Price Discovery during Parallel Stock-Option Preopening:

An Improvement or Ground for Manipulation? ‡

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JEL Codes: D84, G12, G13, G14.

‡ We are thankful to Luigi Zingales, Yakov Amihud ,Jacob Sagi and participants at seminars/conferences at the IDC Herzliya IL, Surrey University UK, for helpful and insightful comments. Any remaining errors are ours.

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ABSTRACT

Many stock exchanges worldwide have long suspected that manipulative orders distort informative pricing during the pre-opening trading session. Using a unique dataset, this paper is the first to explore empirically the presence of illegal manipulation based on Kyle and Viswanathan's (2008) criteria. They render manipulation 'illegal' if both informational (prices) and transactional (liquidity) efficiencies are deprived. We compare the indicative stock market index with the options-implied index, revealing significant price differences and illiquidity patterns similar to those predicted by theoretical models of manipulation. While prosecuting involved traders seems rather challenging, we suggest a few regulatory changes that may alleviate the problem.

May 7, 2014

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Introduction

Manipulation in security prices is deemed illegal for a number of reasons, where the most commonly studied is the distortion of *allocational efficiency* through the manipulator's impact on prices. A recently discussed effect of manipulation is its adverse impact on liquidity, thereby hampering a market's *transactional efficiency*, which is key for risk transfer. While there is an ongoing debate on the specific criteria that render price manipulation illegal, Kyle and Viswanathan (2008, KV) suggest an operational approach. Their approach is consistent both with the US case law paradigm, and with the EU and UK definitions of manipulation that focus on violations of codes of conduct. KV define 'illegal price manipulation' as an event that meets two criteria: both the informational *and* transactional efficiencies must be shown to have been deprived.[1] This definition applies for different types of manipulation, like corners, squeezes, and other "trade-based" manipulation. The latter are defined by Allen and Gale (1992) as those involving trading activities. This paper appears to be the first to use KV's definition in order to empirically identify illegal trade-based manipulation, and measure its magnitude. Using a unique dataset, we analyze data from two markets of the Tel-Aviv Stock Exchange (TASE) during the pre-opening session: First, the stock market, where no actual trade occurs before the daily opening but indicative (hypothetical) prices and volume are published based on orders and quotes in a tâtonnement process. Second, we use *actual* trading data in the market for European index-options, whose underlying asset value is the indicative stock market index. As a result, orders in the stock market affect the value of traded options. We compute the implied underlying index in the options market, compare it with the indicative price, and analyze stock's liquidity before and

[1] While the US system requires a proof of intention to affect prices, KV assert that if both notions of efficiency were deprived, the trading patterns and/or other actions that harmed efficiency should be considered illegal. See Fischel and Ross (1991) and references in Kyle and Viswanathan (2008) for further discussion on this delicate issue.

after the pre-opening phase. We find persistent patterns that are consistent with illegal price manipulation. Such patterns are most severe on expiration days.

To illustrate the manipulation mechanism on expiration days, consider a case where today is an expiration day, and the last trading day in those options ended yesterday, at closing. Today's opening index level, which is determined at the end of the preopening phase, will determine whether options expire in- or out-of-the money. All traders that have call options with exercise price *X* have an incentive to bid up some or all of the 25 stocks that make the index to levels as higher above *X* as possible. Those orders are costless, and may be cancelled before the preopening phase ended, or afterwards. Equivalently, put options holders have an opposite incentive; therefore, exceptionally high orders and cancellations volume are expected in the stock market, aiming to gain in the options market. Similar incentives, with minor differences in execution, exist on non-expiration days for holders of naked options positions.

A number of theoretical models conclude that manipulation is rational given a positive probability for the presence of an informed manipulator among traders. Moreover, manipulation is more profitable and less risky when liquidity is low.[2] A particularly relevant theoretical model has been presented by Medrano and Vives (2001, MV) to explore conditions for manipulation and its impact on market activity during a preopening trading phase similar to the one studied here. MV's choice of the specific preopening procedure is not incidental: it is implemented in

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[2] Allen and Gale (1992) show that if investors attach a positive probability for the manipulator to be informed, manipulation may be profitable. Jarrow (1994), shows that a large trader has an incentive to manipulate prices if options are introduced to an otherwise arbitrage-free market. Similarly, Horst and Naujokat, (2011) show that gains can be earned in the options market by manipulating the underlying asset in a multi-player strategic trade. Chakraborty and Yılmaz (2004, 2008) conclude that in the presence of both informed and uninformed traders, informed traders have an incentive to increase noise and manipulate prices in all equilibria, provided there remain sufficiently many periods to trade. Goldstein and Guembel (2008) obtain comparable results in a model where a firm plans to invest in real projects but manipulators have incentive to distort relevant information.

many stock exchanges around the world, including most European exchanges, NYSE, Tokyo, Singapore, Taiwan, and others, among them TASE. To demonstrate the ways such exchanges cope with preopening manipulation, we present key properties of TASE procedures.

During the preopening phase, investors may submit, modify, and cancel buy\sell orders in much like a tâtonnement process. While there is no actual stock trading during this phase, the exchange publishes indicative price and volume data for each stock whenever the book is changing. It further publishes the indicative index every 30 seconds. The auction algorithm used to calculate those indicative price and volume data is identical to the one used to calculate the opening price itself. The opening price is the only price at which orders in the book clear and is the one that determines options' values on expiration days. The purpose of this preopening algorithm is to reduce price uncertainty after the market has been closed overnight, with the expectation that toward the opening the process will approximately converge to the informationally-efficient price (Biais, Hillion, and Spatt, 1999).

The opening auction occurs at a random time, expressly to mitigate manipulation.[3] Indeed, some argue that such a price discovery process might be susceptible to manipulation, primarily because traders can modify or cancel orders at no cost (Stoll and Whaley, 1990 and Madhavan and Panchapagesan, 2000). A formal analysis of this argument was conducted by MV. Their model implies that in the presence of manipulation, high trading volume is expected at the beginning, and toward the end of the preopening session, graphically represented by a U shape curve of volume over time.

[3] Exchanges in Germany, Austria, and Ireland write: *"The call phase has a random end after a minimum period in order to avoid price manipulation"*. The stock exchange in Spain wrote *"Random Auction End: for a 30-second period the auction may be concluded at any moment without prior warning. This is to reduce price manipulation"*.

Our identification of manipulative activity builds on the following notions. First, as MV and others postulated, a preopening procedure in which traders cannot actually trade but merely submit orders and cancel them, poses execution risks that might prohibit 'serious' orders (i.e., non-manipulative orders) from being placed. MV argue that problems in the communication channel (broadly defined) might render order modification or cancellation impossible or late, exposing the trader to risks that are not present during the continuous trading session, after the opening. Moreover, if the trader attempts to form a position that involves several transactions, but one or a few are not executed, this trader ends up facing high risks. In MV's model the manipulator is risk neutral, therefore such risks do not affect the incentives to manipulate. However, in the presence of 'limits to arbitrage'[4], manipulation is not riskless and might be bounded. Our first argument therefore is that the ability to hedge an order that has been placed in the stock market by an actual position in the options market increases the likelihood of manipulation.

Second, once the indicative stock price has been manipulated, there is no need to manipulate option prices, because this would increase manipulation risks. Moreover, because the options market is populated by informed traders of comparable size (i.e., there are no dominant investors), and the likelihood of noise trading is low, no options trader has an incentive to manipulate options prices. Therefore, if stock prices are indeed manipulated, there must be a significant difference between the indicative stock index and the index implied from at-the-money options.

[4] There are a number of arguments suggesting limits to arbitrage, among them the presence of noise traders (De Long, Shleifer, Summers, and Waldmann, 1990), which are present in MV's model, high risk-aversion of portfolio owners (Shleifer and Vishny, 1997), and synchronization problems (Abreu and Brunnermeier, 2003).

To meet both of Kyle and Viswanathan's criteria that deem manipulation 'illegal', we must demonstrate that not only prices are distorted, but that liquidity is lower than a reference level. We take this reference to be the average liquidity of the opening, and 15 minutes later. Our illiquidity measure is based on Amihud (2002), and it uses indicative returns and volume data.[5] Based on MV's U-shaped expected volume in the presence of manipulation, we expect to find an inverted U-shape curve of illiquidity, since volume enters Amihud's measure through the denominator.

Our null hypothesis is that the underlying index value implied from at-the-money index options will not deviate systematically from the indicative TA-25 index. We therefore calculate the percentage gap between the options-implied index and the indicative index. Based on it we calculate the mean absolute daily gap as the average across all intra-daily at-the-money options transactions written on this index between the open and close. Next, we calculate the "Excess-gap" (*Egap*), measured as the difference between absolute current gap and the mean absolute daily gap every 30 seconds, from 15 minutes before to 15 minutes after the opening. We analyze the time-series patterns of *Egap*, its interactions and causality with different explanatory factors, and with illiquidity. We made use of about 81 million observations throughout the sample period, 2005 and 2009.

We find that *Egap* starts at about 35 basis points 15 minutes before the opening, it gradually declines toward the opening, virtually disappearing after the opening and remains nil throughout the trading day. That pattern is pronounced on options expiration days where the pre-opening *Egap* is about seven folds that of non-expiration days.

[5] Indicative price and volume are calculated for each stock as the intersection of aggregate demand and supply that constitute the book, and maximize volume.

If the preopening indicative index has been manipulated, one would expect a reversal after the opening. We conduct lead-lag tests between the options-implied and the TA-25 index returns by a vector error correction model (VECM). We find that during the preopening phase, the indicative index is led (Granger-caused) by the options-implied index by about 2.5 minutes, and the latter is not serially correlated. This implies that information is revealed faster in the options market. After the opening, the options-implied index leads the actual index by about 1 minute, with an order of magnitude higher coefficients and an opposite sign. This finding highlights the rapid reversal immediately after the opening. Moreover, to avoid actual buying or selling, manipulators either close prior positions or cancel manipulative orders in the stock market. Consistent with MV's model, if stock prices were manipulated, high trading volume and order cancellation are expected five minutes prior to the opening time, as the exchange restricts cancellation thereafter. Indeed, we find that order cancellation is a highly significant explanatory variable of reversal.

While large *Egap* and price reversal capture the first criterion in KV's test for illegal manipulation, one of our unique additions refers to liquidity effects during the pre-opening phase. As noted, we measure illiquidity by applying Amihud's (2002) *ILLIQ* to each of the 15 minutes before and after opening. We use the exchange-published indicative rate of return and indicative volume, and regress *ILLIQ* on *Egap*. The regression slope coefficient is indeed positive and highly significant as long as order cancellation is not restricted (between minutes -15 to -5 before the opening, minute 0). This suggests that on average, days with high illiquidity were also characterized by high *Egap* values. The first 10 minutes of the preopening phase are highly illiquid, and obey the inverted U-shape that is expected in the presence of manipulation. Starting slightly more than five minutes before the opening, where order cancellation is restricted, the regression coefficients of illiquidity decline by about an order of magnitude relative to its initial level and turning insignificantly different from zero. This finding is consistent with KV's criterion for illegal manipulation.

We extend the analysis and examine price-reversal and illiquidity effects on options' expiration dates as well, finding that reversal is three times more intense on expiration days and illiquidity about two orders of magnitude higher. This may stem from the more aggressive orders that manipulators submit as manipulation on expiration days is more profitable.

Lastly, one may wonder why such profitable trades would persist for so many years. One explanation is that large informed investors have an economically justifiable incentive to act this way, therefore regulators cannot prove in court that the suspected manipulative trades were illegal. Alternatively, the answer would involve the relatively sophisticated level of trading practices that manipulators must apply, and are not accessible to small informed investors: the need to calculate the implied index continuously and in real-time, and the need to trade large quantities in both markets.[6]

The rest of the paper starts by a detailed presentation of the data and methodology in Section 1, the results are discussed in Section 2 and Section 3 summarizes.

1. Data and methodology

1.1. Data and summary statistics

Our dataset includes all intra-daily at-the-money call and put options transactions whose underlying asset is the TA-25 index between January 2nd 2005 and December 31st 2009. The TA-25 is a value-weighted index of the biggest 25 stocks in the market, with weight limit of 10%. We account for all options transactions starting at the pre-opening phase, into the continuous trading phase, and until the closing. After filtering-out transactions with strike-prices residing outside the

[6] We thank Luigi Zingales for highlighting this point.

range of ±30 points from the current underlying index[7] the remaining dataset constitutes more than 81,000,000 options transactions. Using put-call-parity, we retrieve the options-implied underlying index, and compare it with the stock-market index. The latter is an "indicative", or hypothetical index before the stock market opens, and actual thereafter. Before the opening, it is calculated based on submitted, but not executed, supply and demand orders for each of the 25 stocks that make the index. Actual trade in stocks is allowed only after the opening, therefore from this time onward the index is "actual" rather than "indicative". The opening price is the one by which orders in the book are cleared. Additional data include the riskless interest rates and the indicative stock trading volume that the exchange publishes every 30 seconds. The riskless interest rates were adjusted to the remaining expiration time of the options. All data items were extracted from the official historical data release files provided by the exchange.

The pre-opening, indicative-index as well as the post-opening, actual-index are calculated by the exchange along a number of rules. The more relevant ones are: (1) Before the opening, the TASE calculates and releases the indicative index level and its associated turnover from 9:10 a.m. until a random opening time, between 9:45 and 9:50 a.m. (2) The indicative index values are provided together with all buy and sell orders, as well as cancelled orders, throughout the preopening phase and thereafter. (3) Order cancellation is restricted after 9:40. (4) Options start trading on 9:30, and unlike the stock market, actual trade is allowed.

Table 1 and Figure 1 offer a concise view of key data. The sample period includes the years 2005-2007 before the outbreak of the sub-prime crisis, 2008 in which returns fluctuated severely ending the year -39% below the opening index, and 2009 where the index rebounded +70%.

[7] Similar filtration rules were applied by Bakshi et al. (1997), Dumas et al. (1998), and they are relevant to our case as well.

Panel A of Table 1 shows that during this period standard deviations of daily returns and daily trading volume surged in 2008 to unprecedented levels. Panel B of Table 1 shows that the number of order cancellations on expiration days is significantly higher than the number of order cancellations on non-expiration days (almost five-fold). This finding indicates that the number of order cancellations may be related to a higher level of manipulation during the preopening phase. Because no trade takes place in the stock market during the 35-40 minutes before the opening, but options do trade during the 15-20 minutes prior to opening (depending on the random opening time), it is possible that indicative stock prices were manipulated. This issue is detailed below.

[Table 1]

[Figure 1]

1.2. Variables construction

To explore differences between the option-implied underlying index[8], denoted SI_t, and the stock market index, denoted by S_t, we use Put Call Parity (PCP):

$$SI_t = C_t - P_t + \frac{X}{(1+r)^{T-t}}, \qquad (1)$$

where C_t and P_t the call and put prices at time *t*, respectively; *X* is the strike price, and *T*-*t* is time to expiration. To calculate the implied index value based on traded options we use put and call pairs as long as their transaction prices are within the range of ± 15 seconds away. This filter leaves us with more than 31,000,000 options pairs. Table 2 shows the number of PCP pairs across our sample years, 2005-2009.

[Table 2]

[8] European index-options, no dividends, whose underlying asset value is determined by quotes in the stock market

Based on the implied index calculated in (1) we calculate the gap between the index value at time *t*, S_t, and SI_t,

$$Gap_t = \frac{SI_t}{S_t} - 1. \tag{2}$$

Next, we calculate the mean absolute value of the gap each day from open to close, $\overline{|Gap|}_{open \to close}$. Based on these, we calculate at each time interval *t*, from 15 minutes before to 15 minutes after the opening the excess gap, denoted $Egap_t$, as an absolute value beyond $\overline{|Gap|}_{open \to close}$, as follows:

$$Egap_t = |Gap_t| - \overline{|Gap|}_{open \to close}. \tag{3}$$

The frequency of calculating $Egap_t$ was thirty seconds, to allow robust time-series tests.

1.3. Volatility-reducing opening procedure

The pre-opening trading phase has been suspected for being subject to manipulation in many countries. As a result, some exchanges (e.g., England, Germany, Spain, Switzerland, and the Scandinavian exchanges), end the preopening phase at a random time. The random addition to the formal preopening time often ranges 0-30 seconds but can be as long as 5 minutes (TASE). The expressed purpose of the random opening time is to prevent or mitigate manipulative buy or sell orders. The TASE prohibits order cancellation starting from five minutes before the random time extension starts, and until the opening. In June 2008, the TASE modified the opening procedure in a way that is aimed to reduce the opening price volatility by further extending the opening time if the absolute index return is greater than 2.5% vs. the previous close. The goal of the extension is to let investors more time to consider their trades, increase liquidity and make it harder for traders to impinge on the indicative price.[9] Therefore, we test whether this regulatory change affected the magnitude of manipulation.

1.4. Price reversal

If pre-opening prices are manipulated, then immediately after the opening one may expect a reversal. Accordingly, we test the interaction between factors that seem to be relevant for the level of *Egap* and the presence of price reversal. These factors include: 1) the level of uncertainty in the market, as measured by the volatility index VIXTA[10]; 2) the number of order cancellations; and 3) we control for the change in the volatility-reducing opening procedure of June 2008 by introducing a dummy variable. We distinguish between ordinary trading days and options expiration days by introducing an additional dummy variable.

We test the price reversal hypothesis using a *Logit* regression whose dependent variable is a dichotomous variable of 1 (if there was a price reversal) and 0 otherwise. We define two variables for this test: First, $R_1 = S_0 / S_{close} - 1$ is the TA-25 rate of return between the opening price (S_0) and the closing price of the previous day (S_{close}). Second, $R_2 = S_{+15MIN} / S_0 - 1$ is the rate of return between the TA-25 index 15 minutes after opening and its value at the opening. We compute the correlation between R_1 and R_2 on all trading days, and separately on expiration days. We estimate price reversal by the regression equation

[9] The new procedure is implemented in the following manner: (1) If an order arrives that changes the indicative index in excess of 2.5% away from the previous day's closing, the preopening phase will be automatically extended by three to five minutes, randomly. At the end of this first extension, another attempt will be made to determine the opening price. (2) If the expected change in the indicative index remains higher than 2.5%, the preopening phase is again extended by three to five minutes. (3) If the expected index change is still higher than 5%, the opening is postponed by 45 minutes. (4) If the expected index change after the third extension is lower than 12%, the opening price will be set and trading will begin.

[10] VIXTA is calculated based on the standard deviations implicit in at-the-money options on the TA-25 index, like the VIX on the SP500. It is calculated by Aonline along with Ono Academic College.

$$R_2 = \alpha + \beta_1 R_1 + \beta_2 D_1 + \beta_3 (R_1 * D_1) + \beta_4 D_2 + \beta_5 (R_1 * D_2) + \varepsilon, \tag{4}$$

where D_1 is a dummy variable that assumes the value 1 on expiration days and 0 on ordinary days. D_2 is a dummy variable that assumes the value 1 after the volatility-reducing opening rule was implemented and 0 beforehand. $\beta_1 < 0$ is an indication of a negative correlation between R_1 and R_2 on all trading days. $\beta_2 < 0$ and/or $\beta_3 < 0$ support the hypothesis that the correlation is more negative on expiration days, and suggesting a stronger price reversal on these days.

1.5. Liquidity

We use the popular and robust measure of illiquidity developed by Amihud (2002) to analyze the interaction between illiquidity and *Egap*. Amihud's *ILLIQ* measure is given by

$$ILLIQ_m = \frac{|R|_m}{\sum_{i=1}^{n} Vol_{im}} = \frac{|R|_m}{Vol_m}, \tag{5}$$

where $Vol_m = \sum_{i=1}^{n} Vol_{i,m}$ is monetary volume (i.e., units times price), and $|R|_m$ is the absolute index return between minutes *m*-1 and *m*. The parameter *n* represents the number of stocks included in the TA-25 index on the relevant day (ranges 24 to 27, mode=25). Indicative volume before the opening, as well as actual volume after the opening, is calculated as the sum of monetary volume for all stocks included in the TA-25 index on the specific day, *n*. The rate of return between successive minutes, at *m-1* and *m*, is calculated by $|R|_m = |(S_m/S_{m-1}) - 1|_m$, where the index values S_m and S_{m-1} are the farthest within the minute as possible.

Given the data, we assume a linear functional relationship between *ILLIQ* and *Egap*, and estimate its coefficients across all trading days (*D*), and for expiration days separately, in minutes m=-15,-14,…,0,+1,+2,…,+15, by the following regression

$$Egap_{D,m} = \alpha_m + \beta_m ILLIQ_{D,m} + \varepsilon_{D,m}. \tag{6}$$

We omitted observations if one of the variables was missing. The lowest number of cross-sectional observations for all trading days was 1,109 whereas on expiration days the highest number of cross-sectional observations was 60 and the lowest 47.

1.6. Granger-Causality and cross-markets interactions

Next, we examine whether the indicative index is Granger-caused by the options-implied index, or vice versa. We distinguish between the preopening and the actual trading phases, hypothesizing that the interaction is bidirectional but throughout the pre-opening phase the option-implied index would be more dominant in leading the indicative index. The reason is that before the opening the options implied index is calculated based on tradable liquid assets, while the indicative index is calculated based on the illiquid stock market. We see no reason for one market to lead the other after the opening.

To test the hypotheses we use the Vector Error Correction Model (VECM). This model allows one to examine whether the effect is uni- or bi-directional, and what is the magnitude of the effect. To run the test we calculate rates of return of both the indicative and the options-implied indexes every thirty seconds on average, starting 15 minutes before the opening. The rate of return on the actual index is calculated during the first 15 minutes after the opening.

The interactions between the financial variables and the different index returns are estimated using the following model:

$$Y_t = a_0 + \sum_{j=1}^{T} b_j R_{S(t-j)} + \sum_{j=1}^{T} c_j R_{SI(t-j)} + h_j \text{coint}_{r,t} + \eta_t, \quad (7)$$

where coint_t is the co-integration factor should a linear combination between the sample series be non-stationary (Engel and Granger, 1987). $R_{S(t-j)}$ represents the rate of return on the indicative index at *t-j*, during the preopening phase, and the actual index return after the opening. $R_{SI(t-j)}$

represents the rates of return on the options-implied index on *t-j (j=1...- 5).* Letting $Y_t = R_{S(t)}$, then if c_j significantly differs from zero for any *j*, we conclude that *SI* leads *S*. However, when $Y_t = R_{SI(t)}$, then if b_j significantly differs from zero for any *j*, *S* leads *SI*. The degree of stationarity of each variable was examined using the Unit-Root test of Dickey and Fuller (1981, 1979) and co-integration is tested using Johansen's (1988) test.

2. Results

Our null hypothesis is that there should be no excess gap between the indicative and the options-implied indexes, representing no cross-market manipulation. This excess gap is also examined on expiration days. Because the option settlement price on expiration days is equal to the opening price, options traders have a strong incentive to manipulate it, presumably by submitting misleading orders throughout the preopening session (as suggested by MS's model).

2.1. The gap between indicative and actual index values

We start by analyzing the characteristics of the indicative and actual index returns from 15 minutes before the opening to 15 minutes after the opening. From Table 3 and Figure 2 one can readily notice that in the pre-opening phase, the rate of return and the volatility of the option-implied index are significantly lower than those of the indicative index. A similar result is found during the 15 minutes after the beginning of actual trading. The important message of Table 3 is that while the return of the options-implied index between the first pre-opening price to the opening price (minutes -15 to 0) is insignificantly different from zero, there is a significant positive return on the indicative index during the same interval. In fact, the return on the indicative index is more than twice higher than the return on the options-implied index, with both the average returns and their standard deviations significantly different.

[Table 3]

[Figure 2]

We examine *Egap* from 15 minutes before the opening to 15 minutes after the opening on ordinary trading days and on expiration days alone. There is a significant difference between the indexes before the opening but it disappears two minutes after the opening. Table 4 and Figure 3 show the main results at one minute intervals.

[Table 4]

More importantly, *Egap* on non-expiration days is significantly higher than zero throughout the preopening phase, and two minutes into the opening. This finding suggests that the informational efficiency of prices in one, or both markets has been deprived, supporting the contention of many stock exchanges that preopening prices are manipulated. Still, by the Kyle-Viswanathan criterion, this is only one of the two necessary conditions to suggest the finding as an indication of illegal manipulation. The second is analyzed below.

The highest *Egap* in the non-expiration sample days is higher than 30 basis points. It is insignificantly different from zero between minutes 3 and 9, but it turns significantly *negative* during minutes 10 through 15. This significant decline represents a decline in the magnitude of manipulation, as *Egap* measures the difference between the current gap, presumably the manipulation amount, and the entire-day average gap (see eq. 3). A positive *Egap* implies that manipulation at t is higher than the daily average, and a negative *Egap* implies that manipulation at t is smaller than the daily average.

Egap is much greater on expiration days, where it is 1.66% and 1.50%, on minutes -14 and -13, respectively, more than five times higher than the gap on ordinary trading days.

[Figure 3]

We have analyzed *Egap* in each one of the years 2005-2009 separately to see whether its level and/or its volatility vary over time and in particular, during the crisis year of 2008 and the rapid recovery of 2009. The findings in Table 5 below show that *Egap* more than tripled in 2008 and 2009 than the individual years 2005-2007: from an average *Egap* of 10-16 basis points it increased to 35-39 basis points. It's standard deviation also increased about three folds in those turbulent years. As a result, we hypothesize that the level of market volatility is positively correlated with the plausibility of manipulation, as measured by *Egap*.

[Table 5]

2.2. The factors affecting Egap

We explore the sensitivity of *Egap* to a number of factors. First, as explained above, we test whether *Egap* increases with market uncertainty. Second, following Hauser, Kamara and Shurki (2012) we hypothesize that order cancellation is positively correlated with manipulation, both on expiration and non-expiration days. Third, we hypothesize that the implementation of the volatility-reducing opening procedure reduced *Egap*. The regression model we apply is

$$Egap_t = \alpha + \beta_1 Cancl\_Ord_t + \beta_2 VIXTA_t + \beta_3 D_{1t} + \beta_4 D_{2t} + \varepsilon_t . \quad (8)$$

We analyzed the regression model (8) every 5 minutes, where the dependent variable is *Egap* on the one-minute intervals prior to minutes -14, -9, -4, and 0. The explanatory variables are order cancellations, the volatility index (*VIXTA*), a dummy variable D_1 that obtains the value 1 on expiration days and 0 otherwise, and a dummy variable D_2 that obtains the value 1 before June 26, 2008, the start date for the volatility-reducing opening procedure, and 0 thereafter. The findings are in Table 6.

[Table 6]

The first important finding is that order cancellation is positive and significant in all regressions -14, -9, and -4, (the last minute order cancellation is allowed), but it is insignificant at 0, where order cancellation is restricted. The coefficient of the order cancellation variable is highest on minute -14, 0.05%, and it declines to 0.03% and 0.02% on minutes -9 and -4, respectively, resembling the increasing cost of manipulation toward the opening, as predicted by theory. These findings highlight the importance of order cancellation as a manipulation mechanism. Second, we find that higher market volatility (*VIXTA*) increases *Egap* on -14 and -9, but not any closer to the opening time. This is apparently due to the diminishing level and volatility of *Egap* about 5 minutes before the opening. Expiration days are characterized by significantly higher *Egap* throughout the pre-opening, and they have the highest loading. Lastly, we find that the volatility-reducing opening procedure, captured by D_2, significantly affects *Egap* on minutes -4 and 0, but not earlier. This finding highlights that the effect that postponing the opening time had on manipulation.

2.3. Price reversal

If the significantly high-levels of *Egap* during the pre-opening indeed account for manipulation, than one may expect a price-reversal immediately after the opening. Furthermore, this reversal should be higher on options-expiration days, where we found much higher *Egap*. Indeed, as a preliminary indication we note that the correlation coefficient between R_1 and R_2 of regression model (4) was -0.19 on all trading days and about triple, -0.58 on expiration days.

Test results of regression model (4) are given in Table 7 below through four alternative models that account for different combinations of the explanatory variables. Regressions I and II reveal a significant price reversal on all trading days ($\beta_1 < 0$ in equation I) and more so on expiration days ($\beta_3 << \beta_1$ in equation II). Regression III, with its highly significant $\beta_4 > 0$ indicates that the volatility-reducing opening procedure that was implemented after June 2008 reduced price reversal, albeit the economic magnitude is rather small. These findings are substantiated by the coefficients of regression IV. It should be noted that expiration days seem to contribute most to the explanatory power of the regressions, as in equations II and IV. All of these findings support the reversal hypothesis after the opening on all trading days and particularly on expiration days.

[Table 7]

Finally, we examined the factors affecting the probability of price reversal. For this purpose, we defined the variable $Sign\_R_1R_2$ as a dummy variable that assumes the value 0 if there is no difference between the sign of R_1 and R_2 and the value 1 if they have different signs. We use *Logit* regression that allows a binary dependent variable to examine the effect of various factors on the probability of a change in sign. The explanatory variables we examine are $Egap_0$, expiration-days vs. ordinary-days (through the residual ξ)[11], and the number of order cancellations, *Cancl_Ord*. Equation (9) below shows the results:

$$Sign\_R_1R_2 = -0.5451 + 121.02 \cdot Egap_0 + 0.8978 \cdot \xi + 0.00026 \cdot Cancl\_Ord + \varepsilon \qquad (9)$$

(0.000) (0.048) (0.000) (0.000) R^2=0.024

The results indicate that the frequency of price reversal increases with $Egap_0$, as well as with an increase in order cancellations. The positive coefficient of ξ indicates that the probability of a reversal is higher on expiration days than on other trading days. The significant effect of orders cancellation on the probability of a change in sign on all trading days, and particularly on expiration days, is an additional evidence of manipulation. Apparently, some buy or sell orders are submitted to affect the indicative price, but they are cancelled just prior the opening time.

[11] Due to the high correlation between D_1 and the number of order cancellations (*cancl_ord*) of approximately 60%, the variable ξ represents the residuals in regression $D_1 = \alpha + \beta * Cancl\_Ord + \xi$. The results of the regression in equation (9) do not change even when the variables *VIXTA* and D_2 (postponed opening) are added.

These results support our previous conclusion that despite the positive effect of a random opening time, there still are manipulative trades in the preopening phase.

2.4. Liquidity

Liquidity enters the preopening phase through Medrano and Vives's (2001) model. They focus on the large investor's impact on the informational-efficiency of the preopening procedure, on volume, market depth, and volatility. They assume a preopening phase that starts at a given time but uncertain ending time, within a fixed minute range, therefore the probability of the opening call increases in time. The strategic investor in MV's model is risk-neutral, and he is 'manipulative' in the sense that he knows that the indicative price will move along his demand or supply function. Other market participants include competitive informed agents, and noise traders. The model has a few empirically observable results. First, the model implies that the strategic informed investor has an incentive to manipulate the market at all times. This is particularly true at the beginning of the tâtonnement process, when the probability of market opening is low, thereby keeping the market price uninformative throughout, and trade aggressively toward the end as the probability of market opening increases. The way manipulation occurs is by taking an opposite position to the informed traders early in the process, implying that the manipulator trades against his information. Because at that point in time the probability for an opening call is low, the cost of manipulation is low. Toward the end of the tâtonnement, as the probability of opening increases, the manipulator takes the opposite position and closes most, but not all, of the mispricing. A second interesting result is that the intensity of trading increases with the probability of opening, therefore volume increases gradually. Taken together with the incentive to manipulate the market at the beginning of the tâtonnement process, the model predicts a third result, whereby trading volume is 'U' shaped: high at the beginning and toward the end of the preopening phase. Lastly, MV's model suggests that the tâtonnement price would not converge to the fundamental price even if the length of the preopening process is very long. The reason is that the manipulator has an incentive to manipulate at all times, except when the probability of opening is very high.

These theoretical predictions correspond to empirical findings by Biais, Hillion, and Spatt (1999) who studied the preopening of the Paris Burse and to Hauser, Kamara, and Shurki (2012) who studied it in the Israeli TASE. Both tested the informative quality of the preopening procedure while we add the transactional (liquidity) quality. Thus far, both theoretical studies, like Chakraborty and Yılmaz (2004, 2008), Goldstein and Gruembel (2008) or Horst and Naujokat (2011), as well as empirical papers like Aggarwal and Wu (2006) and Jiang, Mahoney, and Mei (2005), categorize illegal manipulation based on price distortion in the stock market only. However, in many exchanges, TASE included, the preopening phase in stocks is paralleled by continuous trade in derivatives for 2-40 minutes.12 In the TASE, options are traded during the last 15 minutes prior to the random opening therefore serving as a liquid market reference to stock market prices. Our paper uses this reference to identify manipulative activity by exploring the price discovery properties in both the options and stock markets, and by measuring liquidity effects.

We use the linear model (6) to regress *ILLIQ* on *Egap*, hypothesizing that if manipulation, as measured by *Egap*, is associated with declining liquidity, then the regression slope coefficient should be positive. The results, shown on Figure 4, testify that the association between *ILLIQ* and *Egap* is indeed highly and significantly positive before the minute -6, indicating that on days where *ILLIQ* was high, *Egap* was high as well. This positive association was highest between minutes -15 and -6, but once order cancellation is restricted, from minute -5 to the opening, it

[12] These countries are: France, Germany, Austria, Spain, Taiwan, and Singapore. Scandinavian countries only allow order cancellation in the derivatives market during the 30 minutes that both markets operate in parallel.

declined and turned insignificant. The polynomial curve fit reveals an inverted U shape that captures high volume at the beginning on the opening phase, and toward minute -6, after which order cancellation is restricted. This result is expected in the presence of manipulation, based on MV's model.

[Figure 4]

Panel A of Figure 4 shows that the regression coefficients substantially decline about 5 minutes before the opening. This prompt decline in the regression coefficients is common to both expiration days and to all trading days, albeit the expiration days' coefficients are more volatile, possibly due to the much smaller sample size (about 55 vs. more than 1,100).

The finding whereby the regression coefficients turn virtually zero immediately after the opening demonstrates that illiquidity is not associated with *Egap* after the opening. This is consistent with our previous and complementary findings of reversal and the elimination of *Egap* after the opening. Taken together, the three indicators *Egap*, reversal, and illiquidity, together with the inverted U shape of the polynomial fit, are as expected by MV's model and therefore satisfy KV's criteria to identify illegal manipulation.

2.5. Dynamic interactions between the indicative and options-implied indexes

We assume that if traders manipulate the indicative index, its rate of return must be serially correlated with rates of return of the options-implied index. Therefore, lead-lag patterns should be detectable in the data. This section examines the hypothesis that the indicative index is Granger-caused by the options-implied index, and vice versa. Should such interactions be found, it would support the findings in previous sections concerning the diminishing *Egap* toward, and after the opening, as well as the price reversal patterns.

To explore the dynamic interactions between both indexes we apply the VECM of equation (7). We use rates of return because index levels were found non-stationary by the Dickey and

Fuller (1979, 1981) Unit-root test, while rates of return were stationary. We use variables with a lag of up to *T=5* intervals, i.e., 2.5 minutes. Longer intervals did not alter our results, whereas shorter intervals were not significant. We estimate equation (7) twice, once for the pre-opening phase and once again for the first 15 minutes after the opening. Table 8 shows the main results.

[Table 8]

Our findings suggest that during the pre-opening phase the indicative index *S* reflects information after *SI*, possibly because *S* is only published once every 30 seconds. *S* is negatively serially correlated up to 2.5 minutes. While the coefficients are mostly significant, they decline gradually. More importantly, *SI* is generally not led by *S* and is not serially correlated, supporting our assumption that manipulation occurs at the indicative index during the pre-opening.

After the opening, during the continuous trade phase, lead-lag interactions are faster, up to one minute, where the major effect is demonstrated by the very high and significant coefficients between *SI* and *S*. That is, the options-implies index leads by about one minute the actual index but in an *opposite direction* than the pre-opening, revealing the previously described reversal. The 30 seconds and one-minute coefficients of *SI* on *S* after the opening are about an order of magnitude higher than those of the pre-opening, indicating that the reversal is rapid. As the last column shows, *SI* is serially positively correlated at a one-minute lag, however the coefficients here are about a quarter the size of the coefficients of *SI* on *S*.

3. Summary and conclusions

This paper tests directly for trade-based manipulation based on Kyle and Viswanathan's (2008) dual criteria that render illegal manipulation as cases where both the allocational and transactional market efficiencies are hampered. Adverse impact on allocational efficiency is measurable by distorted prices, and adverse effects on transactional efficiency are measurable by lower liquidity. We use a unique sample to test manipulation across two markets, the options market in Tel-Aviv Stock Exchange, and the underlying stock market index. We focus on the pre-opening session where stocks are non-tradable but indicative prices and volume are revealed. However, starting 15 minutes before the opening time, investors can also trade index options.

We conduct a series of tests that together seem to reveal significant manipulation during the pre-opening session on ordinary trading days. Manipulation is significantly higher on options' expiration days. This is the first paper that tests directly illegal manipulation based on Kyle and Viswanathan's criteria, and our findings seem to be relevant for many exchanges in Europe, the US, Scandinavia and more.

Our study offers a few regulatory implications to eliminate what seems to be manipulation between the stock and options markets. Specifically, the regulator and\or the exchange may modify the market structure in one or more of the following ways: First, open the options market on or after the continuous trading starts in the stock market. This way cross-market manipulation becomes riskier as positions established in the stock market cannot be hedged in the options market. Second, the regulator may not allow, impose cost, or otherwise constrain order cancelation in the stock market throughout the pre-opening session, as this appears to be a key tool for manipulation. Third, if the market for derivatives is open in parallel with the pre-opening phase in the stock market, the regulator may allow order cancellation only in the options market. This practice, which is common to Scandinavian markets, warrants a detailed empirical test aimed at exploring whether it reduced or eliminated manipulation after it was introduced. Lastly, the exchange can set rules to calculate the indicative index value based on orders that remain in the book long enough, thereby neutralize the impact of order cancellation.

References

Abreu, D., and M. K. Brunnermeier, 2003, Bubbles and Crashes, *Econometrica*, 71, 173-204.

Aggarwal, Rajesh K., Wu, Guojun, 2006. Stock market manipulations. *Journal of Business*, 79, 1915–1953.

Allen, Franklin, and Douglas Gale, 1992. Stock price manipulation, *Review of Financial Studies* 5: 503–29.

Amihud, Y., 2002. Illiquidity and stock returns: cross-section and time-series effects. *Journal of Financial Markets* 5, 31-56.

Bakshi, G., Cao, C., Chen, Z., 1997. Empirical performance of alternative option pricing models. *Journal of Finance* 52, 2003-2049.

Biais, B.; P. Hillion; and C. Spatt. 1999. Price Discovery and Learning during the Preopening Period in the Paris Bourse. *Journal of Political Economy*, 107, 1218-1248.

Chakraborty, Archishman, and Bilge Yilmaz. 2004. Informed manipulation. *Journal of Economic Theory*, 114: 132–152.

Chakraborty, Archishman, and Bilge Yilmaz. 2008. Microstructure Bluffing with Nested Information. *American Economic Review Papers and Proceedings*, 98:2 280-284.

Comerton-Forde Carole, and Talis J. Putninš, 2011, Measuring closing price manipulation, *Journal of Financial Intermediation*, 20, 135–158.

DeLong, B., A. Shleifer, L. Summers, and R. Waldmann, 1990. Noise Trader Risk in Financial Markets, *Journal of Political Economy*, 98, 703-738.

Dickey, D. A., and Fuller, W. A, "Distribution of the Estimators for Autoregressive Time Series with A Unit Root". *Journal of the American Statistical Association*, 1979, 74, 427-431.

Dickey, D. A., and Fuller, W. A, 1981, "Likelihood Ratio Statistics for Autoregressive Time Series with A Unit Root". *Econometrica*, 49, 1057-1072

Dumas, B., Fleming, J., Whaley, R.E., 1998. Implied volatility functions: Empirical tests. *Journal of Finance* 53, 2059-2106.

Engle, R.F and Granger, C.W.J 1987 “Forecasting and testing in co-integrated systems” *Journal of Econometrics,* 35, 143-159

Fischel, Daniel R., and David J. Ross. 1991. Should the Law Prohibit 'Manipulation' in Financial Markets? Harvard Law Review, 105(2): 503-53.

Fleming, J., Ostdiek B., & Whaley, R. E. 1996. Trading costs and the relative rates of price discovery in the stock, futures, and option markets. *Journal of Futures Markets*, 16, 353-387.

Goldstein, Itay and Alexander Guembel, 2008. Manipulation and the Allocational Role of Prices, *Review of Economic Studies* 75, 133–164.

Hauser Shmuel, Kamara Avraham, Shurki Itzik. 2012. The effects of randomizing the opening time on the performance of a stock market under stress. *Journal of Financial Markets*, 15, 4, 392–415

Horst Ulrich, and Felix Naujokat, 2011, On derivatives with illiquid underlying and market manipulation, *Quantitative Finance*,11, 7, 1051–1066.

Jarrow, Robert A., 1994. Derivative security markets, market manipulation, and option pricing theory. *Journal of Financial and Quantitative Analysis*, 29: 241–61.

Jiang, Guolin, Paul G. Mahoney, Jianping Mei, 2005. Market manipulation: A comprehensive study of stock pools, *Journal of Financial Economics*, 77, 1, 147-170.

Johansen, S. 1988. Statistical analysis of cointegrating vectors. *Journal of Economic Dynamics and Control*, 12, 231-254

Kyle, Albert S. and S. Viswanathan 2008. How to Define Illegal Price Manipulation. *The American Economic Review*,98 (2), 274-279.

Madhavan A, and V Panchapagesan, 2000. Price discovery in auction markets: a look inside the black box, *Review of Financial Studies*, 13 (3): 627-658

Medrano, Louis Angel and Xavier Vives, 2001. Strategic Behavior and Price Discovery, *RAND Journal of Economics*, 32, 221-248.

Shleifer, Andrei and Robert W. Vishny, The Limits of Arbitrage, *The Journal of Finance*, 52, 1, 1997, pp. 35-55

Stoll, HR and RE, 1990. Whaley, Stock market structure and volatility, *Review of Financial Studies*, 3 (1): 37-71

Table 1

Mean daily trading volume, turnover in option units, as well as mean TA-25 returns, together with the standard deviation of return and its median.

Panel A: Summary statistics

	Average daily trading volume in stocks (NIS, millions)	Average daily trading turnover in TA 25 options (units)	Average daily return	Standard deviation	Median
Entire period	885	306,836	0.0594%	1.3617%	0.0952%
2005	578	257,952	0.1220%	0.9723%	0.1183%
2006	767	304,513	0.0529%	1.0446%	0.1092%
2007	1,088	384,733	0.1169%	1.0440%	0.1583%
2008	1,123	331,981	-0.2336%	1.9556%	-0.1926%
2009	870	255,000	0.2367%	1.4934%	0.2127%

Panel B: Number of orders cancellations in the preopening phase

	Expiration days only	All trading days without expirations days	p-value
Average	330.77	73.32	0.000
Standard deviation	116.92	56.39	

Table 2: Number of options, 2005-2009

Number of Call and Put options-pairs based on which the implied TA-25 index was calculated.

	2005	2006	2007	2008	2009
Daily average	5,211	7,796	22,486	49,950	42,628
Monthly average	106,383	161,109	455,335	1,019,808	880,973
Total number PCP pairs	1,276,601	1,933,311	5,464,021	12,237,699	10,571,676

Table 3: Comparison of the actual TA-25 index and the indicative index

The indicative rate of return is calculated based on half-minute intervals from 15 minutes prior to, and until the opening time. Immediately after the opening time, the rate of return is calculated for the actual TA-25 index. The rate of return on the options-implied index is calculated at half-minute intervals from 15 minutes before to 15 minutes after the opening.

	Rate of return on underlying index	Rate of return on option implied index	p-value
15 minutes to opening			
Average	0.00112%	0.00051%	0.002
Standard deviation	0.00523%	0.00461%	0.000
15 minutes after opening			
Average	0.00077%	0.00039%	0.012
Standard deviation	0.00376%	0.00356%	0.000
p-value of average difference	0.052	0.474	
p-value standard deviation	0.015	0.000	

Table 4: *Egap* in all trading days and in comparison with expiration days

Gap_t is the mean percentage gap between *S* and *SI* at a one-minute interval and $\overline{|Gap|}_{open \rightarrow close}$ is the mean daily gap in 2005-2009 on all trading days and on expiration days.

Minutes from Open	**Non-expiration vs. Expiration days**			**Non-expiration days**
	Egap			
	Expiration days only	Non expiration days	p-value for difference	p-value vs. zero
-14	1.66%	0.317%	0.000	0.000
-13	1.50%	0.319%	0.004	0.000
-12	1.37%	0.291%	0.000	0.000
-11	1.36%	0.273%	0.000	0.000
-10	1.13%	0.256%	0.000	0.000
-9	1.18%	0.239%	0.000	0.000
-8	1.11%	0.232%	0.000	0.000
-7	0.87%	0.217%	0.000	0.000
-6	0.79%	0.195%	0.001	0.000
-5	0.99%	0.172%	0.001	0.000
-4	0.87%	0.146%	0.001	0.000
-3	0.74%	0.124%	0.001	0.000
-2	0.50%	0.094%	0.004	0.000
-1	0.34%	0.060%	0.003	0.000
0	0.18%	0.036%	0.014	0.000
1	0.10%	0.013%	0.024	0.004
2	0.01%	0.009%	0.827	0.022
3	-0.02%	0.007%	0.163	0.080
4	-0.01%	0.008%	0.286	0.030
5	-0.01%	0.005%	0.378	0.164
6	0.00%	0.002%	0.879	0.647
7	0.00%	0.000%	0.895	0.979
8	-0.02%	0.000%	0.230	0.933
9	-0.01%	-0.004%	0.776	0.210
10	-0.02%	-0.007%	0.677	0.030
11	-0.02%	-0.011%	0.615	0.002
12	-0.03%	-0.012%	0.169	0.000
13	0.01%	-0.011%	0.467	0.001
14	-0.02%	-0.013%	0.801	0.000
15	-0.02%	-0.012%	0.752	0.000

Table 5: *Egap* during 2005-2009

Mean and standard deviation of *Egap* by minute, for each of the sample years 2005-2009 in all trading days.

Minutes from Opening	2005	2006	2007	2008	2009
-14	0.1474%	0.1653%	0.2894%	0.5459%	0.5949%
-13	0.1408%	0.1383%	0.2810%	0.6277%	0.5635%
-12	0.1397%	0.1362%	0.2544%	0.5221%	0.5333%
-11	0.1338%	0.1387%	0.2309%	0.4896%	0.5022%
-10	0.1283%	0.1429%	0.2100%	0.4683%	0.4683%
-9	0.1289%	0.1626%	0.1897%	0.4151%	0.4441%
-8	0.1710%	0.1365%	0.1957%	0.3872%	0.4248%
-7	0.1603%	0.1221%	0.1510%	0.3560%	0.4061%
-6	0.1301%	0.1119%	0.1337%	0.3294%	0.3752%
-5	0.1245%	0.0916%	0.1200%	0.2855%	0.4039%
-4	0.1057%	0.0797%	0.1047%	0.2548%	0.3242%
-3	0.0873%	0.0826%	0.0892%	0.2122%	0.2691%
-2	0.0586%	0.0479%	0.0753%	0.1470%	0.2268%
-1	0.0435%	0.0167%	0.0423%	0.0949%	0.1649%
0	0.0397%	-0.0016%	0.0339%	0.0462%	0.0948%
Average	0.1160%	0.1048%	0.1601%	0.3455%	0.3864%
Standard deviation	0.0408%	0.0512%	0.0834%	0.1722%	0.1462%

Table 6: The factors affecting *Egap*

The following regressions are for t=-14,-9,-4,0. *Cancl_Ord* represents the number of order cancellations in the preopening phase and *VIXTA* represents the fear index (*VIXTA*) on the Tel Aviv Stock Exchange. D_1 assumes the value 1 on expiration days and 0 on ordinary trading days. D_2 assumes the value 1 before June 26, 2008, the implementation date of the "volatility reducing" opening procedure, and 0 after this date.

$$Egap_t = \alpha + \beta_1 Cancl\_Ord_t + \beta_2 VIXTA_t + \beta_3 D_{1t} + \beta_4 D_{2t} + \varepsilon_t$$

Independent variables	$Egap_{-14}$	$Egap_{-9}$	$Egap_{-4}$	$Egap_{0}$
α	-0.25%	-0.14%	0.09%	0.06%
	-0.013	-0.078	-0.207	-0.055
Cancl_Ord	0.05%	0.03%	0.02%	0.00%
	0.000	**0.000**	**0.000**	-0.348
VIXTA	0.09%	0.08%	0.01%	0.00%
	-0.005	**-0.002**	-0.538	-0.977
D_1	0.29%	0.26%	0.35%	0.12%
	-0.045	**-0.0016**	**0.000**	**-0.003**
D_2	0.03%	0.03%	0.11%	0.05%
	-0.621	-0.943	**-0.004**	**-0.004**
R^2	0.317	0.240	0.181	0.045

Table 7: Price reversal on ordinary trading days and on expiration days

Price reversal is calculated as the correlation coefficient between R_1 and R_2, where $R_1 = S_0 / S_{close} - 1$ and $R_2 = S_{+15MIN} / S_0 - 1$. D_1 is a dummy variable that assumes the value 1 on expiration days and 0 on ordinary trading days. D_2 is a dummy variable that assumes the value 1 after the "volatility reducing" opening procedure was implemented (June 26, 2008), and 0 beforehand.

$$R_2 = \alpha + \beta_1 R_1 + \beta_2 D_1 + \beta_3 (R_1 * D_1) + \beta_4 D_2 + \beta_5 (R_1 * D_2) + \varepsilon$$

	Regression model (4)			
Coefficient	I	II	III	IV
α	0.00025	0.00008	(0.00019)	(0.00020)
	(0.013)	(0.372)	(0.285)	(0.176)
β_1	(0.06649)	0.01334	(0.06882)	0.01091
	0.000	(0.124)	**0.000**	(0.328)
β_2		0.00265		0.00264
		0.000		**0.000**
β_3		(0.57249)		(0.56978)
		0.000		**0.000**
β_4			0.00064	0.00040
			(0.002)	**(0.027)**
β_5				0.00128
				(0.938)
R^2	0.036	0.357	0.043	0.36

Table 8: Causality between *S* and *SI*

Granger causality between financial variables and stock indexes are estimated using the VEC model:

$$Y_t = a_0 + \sum_{j=1}^{T} b_j R_{S(t-j)} + \sum_{j=1}^{T} c_j R_{SI(t-j)} + h_j \text{coint}_{r,t} + \eta_t$$

$R_{S(t-j)}$ represents rates of return on the indicative TA-25 index on minute *t-j*, in the preopening phase and the actual index after the opening. $R_{SI(t-j)}$ represents rates of return on the options-implied index on minute *t-j (j=1...- -5).*

	Pre-opening phase		Continuous phase	
Variable	Dependent variable $R_{S(t)}$	Dependent variable $R_{SI(t)}$	Dependent variable $R_{S(t)}$	Dependent variable $R_{SI(t)}$
$R_{S(t-j)}$				
-1	-1.1734*	-0.2638	-1.0567*	-0.2341
-2	-0.8878*	-0.2109	-0.6839	-0.2560*
-3	-0.4203*	-0.1506	-0.1951	-0.1055
-4	-0.2575	-0.4121*	-0.2661	-0.1003
-5	-0.3064*	-0.2493	-0.0501	-0.0406
$R_{SI(t-j)}$				
-1	-0.4247*	0.0543	4.2360*	1.0659*
-2	0.055	-0.3891	3.5478*	1.0052*
-3	0.3282*	-0.1592	1.5301	0.6792
-4	0.6163*	-0.0741	1.5272	0.5184
-5	0.3978*	-0.2284	-0.513	0.1516
R^2	0.9	0.395	0.529	0.517

Figure 1: TA-25 index and VIXTA index

Daily TA-25 index (left axis) and VIXTA (right axis). The latter is based on the TA-25 index throughout the trading day. VIXTA is calculated by Aonline in collaboration with Ono Academic College, following a procedure comparable to the calculation of the S&P500 VIX of the Chicago stock exchange.

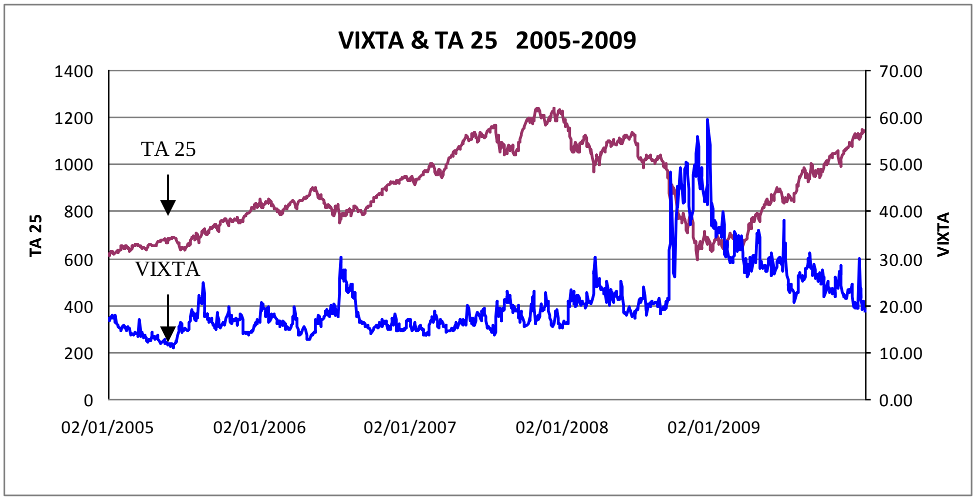


Figure 2: Indicative index, actual index, and options-implied index

The time-series patterns of S (the indicative index before opening and the actual index after opening of stock trading) and SI (the option-implied index).

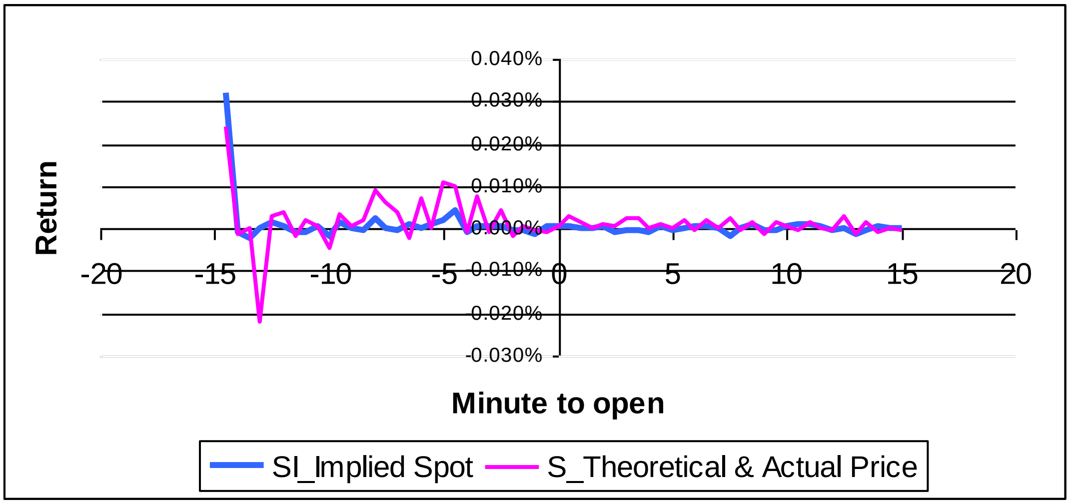
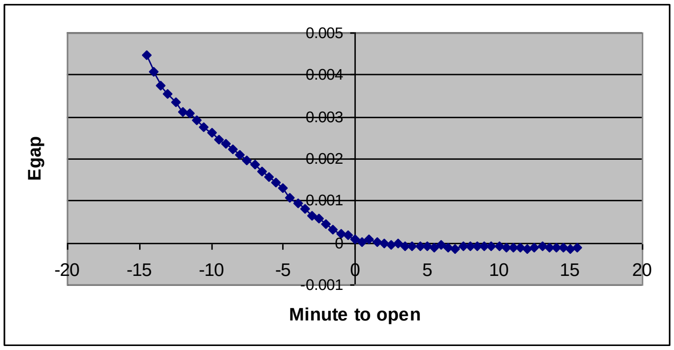


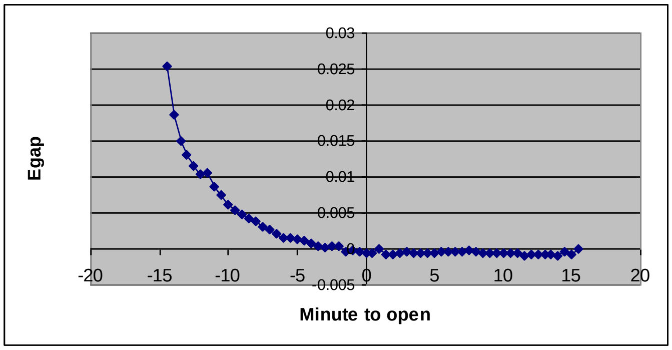
Figure 3: *Egap* before and after the opening

The pattern of *Egap* from 15 minutes before to 15 minutes after the opening. Vertical axis measures Egap and the horizontal axis measures minutes before and after the opening of stock trading.

Panel A: All non-expiration trading days



Panel B: Expiration days only



Panel C: Expiration and non-expiration days

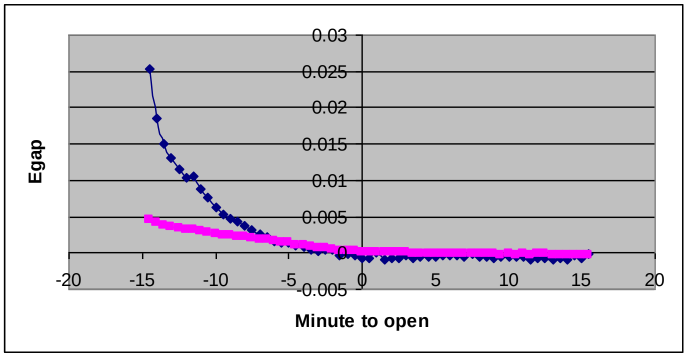
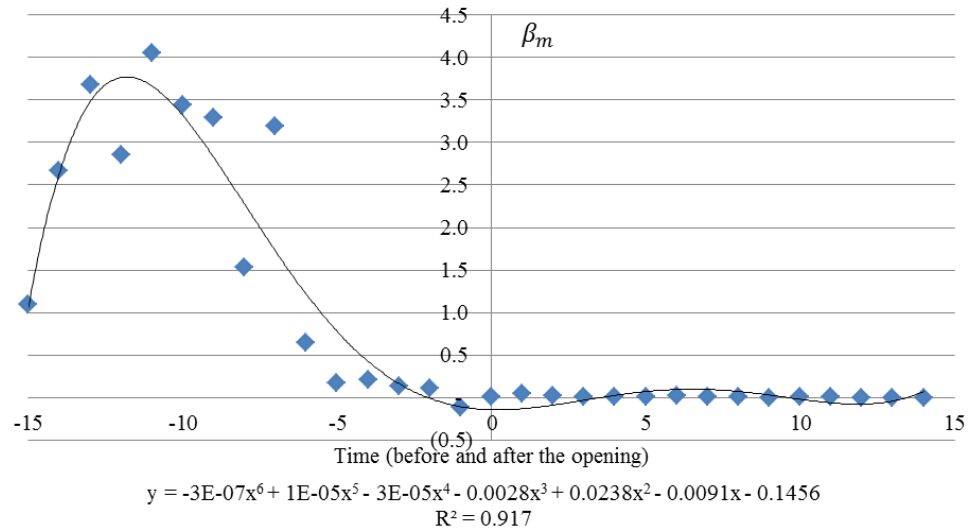


Figure 4: Illiquidity vs. *Egap*

Regression coefficients of *ILLIQ* on *Egap* (vertical axis) in the 15 minutes before and after the opening (horizontal axis). The minute-by-minute sample includes all *ILLIQ* and *Egap* observations across trading days and all expiration days, separately. Regressions in Panel A have more than 1,000 observations per minute, and in Panel B between 47 to 60 observations (The first two observations in this panel were omitted due to insufficient data). Polynomial fit to the 5th-6th power reveal inverted U shape before the opening, consistent with the presence of manipulation in MV's model.

$$Egap_{D,m} = \alpha_m + \beta_m ILLIQ_{D,m} + \varepsilon_{D,m}$$

Panel A: All trading days, and expiration days



Panel B: Expiration days only