourse do not contain any new information until about 10 minutes before the opening session, we find that the preopening prices on TASE always contain some new information that helps predict the opening prices. But, while Biais, Hillion and Spatt (1999) cannot reject the hypothesis that the preopening prices with less than 10 minutes to opening are fully informative, we always reject the hypothesis that the preopening prices on TASE are fully informative.[17]

Similar to Biais, Hillion and Spatt (1999), we also find that the preopening price discovery process is a learning process. The averages of the betas in Table 3 increase monotonically as the opening session approaches: from 0.059 at 9:00, to 0.105 at 9:15, 0.236 at 9:30, 0.603 at 9:40, and 0.855 at 9:44 AM. Hence, despite the absence of immediate trades, the betas estimated over the entire sample suggest that the informational efficiency of the preopening prices improves monotonically as the market approaches the opening session.

We will now examine how the expiration of stock index options and the change in the design of the opening session have affected the trading activity in the preopening process and the noise and information components of the preopening prices.

5. The Impact of the Expiration of TA-25 Index Options

As we described above, the stocks in our sample are part of the underlying asset of the TA-25 index options. The TA-25 options are cash-settled European options and have three possible durations: 1, 2, and 3 months. The options expire on the last Thursday of the month, and their settlement day is the last Friday of the month. The critical issue for our purposes is that the price used to settle the TA-25 index options is calculated using the *opening prices* of the constituent stocks on the expiration day (Thursday).

In this section we will examine how options expiration affects the trading patterns in the preopening period, the opening prices, and the information content of the preopening prices of

[17] Davies (2003) studies the preopening period on the Toronto Stock Exchange and reports findings that are similar to Biais, Hillion and Spatt (1999). Toronto Stock Exchange differs from TASE in the way it manages the preopening process on the expiration days of index futures and index options. The Exchange has designated market makers, and on the evening before the expiration day traders can submit must-be-filled orders, which receive complete fill at the opening price.

the TA-25 stocks. To investigate the role of options related trading activity and of possibly manipulative activity, we will compare the order flows and price discovery processes on the options' expiration days and non-expiration days.

Table 4 presents summary statistics of the trading volumes, order flows and cancellations for the entire sample divided into days on which the index options expire and all other days. The most striking evidence is the substantial effect of options' expiration on the trading activity in the opening session and preopening period. Options expiration has led to a tremendous increase in the number of orders submitted in the preopening period and the opening session. The average opening volume per company on expiration days is more than 18 million NIS, whereas the average opening volume per company on non-expiration days is less than 0.4 million NIS. In addition, the volume of trade at the open as a percentage of total daily volume is also much higher on expiration days (56%) than on non-expiration days (4%).[18]

The data also reveal that the volume of cancelled orders before 9:30 AM as a percent of total trading volume (average per company) is 10.54% on expiration days versus 3.52% on non-expiration days. In contrast, there is no difference in the percents of cancelled orders after 9:30 AM, when traders may not be able to cancel their orders. In addition, the timing of orders arrival is also different between the two subsamples. The fraction of orders that arrive early is substantially larger on expiration days than on non-expiration days. Fifty percent of the orders submitted during the preopening period on expiration days were submitted by 9:00, compared to only 16% on non-expiration days. Sixty nine percent of the orders on expiration days were submitted by 9:30, compared to 53.57% on non-expiration days. Absent the time priority rule of the trading system one would expect arbitrageurs and hedgers who are mostly concerned with the

[18] Expiration days are also characterized by larger trading volumes during the rest of the day. After the opening, the average volume on expiration days is almost 1.5 times the average volume on other days.

risk of mismatching their equity and options prices to trade as closely as possible to 9:45 AM. With the time priority rule and the unrestricted ability to cancel orders before 9:30 AM, one can rationalize that some of the orders and cancellations before 9:30 AM also reflect the activity of hedgers and arbitrageurs. It is also possible that some of the orders and cancellations before and after 9:30 AM reflect manipulative trades that are intended to blur the information reveled by the prices and confuse other traders.

Table 5 presents our findings regarding the informational efficiency of preopening prices on options' expiration days and non-expiration days. The average betas are always lower on the options expiration days than on non-expiration days, and the differences are almost always statistically significant at conventional levels. The data also reveal that price discovery on option expiration days occurs later in the preopening period than on non-expiration days. Figure 1 plots the average betas for the two subsamples. The differences in the betas are considerable and statistically significant at 3.2% or less until 9 minutes before the opening session. For example, until 13 minutes to opening average betas on non-expiration days are always at least twice as large as average betas on expiration days. Afterward, the differences in betas remain positive throughout the entire process, but become much smaller. They are not statistically significant at conventional levels with 8 to 5 minutes to opening, but became statistically significant at 3% or lower, in the last 4 minutes. Recall that in the last 15 minutes cancellations of orders are not accepted, unless they have absolutely no bearing on the theoretical price.

Though not reported in the table, we continue to reject both the pure-noise hypothesis and the full-information hypothesis in each of the subsamples, as the average betas remain always significantly larger than zero and significantly smaller than one.

The data reveal that the price discovery processes in both subsamples are learning processes. The average betas on options expiration days increase from less than 0.04 thirty minutes before the opening time to 0.13 fifteen minutes before the opening time, 0.22 ten minutes before the opening time, 0.54 five minutes before the opening time, and 0.80 in the last minute prior to opening. The average betas on non-expiration days increase from less than 0.18 thirty minutes before the opening time to 0.29 fifteen minutes before the opening time, 0.38 ten minutes before the opening time, 0.54 five minutes before the opening time, and 0.86 in the last minute prior to opening.

Part B of Table 5 reveals that the standard deviations of the changes in estimated betas during the preopening period, from 9:15 until 9:30, and from 9:30 until 9:45, are substantially larger (by 60% and 106%, respectively) on expiration days than on other days, and the differences are statistically significantly at less than 1% p-values. Moreover, the opening prices are also noisier on expiration days. The standard deviation of the overnight (from the previous-day's closing prices to today's opening price) rate of return is substantially higher (1.88% versus 1.23%, with a less than 0.001 p-value) on expiration days than on non-expiration days.[19] Hence, the price discovery process is less informative and more volatile on expiration days than on other days.

The data in Tables 4 and 5 reveal that although the trading volumes of the underlying shares are substantially larger on options' expiration days, their preopening prices are noisier and less informative. Asymmetric information models and market microstructure models typically predict that a higher volume of liquidity trades enables informed traders to incorporate their information into prices more aggressively and faster. This would suggest that the price discovery process on options expiration days will be more informative than on other days. Our evidence suggests the

[19] Note that Mondays are always in the subsample of non-expiration days. Consequently, to the extent that weekend returns (from Friday close to Monday open) are more volatile than overnight returns (French and Roll, 1986), the tests are biased against finding that overnight returns are more volatile on options expiration days.

opposite. We find that despite the huge increase in trading volume at the opening of trade on options expiration days, preopening prices are noisier and less informative. In Kumar and Seppi (1992) uninformed traders (who hold futures contracts) trade strategically to manipulate the spot price used to calculate the settlement price of futures contracts. They predict that attempted manipulation, regardless of whether it succeeds or fails to distort the spot price, will substantially increase the amount of trades and make the underlying stock prices noisier. Our results are consistent their predictions. The expiration of cash-settled stock index options increases the volume of orders and trades tremendously, and the preopening prices of the underlying stocks are noisier and less informative.

6. The Effects of the Modification of the Opening Mechanism on Preopening Prices

The evidence above suggests that preopening and opening prices on the expiration days of cash-settled index options are less informative and more volatile than on other days. TASE officials believed that these prices were distorted by manipulation. To alleviate these problems, TASE decided to change the design of its opening session. On December 20, 2000, TASE changed the time it sets opening prices from the fixed time of exactly 9:45 AM to a random time between 9:45 and 9:50 AM. According to TASE, the reason for the modification was the tendency of manipulative investors to submit last-minute (and even last-second) orders, when it is practically impossible for other investors to react to these orders. TASE expected that this modification will hinder manipulation by adding execution uncertainty and improving the ability of traders react to manipulative trades, thereby reducing or eliminating the effects of ‘gaming’ on the price discovery process. In this section we study the effect of the modification on the price discovery process during the preopening session.

We begin by comparing the informational efficiency of preopening prices during January 2000-December 19, 2000, when the opening time was at exactly 9:45, and December 20, 2000-July 2004, when the opening time was randomly chosen between 9:45 and 9:50. We further divided each period into options expiration days and non-expiration days.

Part A of Table 6 examines the subsample of options expiration days. The betas before and after the modification of the opening session are almost never significantly different from each other at the 5% level until 10 minutes before the opening. Afterward, however, the average betas in the random-opening-time period are typically 2 to 3 times larger than in the fixed-opening-time period. The differences in the betas are also statistically significantly (at less than 3% 10 and 9 minutes before the open, and at less than 0.002 afterward). In particular, the average beta doubled (from 0.37 to 0.74) two minutes before the opening (with 15 of 17 firms having higher betas), and increased by 56% (from 0.55 to 0.86) one minute before the opening (with 16 firms having higher betas).

Another important change after the modification in Part A involves the behavior of the betas over the last 15 minutes before opening. Before the modification, the betas on expiration days do not exhibit a learning process: The estimated beta is 0.17 fifteen minutes before the opening but only 0.08 ten minutes before the opening. The beta also declines from 9 to 8 minutes, and from 6 to 4 minutes, before the opening. In contrast, after the modification, the betas do exhibit a learning process, and increase monotonically as we approach the opening.

Part B of Table 6 reports the results for non-expiration days. Though much less dramatic than the improvement on options expiration days, the informational efficiency on non-expiration days has also improved. There is no noticeable effect on the betas until about 5 minutes before the opening. But, afterward, the average betas in the second period are always significantly higher and closer to one than the average betas in the first period. The average betas in the last 2 minutes before opening are larger in the random opening period than in the fixed period by 13% and the improvement is statistically significant at the 1%. Also note that the betas on non-expiration days exhibit a learning process both before and after the modification.

Part C of Table 6 reports the improvement in the informational efficiency of preopening prices on expiration days relative to other days. The last column shows that the differences in average betas in the last 10 minutes before opening declined significantly after the modification. In particular, the average differences in betas fell from 0.35 to 0.06 two minutes before the opening, and from 0.25 to 0.04 one minute before the opening. Hence, the informational efficiency of preopening prices on expiration days has improved substantially after the modification both in absolute terms and relative to other days.

A possible concern about the comparison of the betas across "minutes to open" in Table 6 is that the random opening time (9:45-9:50) is on average 2-3 minutes later than the fixed opening time of 9:45 AM. The results in Table 6 suggest, however, that this is not the driving force behind the improvement in the information content of preopening prices. Examining options expiration days, note that before the modification, the beta with one minute to open is 0.55. In contrast, after the modification, the betas exceed this value in the entire last five minutes to opening. Moreover, this is not the case on non-expiration days, where the betas after the modification do not exceed the beta with one minute to open before the modification, until 2 minutes to opening.

Figure 2 illustrates the improvement in the informational efficiency on expiration days relative to other days for the entire 45 minutes before the opening. The graphs chart the average differences between the betas on non expiration days and expiration days, by periods of fixed and random opening times. Because each point on the graphs represents the difference between the betas on non expiration days and expiration days, a movement downward (upward) on the graphs implies an improvement (deterioration) in the relative information content of prices on options expiration days. The graphs show the dramatic improvements in the relative informational content of preopening prices on expiration days after the modification, especially in the last 8 minutes. Before the modification, there is a clear deterioration in the relative information content of prices on expiration days in the last 12 minutes. Indeed, while the difference in betas from 45 to 13 minutes to opening is between 0.05 and 0.16, the difference in betas jumps from 0.11 to 0.30 with 12 minutes to opening, and remains between 0.25 and 0.36 until the opening. In contrast, after the modification, with 8 minutes to opening the difference in betas, which ranges between 0.11 and 0.19 until then, falls from 0.11 to 0.02, and remains small until the opening. That the improvement in the information content of prices on expiration days after the modification becomes economically and statistically significant with about 10 minutes to opening supports the hypothesis that it is related to the modification of the opening session.

One of the issues that we examine later in the paper is the possible distortion of opening prices on options expiration days. The analysis of the betas so far uses the opening stock price as the true value of the stock. It is, therefore, useful to examine the betas of preopening prices with respect to prices soon after the opening. We address this issue by examining the informational efficiency of the pre-opening prices with respect to the market prices that are observed 15 minutes after the opening, after the beginning of continuous trade. That is, we re-estimate equation (3) but replacing the opening prices with the stock prices that are observed 15 minutes after the opening as V - the equilibrium share price. Figure 3 graphs the average differences between the betas on non expiration days and expiration days, by periods of fixed and random opening times. The inferences are similar to those from Figure 2. In particular, notice the similar patterns in the last 10 minutes to opening. Before the modification, the difference in betas trends upward and becomes markedly larger in the last two minutes. In contrast, after the modification, the difference in betas trends downward and, in fact, is almost never positive, which implies that the betas on expiration days are not lower than on non-expiration days.

To summarize, our results suggest that, as the TASE intended, the modification has improved the ability of informed traders to incorporate their information into preopening prices. The information content of preopening prices on options expiration days has improved after the modification both in absolute terms and relative to non-expiration days.

7. The Effects of the Modification on Opening Prices

In the sections above we investigated the effects of options expiration and the modification of the opening mechanism on the preopening prices. In this section we investigate their effects on the opening prices. After all, the reason for having a preopening session and modifying the opening mechanism is to improve the informational efficiency of opening prices.

7.1. The Effects on the Informational Efficiency and Volatility of Opening Prices

We begin by examining the informational efficiency of the opening prices with respect to the market prices that are observed 15 minutes after the opening, after the beginning of continuous trade. That is, we re-estimate equation (3) using the opening stock price as P_t and the stock price 15 minutes later as V - the equilibrium share price. We continue to use the previous day's closing price for $E(V \mid I_0)$. The hypothesis that the modification has improved the informational efficiency of opening prices postulates that the betas will increase towards one after the modification.

Table 7 reports the estimated betas. Part A reports the results for the entire sample period divided into expiration and non-expiration days, and pre- and post-modification subperiods. The data suggest that the informational efficiency of opening prices is worse on options expiration days, and that the modification has improved the informational efficiency of opening prices on expiration days, both in absolute terms and relative to non-expiration days. Examining the betas of opening prices on options' expiration days reveals that the average beta has increased by 36% from 0.621 to 0.847, and that the increase is statistically significant at near-zero levels. In addition, 16 of the 17 the betas have increased towards one after the modification. The average beta on non-expiration days has also increased, but by only 7% from 0.861 to 0.922 (which is statistically significant at 1%), and only 11 firms have higher betas (which is not significantly higher than one-half at conventional levels). The informational efficiency of opening price on options' expiration days has also improved relative to non-expiration days. The informational efficiency of opening price on options' expiration days is significantly worse than on non-expiration days, both before and after the modification, but the underperformance is substantially smaller after the modification. The difference between the betas on expiration and other days has declined after the modification for 14 stocks, with the average difference falling significantly from 0.24 to 0.07. Hence, the modification of the opening mechanism has led to a substantial improvement in the informational efficiency of the opening prices on options expiration days, both in absolute terms and relative to other days.

One possible concern is that our findings above are not because of the change in the opening mechanism, but simply because the random opening mechanism period is subsequent to the fixed opening mechanism period, and is also much longer. We address this concern in two ways. First, our results above show very convincingly that the improvements in informational efficiency of the preopening and opening prices are significantly larger on expiration days than on other days, and that this improvement becomes considerably more meaningful in the last few minutes before opening. Hence, even if one believes that the entire improvement on non-expiration days is due to a more recent time period, it is clear that a substantial fraction of the improvement on expiration days reflects the modification of the opening session.

Second, we also examine a shorter post-modification period with the same number of observations as the pre-modification period.[20] Part B of Table 7 reports the effects of the modification on the information quality of opening prices, but using a post-modification period that has the same number of observations as the preopening period. The conclusions for options expiration days remain the same. If anything, they are slightly more favorable to the hypothesis that the modification has improved the informational efficiency of opening prices on expiration days. The average beta on expiration days has increased after the modification by 40% from 0.62 to 0.87, and the difference between the betas on expiration and other days has declined for 16 of the 17 stocks. The results for the non-expiration days, however, show a smaller improvement in betas than in Part A of the Table, suggesting that part of the improvement reported above for non-expiration days may be due to the fact that the post-modification period is larger and more recent.

Earlier we reported that the volatility of close-to-open (overnight) returns is significantly higher on expiration days than on non-expiration days (1.88% versus 1.23%, with a less than 0.001 p-value). In Table 8 we examine the effect of the modification on the volatility of opening prices. The Table reports the standard deviations of close-to-open returns and of returns calculated from previous-day's closing prices to 15 minutes after the opening. The data are

[20] TASE does not have the detailed data that we are using, such as minute by minute theoretical preopening prices, for the period before 2000.

segregated by expiration and non-expiration days, before and after the modification. The first striking pattern is that on expiration days, the volatility of close-to-open returns is significantly higher than the volatility of close-to-(open+15) returns in each of the 3 subperiods. In contrast, on non-expiration days, the volatility of close-to-open returns is significantly lower than the volatility of close-to-(open+15) returns in each of the 3 subperiods. Moreover, this pattern holds for almost all the firms. Together with our earlier results, the data in Table 8 further support our assertion that the substantially larger opening trading volumes and preopening orders on expiration days result in opening prices that are substantially noisier than on other days.[21] The second finding is that the excess volatility of opening prices (over prices 15 minutes later) on expiration days fell dramatically after the modification. Looking at the entire sample period (until July 2004), the average excess volatility at the opening on expiration days fell from 0.51% to 0.11% (which is statistically significant at 0.0004), and it fell for 15 of the 17 firms (which is significantly different from 1/2 with a p-value of 0.0016). The results for the post-modification subperiod of December 20, 2000 – Dec. 13, 2001, are similar. In contrast, on non-expiration days, the changes in excess volatility after the modification are statistically indistinguishable from zero, and the proportions of firms with changes in excess volatility are indistinguishable from one-half.

Consequently, we find that the modification of opening mechanism has significantly improved the informational efficiency of preopening and opening prices, and reduced the excess volatility of opening prices, on options expiration days. Our findings indicate that TASE has

[21] The volatility of close-to-open returns is higher on expiration days than on other days in each of the 3 subperiods, for each of the firms, and the differences are statistically significant at 0.005. Though they are much closer to each other than the close-to-open volatilities, the volatilities of close-to-(open+15) returns are also significantly higher on expiration days than on other days.

achieved its objective of improving the informational efficiency of the preopening process on the options expiration days.

7.2. The effects on the Distortion of Opening Prices

Using the opening stock prices to cash-settle the expiring stock index options creates conditions that favor manipulative trades that distort the opening stock prices away from their true values. In this section we study the effects of options expiration and the modification of the opening mechanism on the distortion of opening stock prices.

Before we continue we note that there are two reasons why opening prices on expiration days can be distorted. The first is successful manipulation. The second is that the expiration of stock index options creates large order imbalances from investors who need to adjust their stock positions because their options positions expire. Liquidity suppliers will accommodate large order imbalances only if they are compensated. Consequently, they will buy (sell) only if opening prices are at a discount (premium) to expected subsequent prices. Hence, opening stock prices on expiration days will contain larger than usual liquidity premiums. We call these hypotheses: the (successful) ***manipulation hypothesis*** and the ***liquidity supply hypothesis***. Notice that these hypotheses are not mutually exclusive.

We study the distortion of opening prices by examining the relation between the opening prices and the prices observed 15 minutes later. Clearly, prices after the opening can differ from opening prices in reaction to information revealed by opening and subsequent prices. However, in the absence of successful manipulation and liquidity premium due to large order imbalances, stock price changes over the first 15 minutes should not exhibit any systematic pattern, and moreover, should not exhibit more pronounced patterns on expiration days than on other days.

The first set of tests investigates the existence of price reversals from the opening to 15 minutes later. We examine the correlation between the overnight rate of return (from the previous-day's closing prices until the opening price), and the rate of return from the opening price until 15 minutes after the beginning of continuous trade. Both the manipulation hypothesis and liquidity supply hypothesis predict that these returns are negatively correlated on options expiration days, and more negatively correlated on options expiration days than on other days. Negative correlations suggest that price changes from the close to open are more likely to be reversed than to be continued during the first 15 minutes of the continuous trade phase.[22] Table 9 reports the coefficients of correlation between these two rates of return averaged over the 17 stocks, segregated by options expiration days and other days.[23] The correlations are almost always negative (all 17 coefficients on expiration days and 16 coefficients on other days are negative over the entire sample). Part A of Table 9 reports the results for the entire sample. We find a strong negative correlation with an average coefficient of –44% on expiration days, as opposed to –13% for non-expiration days; and the difference between the two series is significantly different from zero with a p value smaller than 0.001. Moreover, the coefficient of correlation of each of the 17 stocks is more negative on options expiration days than on non-expiration days. Hence, the expiration of TA-25 options substantially accentuates the price reversals after the opening, which is consistent with both the manipulation and liquidity supply hypotheses.[24]

[22] Comerton-Forde and Puntiņš (2007) examine a sample of prosecuted cases of manipulation of closing stock prices in the US and Canada. They find that closing prices were inflated and were followed by a relatively higher frequency of price reversals on the subsequent morning.
[23] The results are similar when same-day opening-closing returns instead of opening to (opening + 15 minutes).
[24] Barclay, Hendershott and Jones (2008) report more pronounced prices reversals following the opening on NYSE and NASDAQ on index derivatives expiration days. Schlag (1996) examines the effects of the expiration of derivatives on the DAX stock index in Germany. Futures contracts on DAX settle in cash based on the opening stocks prices on the expiration day. Schlag (1996) finds significant increases in return reversals around at open on the futures contracts' expiration days. Neither study explores the possibility of manipulation.

We also examined the effect of the modification in the opening mechanism on the correlations. Part B of Table 9 reports the averages of the coefficients of correlations before and after the modification. The price reversals on expiration days fell significantly after the modification both in absolute terms and relative to expiration days (and the results are slightly stronger for the post-modification period that ends in December 2001). The average correlation on expiration days fell from −0.59 to −0.36, and excess over the average correlation on other days fell from −0.42 to −0.25. In addition, the proportions of firms with less negative correlations after the modification are also significantly higher than one-half. In contrast, though the decline in price reversal on non-expiration days after the modification is significant at 2.5% for the period that ends in 2004, the decline for the period that ends on Dec. 2001 is not significant at conventional levels, and the proportions of firms with less negative correlations after the modifications are also not significantly different from one-half for either post-modification period.

Hence, we find clear evidence that on the price reversals on expiration days are significantly more pronounced on expiration days, and have become significantly less pronounced, both in absolute terms and relatively to non-expiration days, after the modification of the opening mechanism.

The second set of tests involves examining the absolute value of the rate of return from the opening price until 15 minutes later. If opening prices on expiration days are distorted, it should lead to a larger price reversal than on other days. Obviously, this reversal will sometimes be positive and at other times negative. Since we do not have options data, we cannot examine the magnitude of the price reversal conditional on options positions and prices. We, therefore, examine the absolute value of the price reversal. Both the manipulation and liquidity supply hypotheses postulate that the absolute value of this rate of return should be higher on options expiration days than on other days. Part A of Table 10 reports the results for the entire sample period divided into pre- and post-modification subperiods. The data reveal that the average of the absolute values of rates of return on options' expiration days fell by about one-half, from 1.10% before the modification to 0.54% after it, and the decline is statistically significant at near zero levels. Moreover, 16 of the 17 stocks experienced declines in the mean of the absolute values of their rates of return. The average across all stocks on the other days also fell significantly (at the 0.005 level) but by about 14% only. Examining the shorter post-modification period in Part B yields similar (again, slightly stronger) results for the returns on options expiration days. But, the decline in absolute returns on other days is only about one-half of its magnitude in Part A and is statistically indistinguishable from zero. Similarly, the difference between the mean absolute return on expiration days and other days is significant during the fixed period (0.54% with a t-statistic of 6.40 and near-zero p-value), and is positive for all firms. But, the difference becomes indistinguishable from zero after the modification (0.05% with a t-statistic of 1.66 and a 12% p-value - until July 2004, and −0.01% with a t-statistic of −0.20 - until Dec. 13, 2001).

To summarize, we find that the expiration of options is associated with opening stock prices that are distorted away from their true value, and that this distortion has declined significantly after the modification of the opening mechanism.

8. Further examination of the Manipulation Hypothesis

The expiration of the cash-settled options creates conditions that encourage manipulative orders, which obstruct the price discovery process during the preopening session, produce noisier and less informative preopening and opening prices, and distort the opening stock prices away from their true values. Taken together, our findings above are consistent with all of these predictions. Furthermore, the randomization of the opening time, which TASE implemented to hinder manipulation, has significantly improved the price discovery process and reduced excess volatility and price distortion.

But, there are other, not mutually exclusive, explanations for our findings. The evidence that preopening and opening prices on expiration days are noisier than on other days is also consistent with the assertion that it reflects the (non-manipulative) noise trading (e.g., rebalancing of stock portfolios) which accompanies the expiration of stock index options. Similarly, that opening stock prices on expiration days are distorted is also consistent with the view that liquidity suppliers require substantial price concessions to accommodate the large order imbalances created by these trades.

Undoubtedly, our findings do reflect the effects of non-manipulative stock orders and trades that accompany the expiration of index options. The question is whether they also reflect manipulative orders and trades. Because we do not have options data, we cannot test the manipulation hypothesis by examining the behavior of stock traders conditional on options positions and prices. To try to distinguish between the manipulation hypothesis and the noise trading and liquidity supply hypotheses, and test the assertion that our findings also reflect manipulation, we examine the preopening order flows before and after the modification.

The TASE has modified its opening mechanism in a way that hinders manipulation in the last minute or two before the opening of trade. Hence, to the extent that some of the orders near the opening were indeed manipulative, we would expect the modification to result in a decline in orders submitted in the last couple of minutes before opening. Moreover, given our findings that the modification has improved the price discovery process and the informational efficiency of preopening and prices in the last few minutes before the opening, we cannot think of any reason why the modification would discourage other traders from submitting orders in the last minute or two before the opening.[25] Hence, we argue that to the extent that our findings above *also* reflect manipulative orders, we should observe a decline in the fraction of orders submitted near the opening after the modification.

The changes in the timing of the order flow support the hypothesis that our findings above also reflect manipulation. Recall that the preopening period begins at 8:30 AM, but TASE starts publishing the order book at 9:00 AM. The first noticeable difference is that the average percentage of orders submitted before TASE started publishing the order book, rose considerably from 37% prior to the modification to 50% after the modification, and all firms have higher averages. Figure 4 charts the percentages of per-opening orders, per minute, before and after the modification. After 9 AM there are almost no meaningful differences in the order flow until 2 minutes before the opening. There are some noticeable differences in minutes 16 and 17, where all 17 stocks experience a smaller percentage order flow per minute, after the modification. Recall that this is immediately before cancellations are no longer accepted, unless, they have do not effect the theoretical price. Afterward, there are no meaningful differences, per minute, until the last 2 minutes before the opening. Prior to the modification, 15.2% of the orders were submitted during the final two minutes, and 9.4% were submitted in the last-minute. In contrast, after the modification, only 6.6% of the orders were submitted during the last two minutes, and only 3.2% in the last-minute. These differences are statistically significant at near zero levels and

[25] In Kumar and Seppi (1992) both informed and uninformed spot traders benefit from trading against manipulative orders and taking advantage of the liquidity that they provide. Hence, reduction manipulative orders can lead to reduction in orders by informed and uninformed traders. But, in this case they are reacting to declines in manipulative orders. Moreover, since we find that prices at and near the opening became more informative after the modification, it is unlikely that large declines in last minute orders by informed traders are the driving force behind our findings below.

all 17 stocks have lower percentages of orders in each of the last two minutes. They results show that the modification had a dramatic effect on timing of the order flow, and in particular, has drastically reduced the percentages of order submitted in the last to minute or two before the opening.

One may argue that the reduction in the percentage of orders submitted in the last 2 minutes is due to change in the timing of non-manipulative options related stock trades. The rationale is that the opening time after the modification (9:45-9:50) is, on average, 2-3 minutes later than the fixed opening time of 9:45 AM, and more importantly, the opening time after the modification is random. Since traders do not know in advance when the market will open, traders may continue to submit their options-related orders by 9:45 to avoid missing the opening of trade. Figure 4 suggests, however, that this is not the driving force behind the substantial change in the timing of the orders after the modification. As the Figure shows, percentage order submission before the modification has a tremendous spike in the last 2 minutes to open. In contrast, percentage order submission after the modification has no spikes with 5 to 3 minutes to open.

The changes in the timing of orders following the modification, therefore, confirm TASE's belief that manipulation on expiration days has helped distort opening prices. The desire to hinder manipulation in the last minute or two before the openings is the modification's raison d'être. The data imply that TASE has achieved its objective.

To summarize, the evidence is consistent with successful manipulation of opening prices on options expiration days during the period in which prices opened at a fixed time. The evidence further suggests that the modification of opening session has improved the ability of traders to react to orders submitted near the opening of trade, weakened the ability to manipulate the opening prices, and improved the informational efficiency of preopening and opening prices on options' expiration days.

Concerns about potential adverse effects of derivatives trading on the underlying markets, and in particular, the possible use of derivatives contracts to manipulate the derivatives and spot markets and the social costs of such manipulation, have existed since the inception of derivatives markets. Edwards and Edwards (1984), for example, describe how these concerns played an important role in US Congress activity and legislation since the Grain Futures Act of 1992, the first federal legislation aimed at futures markets; through the Commodities Exchange Act of 1982; and the establishment and changing roles and jurisdiction of the CFTC, SEC and Federal Reserve. The effects of cash-settled stock index futures and options, which began trading in the early 1980s, were of particular Congressional concern in the 1980s and 1990s.

The main social benefits of derivatives markets stem from their price-discovery and risk-shifting functions. Even if the prices of TA-25 options fully reflect the anticipated distortion of their settlement values, the risk of manipulation is likely to cause deviation from what would be the optimal allocation of resources in its absence. Jarrow (1994) develops a model in which the risk of manipulation introduces a random factor into the volatilities used to calculate option prices and into the hedge ratios (deltas). As a result, manipulation has adverse effects on the ability to use options to hedge, and on the use of volatilities implied in option prices as estimates of the volatility of the underlying asset.

The issue of whether the exchanges have the proper incentives to address potential abuses and self-regulate their markets or whether additional government regulation is needed, has been debated extensively by regulators, exchange officials and academics. Edwards and Edwards (1984), Easterbrook (1986) and Grossman (1986) are among the leading researchers advocating self regulation, whereas Pirrong (1995) presents the case for additional government regulation. Our evidence provides clear support for self-regulation. Our findings present an unambiguous case that TASE has successfully addressed the problems associated with the adverse effects of cash-settled stock index options contracts on the underlying stock market.[26]

9. Additional Tests of the Information Contained in the Order Book

In the sections above we investigated the informational efficiency of the preopening process using linear regressions to test the ability of equilibrium preopening prices to predict the opening prices. In this section we examine the informational efficiency of the preopening process using a different test methodology, which is based the price elasticities of the supply and demand curves emanating from the order book. As we will see below, the results of these tests complement and validate our findings above.

The additional tests are based on the thesis of Kalay and Wohl (2004) that price elasticities of the demand and supply curves reflect the degree of information embedded in the curves. Greater price elasticity indicates orders and prices that are based on more accurate information, whereas, inelastic demand and supply curves indicate higher levels of noise. Kalay and Wohl (2004) is related, inter alia, to the work of Madhavan and Panchapagesan (2000), Cornelli and Goldreich (2001) and Kaniel and Liu (2006) who document that informed traders tend to condition their trade size on the transaction price. Consistent with existing microstructure theory, Kalay and Wohl (2004) develop a model in which informed investors divide the size of their

[26] First, we should note that officials of TASE and the Israeli Securities Authority did consult with each other before modifying the opening session. Second, the stocks and options that we study trade on the same exchange, the TASE. Often, stocks and their derivatives trade on different exchanges. Competition provides exchanges with an incentive to self-regulate in order not lose trading volume. But, there can be conflict of interests between the options and stock exchanges, which may require government intervention. Merrick, Naik and Yadav (2005) examine manipulation in the UK bond markets. They find that differences in settlement-failure penalties in the futures and cash markets created conditions that favor squeezes. In their case, the Bank of England, which also trades in the bond market, changed its repo policy in the cash market to prevent squeezes.

orders in a manner that is consistent with linear demand and supply curves. In contrast, uninformed traders have inelastic supply and demand curves, because the quantity that they buy or sell does not depend on the price. Consequently, when the demand or supply curve is dominated by informed trades, it is relatively more price elastic. In contrast, when either curve is dominated by uninformed trades, it is relatively inelastic. Kalay and Wohl (2004) and Kalay, Sade and Wohl (2004) provide empirical support for these hypotheses. [27]

Based on these studies we postulate that the supply and demand curves calculated from the order book will be *less elastic* on options expiration days than on non-expiration days; and during the fixed-opening-time period than the random-opening-time period.

To test these hypotheses, we estimated the price elasticity (η) of the supply and demand curves derived from the order books as follows:

$$\eta = \left| \frac{(Q_1 - Q_0)/Q_0}{(P_1 - P_0)/P_0} \right| \qquad (4)$$

Where η is expressed in terms of absolute value; and $[(P_1 - P_0)/P_0]$ and $[(Q_1 - Q_0)/Q_0]$ are the percent price change and quantity change, respectively, calculated according to the closest values to the theoretical preopening prices *(P_0, Q_0)* in the order book at the time. Estimating supply and demand elasticity in this manner follows Kalay, Sade and Wohl (2004) method, which assumes that investors who have not placed orders during preopening remain out of the market at any price at this phase. Because they find that estimated elasticity values differ depending on whether one uses rising prices or falling prices, our calculations always use rising prices.

For each of the different subsamples, we estimated the demand and supply elasticities at the opening of trade and at four additional points of time prior to opening: at 9:15, 9:30, 9:35, and

[27] Kalay and Wohl (2004) findings are also related to the findings of Kandel, Sarig and Wohl (1999) that the return on shares in IPO auctions is positively correlated with the elasticity of the demand curve.

9:40 AM. Table 11 reports the results. The findings from the comparison of the estimated demand and supply elasticities are almost perfectly consistent with our earlier findings. First, both demand elasticity and supply elasticity are always substantially lower (in absolute values) on options' expiration days than on other days, and the differences are always significant at less than 0.001 p-values. The demand elasticities on non-expiration days are about 2.5-3.5 times larger than the demand elasticities on options' expiration days. The supply elasticities on non-expiration days are about 1.5-2.5 times larger than the demand elasticities on expiration days.

Second, both demand elasticity and supply elasticity are always higher (in absolute values) when opening prices were set at a random time than when opening prices were set at exactly 9:45 AM. The demand elasticities in the random-opening-time period are larger by about 20-30%, and the differences are always significant at the 0.012 p-value or lower. The supply elasticities are also always larger in the random-opening-time period, but the differences are statistically significant at the 5% level only at 9:15 AM and at the opening.

Another important finding is that the supply and demand curve elasticities in all subsamples always increase substantially over time as we approach the opening time, with one exception. The one exception is on options expiration days where the demand and supply elasticities calculated from the order book at the opening of trade are lower (in absolute values) than those estimated 5 minutes earlier at 9:40. Hence, we continue to find that the preopening process is generally a learning process with the information component increasing relative to the noise component as the opening time approaches. But, there is some evidence that orders submitted after 9:40 AM on options expiration days blur the information embedded in opening prices.

Cornelli and Goldreich (2003) who find that the elasticities of supply and demand increase on heavy trading days. In contrast, we find a significant decline in estimated elasticities on options expiration days when the trading volume (at the opening) is substantially higher than on non-expiration days. The difference between their results and ours suggest that the reason for the increase in trading volume, and the strategic trading behavior that results from it, play a critical role in whether higher trading volumes improve or worsen the informational efficiency of prices.

10. Conclusions

We study unique data from the Tel Aviv Stock Exchange (TASE), which enable us to explore in depth the price discovery process in the preopening period and the opening session. All the stocks in our sample are in the TA-25 index, which is the underlying asset of TASE's index options. The TA-25 index options are cash-settled European options whose settlement price is calculated using the opening prices of the constituent stocks on the expiration day. We find that options expiration has led to a tremendous increase in the number of orders submitted in the preopening period and the trading volume at the opening session. Yet, preopening and opening prices on expiration days are significantly noisier and less informative than on other days. We also find that some of the orders on expiration days appear to be manipulative and successful in obstructing the price discovery process and distorting the opening stock prices and settlement values of the index options.

In an attempt to alleviate these problems, TASE changed the design of its opening session. Until December 20, 2000 opening prices were set at exactly 9:45 AM. Starting in December 20, 2000, opening prices were set randomly between 9:45 and 9:50 AM. We find that this simple modification has succeeded in improving the informational efficiency of the preopening and opening prices. The modification has changed the rules of the game played by investors, manipulators and liquidity suppliers. It has increased the ability of informed investors to respond to last-minute orders and reduced the ability to manipulate the opening stock prices. The modification also helps index options traders settle their positions using prices that are closer to their true values. This should also increase the social benefits of the options by improving the hedging effectiveness and price discovery provided by the options.

Our findings have implications for equity and derivatives markets around the world as they face the challenges presented by expiration of stock index derivatives. Stock index derivatives contracts around the globe are typically settled in cash, based on the value of the underlying index at a predetermined time during the expiration day. Our study suggests that the cash-settlement of these derivatives can worsen the informational efficiency of stock prices and lead to manipulation of opening stock prices. TASE’s experience suggests a simple and effective way to reduce the adverse effects of the expiration of cash-settled derivatives contracts. Our findings should help exchanges develop and improve their trading mechanism and mitigate the stressful effects of extreme liquidity events. One of the key policy issues continuously debated by regulators, exchange officials and academics, is whether exchanges should self-regulate their markets or whether additional government regulation is needed. Our study presents an unambiguous case of successful self-regulation.

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Table 1
Determining the opening price on TASE

The priorities for executing sell orders are from a price limit of NIS 55, which has the highest chance of execution, to a price limit of NIS 58, which has the lowest chance of execution. Conversely, the priorities for executing buy orders are from a price limit of NIS 58, which has the highest chance of execution, to a price limit of NIS 55, which has the lowest chance of execution. The opening price is the price in which the highest trading volume is achieved. In Part A, the highest trading volume (500 shares) is achieved at the price of NIS 56. In Part B, a trader submit a new order to buy 200 shares at NIS 57, which raises the demand at 57 from 200 shares to 400 shares. As a result, the opening price increases to NIS 57, which has the highest trading volume of 600 shares.

<u>Part A</u>

		Supply Curve			**Demand Curve**		
Equilibrium Volume	**Price Limit**	**Cumulative Supply**	**Supply**	**Priority**	**Cumulative Demand**	**Demand**	**Priority**
200	55	200	200	1	700	200	4
500	**56**	**500**	300	2	**500**	100	3
400	57	600	100	3	400	200	2
200	58	800	200	4	200	200	1

<u>Part B</u>

		Supply Curve			**Demand Curve**		
Equilibrium Volume	**Price Limit**	**Cumulative Supply**	**Supply**	**Priority**	**Cumulative Demand**	**Demand**	**Priority**
200	55	200	200	1	900	200	4
500	56	500	300	2	700	100	3
600	**57**	**600**	100	3	**600**	400	2
200	58	800	200	4	200	200	1

Table 2
Sample Average Market Values and Trading Volumes

The table describes the average market values and the average daily trading volumes of all the stocks on the Tel Aviv Stock Exchange (TASE), the TA-25 index, and our sample of 17 firms. The TA-25 index includes the 25 firms with the highest market value. We study the 17 firms that were in the TA-25 throughout our sample period of January 2000-July 2004. The average daily exchange rate over the period was 1 NIS = 0.23 $US.

	Average market value (NIS, millions)	**Average daily trading volume (NIS, thousands)**	**Average daily trading volume (thousands of shares)**
TASE index of all stocks	262,683	323,500	18,363
TA-25	162,640	239,484	12,771
Our sample of 17 stocks	140,150	190,193	12,223

Table 3
Description of the preopening price discovery process

Average estimated betas in

$$\frac{V - E(V \mid I_0)}{E(V \mid I_0)} = \alpha_t + \beta_t [\frac{P_t - E(V \mid I_0)}{E(V \mid I_0)}] + Z_t$$

Where V is the day's opening price, $E(V \mid I_0)$ is the previous day's closing price (I_0 is the public information available before the preopening phase of trade), P_t is the theoretical preopening price at time t, and Z_t is the error term. The sample period is January 2000-July 2004.

Minutes before opening	**Average estimated betas**
45	0.059
30	0.105
15	0.236
10	0.329
5	0.543
4	0.603
3	0.684
2	0.760
1	0.855

The average betas are always significantly positive and smaller than one at the 5% level.

Table 4
Order flows and trades by options expiration and non-expiration day

	Expiration days	Non-expiration days	P-value of difference
A. Summary statistics of trades and cancelled orders (NIS, thousands)			
Average opening trading volume per company	18,226	391	0.000
Volume of cancelled orders until 9:30 (Average per company)	11,017	316	0.000
Volume of cancelled orders from 9:30 (Average per company)	1,799	184	0.004
Cancelled orders as percent of total volume: until 9:30	10.54	3.52	0.000
Cancelled orders as percent of total volume: from 9:30	1.42	1.69	0.140
Average total daily volume per company (NIS, thousands)	32,335	10,117	0.000
B. Order flow			
Minutes to opening	**Percent cumulative volume of orders by minutes before opening**		
45	50.35	16.06	0.000
30	57.77	31.75	0.000
15	69.11	53.57	0.000
10	75.12	64.22	0.000
4	85.85	80.89	0.000
3	89.04	85.60	0.000
2	92.37	89.69	0.000
1	96.07	94.63	0.000
Opening	100.0	100.0	

Table 5
The preopening price discovery process by options expiration and non-expiration days

See Table 3 for a description of β. P-values are for the differences between the two subsamples.

Part A: Average of firms' estimated beta			
Minutes to opening	**Expiration days**	**Non-expiration days**	**P-value**
45	0.007	0.128	0.001
30	0.036	0.178	0.000
15	0.127	0.294	0.001
10	0.216	0.376	0.004
9	0.282	0.404	0.031
8	0.393	0.432	0.240
7	0.417	0.459	0.266
6	0.494	0.498	0.895
5	0.535	0.544	0.715
4	0.547	0.608	0.005
3	0.646	0.688	0.006
2	0.676	0.770	0.006
1	0.804	0.862	0.028
Part B: Standard deviations of percent changes in betas during the preopening period			
Average of firms' standard deviations of percent changes in estimated betas:			
During 9:00-9:15 AM	0.011	0.013	0.214
During 9:15-9:30 AM	0.022	0.014	0.009
During 9:30-9:45 AM	0.094	0.046	0.000

Table 6

The preopening price discovery process: Average estimated betas by fixed and random opening times: January 2000-July 2004

See Table 3 for a description of beta. Before December 20, 2000 opening prices were set at the fixed time of 9:45 AM. Since then, opening prices were set randomly between 9:45-9:50 AM. P-values for the hypothesis that the difference is zero are in parentheses.

	Part A: Options expiration days			Part B: Non-expiration days			Part C: Non-expiration days minus expiration days		
Minutes to opening	Fixed time	Random time	Random minus Fixed	Fixed time	Random time	Random minus Fixed	Fixed time	Random time	Random minus Fixed
45	0.046	0.006	–0.040 (0.231)	0.130	0.127	–0.004 (0.364)	0.084 (0.029)	0.120 (0.000)	0.036 (0.259)
30	0.105	0.033	–0.072 (0.049)	0.192	0.174	–0.017 (0.185)	0.087 (0.031)	0.142 (0.000)	0.055 (0.133)
15	0.169	0.130	–0.039 (0.273)	0.312	0.288	–0.025 (0.059)	0.143 (0.000)	0.157 (0.000)	0.014 (0.416)
10	0.080	0.230	0.149 (0.024)	0.383	0.374	–0.008 (0.311)	0.303 (0.000)	0.145 (0.003)	–0.158 (0.024)
9	0.157	0.298	0.142 (0.027)	0.403	0.406	0.003 (0.432)	0.246 (0.000)	0.107 (0.030)	–0.139 (0.039)
8	0.134	0.419	0.284 (0.000)	0.433	0.435	0.002 (0.459)	0.298 (0.000)	0.016 (0.339)	–0.282 (0.000)
7	0.163	0.430	0.267 (0.000)	0.448	0.464	0.016 (0.131)	0.285 (0.001)	0.035 (0.199)	–0.251 (0.002)
6	0.238	0.514	0.276 (0.001)	0.492	0.501	0.009 (0.265)	0.254 (0.004)	–0.013 (0.355)	–0.267 (0.003)
5	0.220	0.561	0.341 (0.000)	0.525	0.553	0.027 (0.018)	0.305 (0.001)	–0.008 (0.372)	–0.313 (0.002)
4	0.213	0.570	0.358 (0.000)	0.569	0.628	0.058 (0.000)	0.356 (0.000)	0.057 (0.006)	–0.299 (0.001)
3	0.289	0.699	0.410 (0.000)	0.642	0.710	0.067 (0.000)	0.353 (0.000)	0.011 (0.203)	–0.342 (0.000)
2	0.367	0.739	0.372 (0.000)	0.712	0.801	0.089 (0.000)	0.345 (0.001)	0.062 (0.003)	–0.283 (0.006)
1	0.553	0.862	0.309 (0.000)	0.799	0.901	0.102 (0.001)	0.246 (0.001)	0.040 (0.016)	–0.207 (0.003)

Table 7
Informational efficiency of opening prices using prices observed 15 minutes later, by options expiration days and non-expiration days, segregated into fixed and random opening time.

Averages of firms' estimated coefficients in

$$\frac{V-E(V\mid I_0)}{E(V\mid I_0)}=\alpha+\beta\,[\frac{P_t-E(V\mid I_0)}{E(V\mid I_0)}]+\gamma_1\{[\frac{P_t-E(V\mid I_0)}{E(V\mid I_0)}]D_1\}+\gamma_2\{[\frac{P_t-E(V\mid I_0)}{E(V\mid I_0)}]D_2\}+\gamma_3\{[\frac{P_t-E(V\mid I_0)}{E(V\mid I_0)}]D_3\}+Z_t$$

Where V is the price observed 15 minutes after the opening, $E(V\mid I_0)$ is the previous day's closing price, P_t is the opening price, and Z_t is the error term. The sample period is January 2000-July 2004. Before December 20, 2000, opening prices were set at the fixed time of 9:45 AM. Since then, opening prices were set at a randomly chosen time between 9:45-9:50 AM. The dummy variable D_1 is for the period before the modification. The dummy variables D_2 and D_3 are for option's expiration days before and after the modification, respectively.

Options expiration days				**Non-expiration days**				**Non-expiration days minus expiration days**			
Fixed ($\beta+\gamma_2$)	Random ($\beta+\gamma_3$)	Random minus fixed (p-value)	Fraction of firms with improved information (p-value*)	Fixed ($\beta+\gamma_1$)	Random (β)	Random minus fixed (p-value)	Fraction of firms with improved information (p-value*)	Fixed (p-value)	Random (p-value)	Random minus fixed (p-value)	Fraction of firms with improved information (p-value*)
Part A: Entire sample (Random opening time period: December 20, 2000-July 29, 2004)											
0.621	0.847	0.226 (0.000)	16/17 (0.000)	0.861	0.922	0.061 (0.008)	11/17 (0.225)	0.240 (0.000)	0.075 (0.000)	0.165 (0.000)	14/17 (0.008)
Part B: Equal periods before and after the modification (Random opening time period: December 20, 2000-Dec. 13, 2001)											
0.619	0.865	0.246 (0.000)	16/17 (0.000)	0.862	0.894	0.032 (0.128)	12/17 (0.090)	0.243 (0.000)	0.029 (0.115)	0.214 (0.000)	16/17 (0.000)

* - The p-value is for testing the null hypothesis that the fraction is ½.

Table 8
The effects of the modification of the opening mechanism on the standard deviation of the rates of return

	OPTIONS EXPIRATION DAYS				NON EXPIRATION DAYS			
	Average standard deviation				Average standard deviation			
	Close-to-open (A)	Close-to-15 minutes after open (B)	Excess volatility at open (A–B) (P-value)	Fraction of firms with noisier Close-to-open (p-value*)	Close-to-open (C)	Close-to-15 minutes after open (D)	Excess volatility at open (C–D) (P-value)	Fraction of firms with noisier Close-to-open (p-value*)
Before modification: (January 3, 2000-December 19, 2000)	2.4003	1.8936	0.5068 (0.000)	16/17 (0.000)	1.4244	1.5766	–0.1522 (0.000)	0/17 (1.000)
After modification:								
December 20, 2000 – July 29, 2004	1.7241	1.6157	0.1084[a] (0.000)	15/17[b] (0.002)	1.1705	1.3277	–0.1571 (0.000)	0/17 (1.000)
December 20, 2000 – Dec. 13, 2001	1.8998	1.7709	0.1289[a] (0.002)	13/17[b] (0.029)	1.2997	1.4283	–0.1286 (0.000)	0/17 (1.000)

* - P-value is for the null hypothesis that the fraction is ½.
[a] - The decline after the modification in average excess volatility is statistically significant at 0.002.
[b] - The proportion of firms with lower excess volatility after the modification is significantly higher than ½ at the 0.008 level.

For non-expiration days: The changes in excess volatility after the modification are statistically indistinguishable from zero, and the proportion of firms with a decline in excess volatility is statistically indistinguishable from 1/2.

Table 9
Averages of estimated coefficients of correlation between rates of return from the previous day's close to today's open and rates of return from today's open to 15 minutes later.

Options expiration days (A)	**Non-expiration days** (B)	**Difference** (A–B) (P-value)	**Fraction of firms with more negative correlation on expiration days** (p-value of different from 1/2)
Part A: Entire sample(January 3, 2000- July 29, 2004)			
–0.443	–0.132	–0.3116 (0.000)	17/17 (0.000)
Part B: Before and after the modification of opening mechanism			
Fixed opening time (January 3, 2000-December 19, 2000)			
–0.590	–0.175	–0.416 (0.000)	16/17 (0.000)
Random opening time			
December 20, 2000 – July 29, 2004			
–0.364 [a,b]	–0.113 [c]	–0.251 [a] (0.000)	17/17 (0.000)
December 20, 2000 – Dec. 13, 2001			
–0.347 [a,b]	–0.151	–0.195 [a] (0.000)	14/17 (0.008)

[a] – Significantly lower than before the modification at less than 1%.

[b] – The correlations became less negative after the modification for at least 13 firms, which is significantly higher than ½ at the 3% level.

[c] – Significantly lower than before the modification at less than 3%.

The proportion of firms with less negative correlations after the modification, on non-expiration days, is statistically indistinguishable from 1/2.

Table 10
Absolute values of rates of return from the opening minute until 15 minutes later, by options expiration days and other days, segregated into fixed and random opening time.

The sample period is January 2000-July 2004. Until December 20, 2000, opening prices were set at the fixed time of 9:45 AM. Starting on December 20, 2000 opening prices were set at a randomly chosen time between 9:45-9:50 AM. The returns are in percent and are not annualized.

Averages of absolute values of rates of returns							
Part A: Entire sample (Random opening time period: December 20, 2000-July 29, 2004)							
Options expiration days: Fixed versus random opening time				**Non-expiration days: Fixed versus random opening time**			
Fixed	Random	T-statistic of change (p-value)	Fraction of firms with declines in mean absolute returns (p-value*)	Fixed	Random	T-statistic of change (p-value)	Fraction of firms with declines in mean absolute returns (p-value*)
1.10	0.54	6.347 (0.000)	16/17 (0.000)	0.56	0.49	3.264 (0.005)	13/17 (0.029)
Part B: Equal periods before and after the modification (Random opening time period: December 20, 2000-Dec. 13, 2001)							
Options expiration days: Fixed versus random opening time				**Non-expiration days: Fixed versus random opening time**			
Fixed	Random	T-statistic of change (p-value)	Fraction of firms with declines in mean absolute returns (p-value*)	Fixed	Random	T-statistic of change (p-value)	Fraction of firms with declines in mean absolute returns (p-value*)
1.10	0.52	6.718 (0.000)	17/17 (0.000)	0.56	0.53	1.526 (0.147)	13/17 (0.029)

* - P-value is for the null hypothesis that the fraction is ½.

Table 11

Average price elasticities of the supply and demand curves in the order book:
Options expiration days versus non-expiration days,
and fixed opening time versus random opening time.

The elasticity is calculated as $\eta = \left|\frac{(Q_1 - Q_0)/Q_0}{(P_1 - P_0)/P_0}\right|$, where $(Q_1 - Q_0)/Q_0$ is the percent quantity change and $(P_1 - P_0)/P_0$ is percent price change, as calculated according to the closest values to equilibrium *(P_0, Q_0)* in the order book at the time.

Part A: Average Demand Elasticities

	Options expiration days versus non-expiration days				**Fixed versus random opening time**			
	Expiration days	**Non-expiration days**	**Difference**	**P-value**	**Fixed**	**Random**	**Difference**	**P-Value**
$\eta_{T=9:15}$	33.20	118.43	–85.23	0.000	97.98	116.64	–18.66	0.003
$\eta_{T=9:30}$	61.63	144.73	–83.10	0.000	125.01	143.02	–18.01	0.012
$\eta_{T=9:35}$	63.13	155.63	–92.50	0.000	121.05	155.81	–34.76	0.000
$\eta_{T=9:40}$	71.65	179.32	–107.67	0.000	147.61	178.12	–30.51	0.000
$\eta_{T=open}$	64.26	208.31	–144.05	0.000	168.49	206.26	–37.77	0.000

Part B: Average Supply Elasticities

	Options expiration days versus non-expiration days				**Fixed versus random opening time**			
	Expiration days	**Non-expiration days**	**Difference**	**P-value**	**Fixed**	**Random**	**Difference**	**P-Value**
$\eta_{T=9:15}$	46.02	104.89	–58.87	0.000	90.93	103.65	–12.72	0.021
$\eta_{T=9:30}$	68.23	123.54	–55.31	0.000	112.56	122.07	–9.51	0.103
$\eta_{T=9:35}$	72.93	135.95	–63.02	0.000	131.31	133.05	–1.74	0.789
$\eta_{T=9:40}$	96.49	149.72	–53.23	0.000	143.39	147.64	–4.25	0.537
$\eta_{T=open}$	75.66	189.44	–113.78	0.000	169.41	186.02	–16.61	0.032

The P-values are for the null hypothesis that the elasticities are equal.

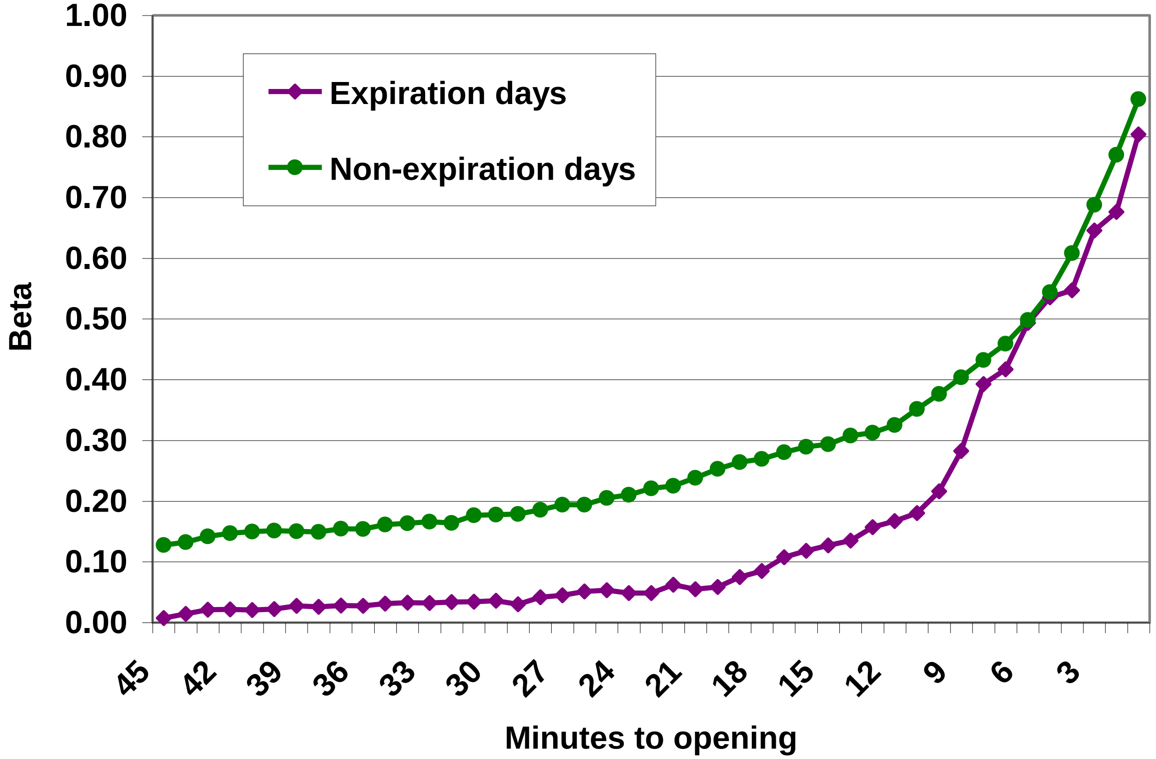

Figure 1. Average estimated betas by minutes to opening: Options expiration days versus non-expiration days

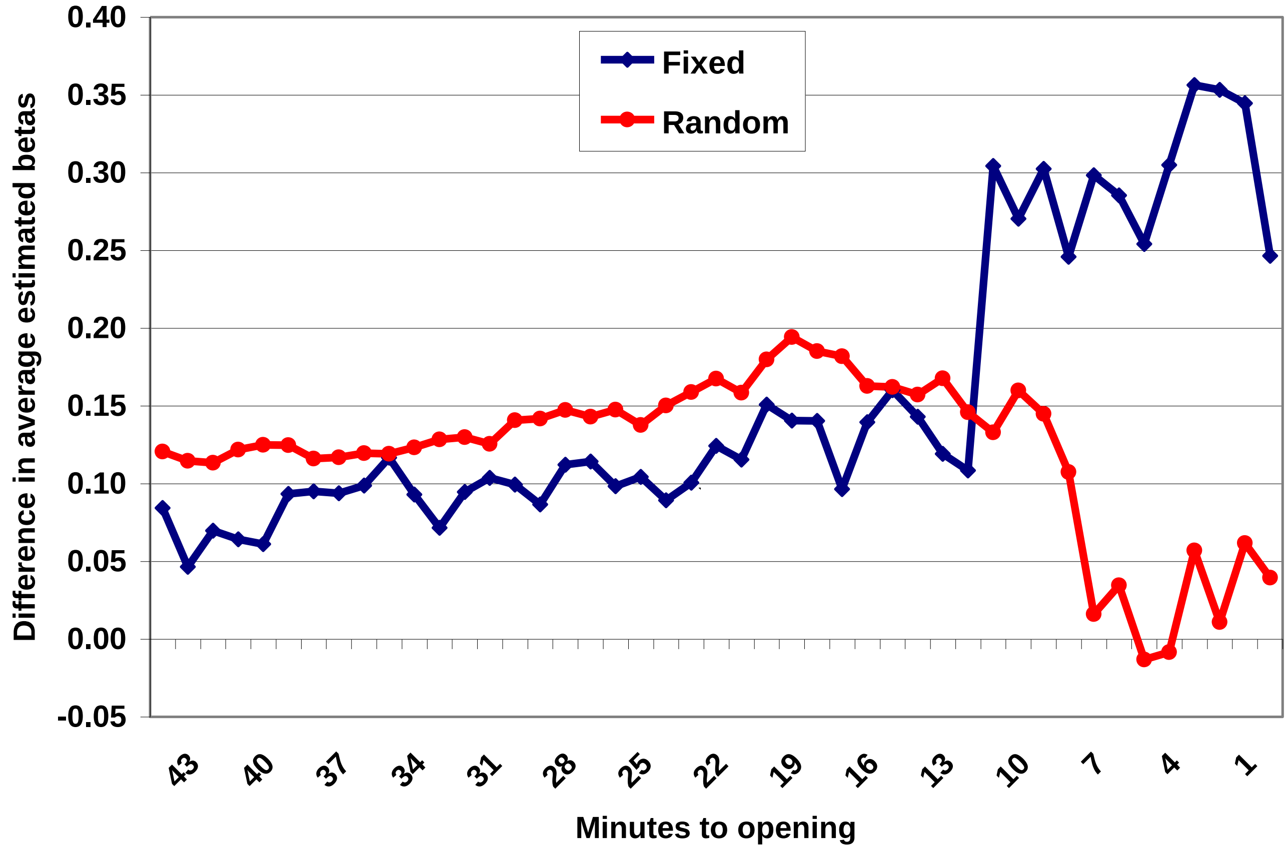

Figure 2. Average estimated betas on non-expiration days minus average estimated betas on options expiration days, by periods of fixed and random opening times

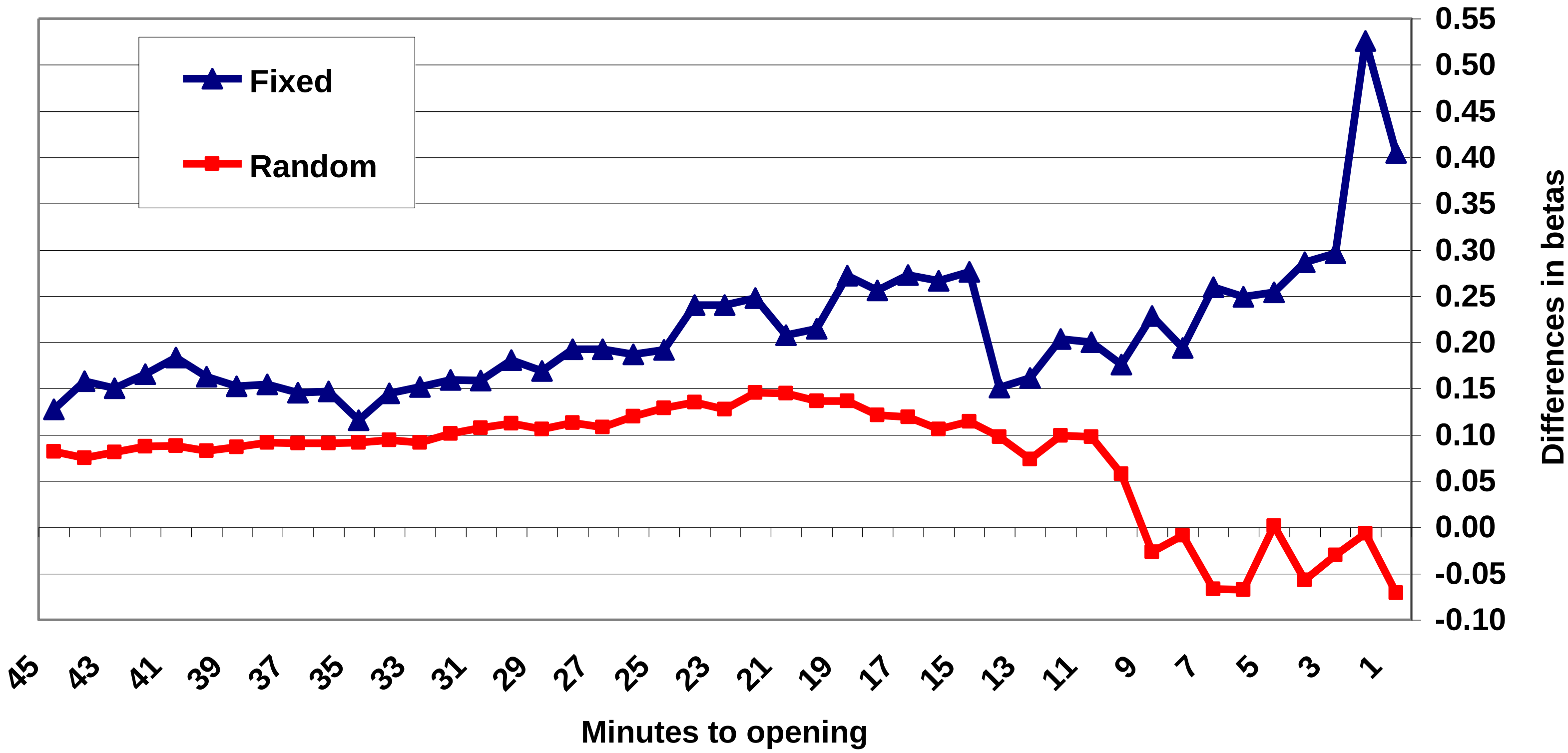

Figure 3. Average estimated betas on non expiration days minus average estimated betas on options expiration days, by periods of fixed and random opening times, using stock prices 15 minutes after the opening as equilibrium values

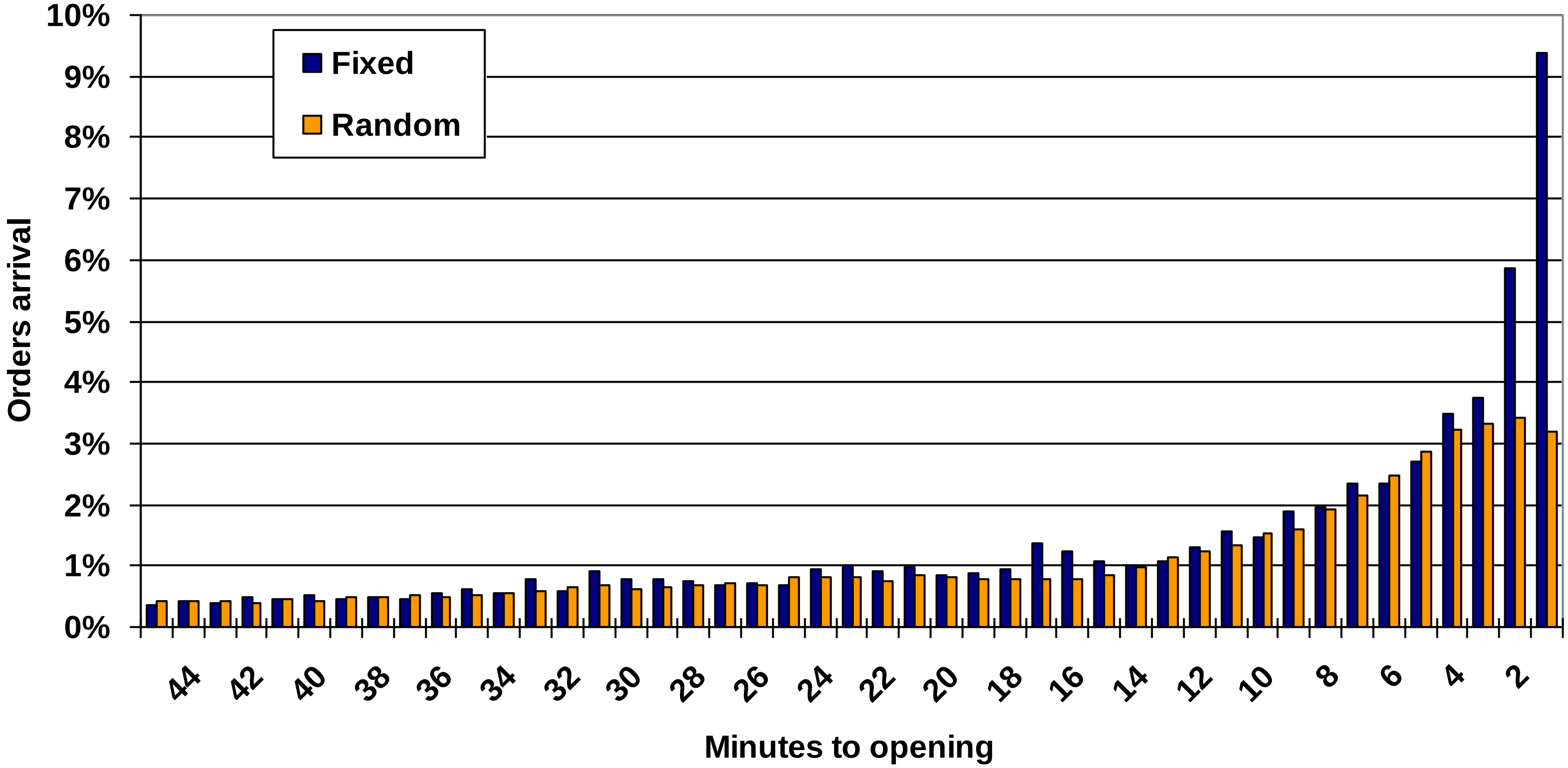

Figure 4. Percentage of orders arrival per minute, by periods of fixed and random opening times