

Does market incompleteness matter for market microstructure? *

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Abstract

Market incompleteness should matter in theory, but it is difficult to identify and measure the magnitude of its effects, especially on market microstructure. We use a natural experiment at the Tel Aviv Stock Exchange (TASE) to analyze how order submission patterns, trading and hedging strategies, and overall market impact are affected by market incompleteness. Options on the dollar are traded on Sundays on the TASE, while their underlying is not, which we use in a difference-in-differences setting with options on the equity index as control.

Overall, our evidence suggests that market incompleteness has two major effects on traders' behaviors. First, likely because of expected higher adverse selection, traders change their patterns, resorting to higher strategic order splitting, nonetheless somewhat reducing their overall trading volumes. Second, because of actually lower information caused by the spot market closure, prices are in fact more efficient and volatility is lower, and aggregate trading costs during periods of incompleteness are slightly reduced, suggesting that informed trading plays a lesser role.

Keywords: market incompleteness, market microstructure, liquidity, options.

JEL codes: C23, D52, D47, G14, G12.

1 Introduction

Market incompleteness matters for asset pricing, consumption and welfare (Levine and Zame, 2002; Gomes and Michaelides, 2007; Krueger and Lustig, 2010), but its consequences on trading patterns, traders' behaviors and market quality are largely unknown. If markets are incomplete, agents cannot always hedge against certain contingencies, prices and consumption deviate from optimality, and social welfare is not maximized. In this paper, we analyze the impact of market incompleteness on microstructure measures using a natural experiment. The Tel Aviv Stock Exchange (TASE) is open from Sunday to Thursday, and options on the shekel-dollar exchange rate are actively traded on Sundays, even though the underlying foreign exchange (forex) market is closed and an active futures market does not exist. Not being able to trade the underlying asset of an option is a case of market incompleteness. In particular, delta-hedging these options is impossible on Sundays. We use a difference-in-difference setting to contrast trading in this market to trading in more typical markets, such as the Tel Aviv 25 (TA-25) equity index, where both the underlying and the options are traded on all five days of the week. We estimate the effect of incompleteness on volumes, strategies and liquidity in forex options on Sundays.

The theoretical literature has few predictions for market microstructure under incompleteness, and many of them revolve around pricing. Better understanding the link between microstructure and incompleteness, however, notably through liquidity and information, is especially critical in the debate of proper market design and the extent to which financial innovation is beneficial. Part of the literature has recently cast doubt on the idea that making markets more complete is necessarily positive. Adding non-redundant securities to the market has the potential to increase price volatility (Bhamra and Uppal, 2009; Brock *et al.*, 2009), and to reduce welfare (Elul, 1995; Cass and Citanna, 1998).

If, on the other hand, reducing incompleteness has a positive effect on information, liquidity and market quality, then new products may be desirable even if they are redundant. Kumar *et al.* (1998) document improvements in the underlying's market quality after introducing options. There is some evidence that this effect can vary with the type of product and some state variables. For example, Boehmer *et al.* (forthcoming) find that the development of single-name CDS markets provides hedging-related benefits that are greater than the negative trader-driven information spillovers only when times are good on the equity market, and the opposite when they are bad.

Biais and Hillion (1994) examine the link between information asymmetry and market incompleteness. They find that the effect of completing the market with an option is not straightforward. The option may prevent a market breakdown due to the joint effects of incompleteness and asymmetries of information, but it also makes it more difficult for non-insiders to interpret information. Depending on parameter values, the profits of insiders can change either way. We use our empirical setup to measure how market incompleteness affects trading through both the hedging and the information channels, which might impact informed and uninformed traders differently.

When the spot market is closed, traders lose of a major source of public, but also private information: key players in an OTC market are likely to obtain valuable clues, especially on inventory positions, that might be used to anticipate spot price moves (Cao *et al.*, 2003). As a consequence of this lower information, traders adjust their behaviors considerably in response to incompleteness. They need to minimize information leakage and therefore practice strategic splitting: our results show that they place smaller, but more frequent orders.

Traders may also use these smaller, more frequent orders to collect information and position themselves in the queue. This is apparent from the more numerous canceled orders relative to matched ones. Matched orders actually spend less time

in the book under incompleteness, and the opposite is true of canceled orders, despite a relatively smaller size. This suggests that traders place their orders with different intentions: some, demanding liquidity, on average larger and with aggressive prices; some, designed to anticipate price moves, sit in the book longer and are canceled whenever they need to be repositioned.

We observe less informational content in order flows, and so even if there were private information, the strategic splitting successfully conceals it. The quoted and effective spreads become slightly tighter under incompleteness, suggesting lower margins for liquidity traders, hence less adverse selection. Trades have less price impact, and returns display less autocorrelation, which also consistent with less informed trading activity. Also in agreement with this scenario, intraday volatility also comes out much lower, especially when filtering out jumps.

This phenomenon is attributable to incompleteness, rather than a day-of-the-week or some other TASE-specific factors, since difference-in-differences is used to eliminate potential confounding effects. The results are robust to controls, notably for moneyness and maturity.

Incompleteness could discourage trading, both by preventing delta hedging and by exacerbating asymmetries of information. The former could be mitigated by dynamic hedging, while the latter does not seem to happen, but it could be enough that some traders fear higher adverse selection or lower liquidity, even if it is not the case, for some activity to get postponed until the Monday or altogether forgone. We do find that volumes of orders and trades decline, but only to a limited extent, and the market is still very much resilient¹. Far from a market collapse, its quality appears to at least match that of the rest of the week. Quoted depth is not significantly changed, nor are realized spreads, which measure trading costs net of the trade's informational content.

¹ Since traders are not identifiable, we cannot determine if Sunday traders on the forex market are the same as the rest of the time on both markets; nevertheless, the limited reduction in volumes and the overall good functioning of the market, as well as some anecdotal evidence, make us rather confident that there is nothing special about Sunday traders.

Overall, our evidence suggests that market incompleteness has two major effects on traders' behaviors. First, likely because of expected higher adverse selection, traders change their patterns, resorting to higher strategic order splitting, nonetheless somewhat reducing their overall trading volumes. Second, because of actually lower information caused by the spot market closure, prices are in fact more efficient and volatility is lower, and aggregate trading costs during periods of incompleteness are slightly reduced, suggesting that informed trading plays a lesser role.

The rest of the paper is structured as follows. First, we develop testable hypotheses for the impact of incompleteness on market microstructure. Second, we introduce the natural experiment at the Tel Aviv Stock Exchange and our econometric strategy for identifying the impact of incompleteness. We then describe our data and variables. Finally, we present our results and discuss their implications for equity markets.

2 Related literature and research hypotheses

Theory offers some indirect predictions as to what happens to trading patterns, strategies and market quality under incompleteness, although they rarely tackle the question explicitly, and generally in static equilibrium models. Models generally distinguish between exogenous and endogenous sources of incompleteness. The former are mostly institutional (caused by trading protocol or regulatory environment) and/or geographical (location might determine traders' actions). The latter usually arise from heterogeneity in characteristics, preferences, or imperfect information.

Does market incompleteness matter? Theory says it does, except under unreasonably limiting assumptions. [Levine and Zame \(2002\)](#) shows in a formal setting that drastic conditions are required for incompleteness not to matter for prices, consumption and welfare. In an economy with no aggregate risk and a single

consumption good, agents have to be sufficiently patient and a risk-free asset needs to be available. With aggregate risk, the conditions are even more stringent: all agents must have a constant relative risk aversion utility function and the corresponding “right” assets need to be traded, i.e. those assets that complete the aggregate risk market. Under these conditions, the losses due to incompleteness go to zero as the agents’ discount factor tends to one.

However, as soon as those restrictive conditions are dropped, market incompleteness becomes important. [Levine and Zame \(2002\)](#) provide some simple examples where it does. For instance, as soon as a second consumption good is introduced (and even in the absence of uncertainty), equilibrium consumptions are no longer Pareto optimal, and utilities do not converge to an optimum as the discount factor tends to one. [Gomes and Michaelides \(2007\)](#) and [Krueger and Lustig \(2010\)](#) obtain similar results in slightly different frameworks. This result translates into welfare losses under incompleteness ([Elul, 1995](#); [Cass and Citanna, 1998](#)).

The impact on volatility has been more debated. [Citanna and Schmedders \(2005\)](#) show that it is generally possible to design securities that, by making the market complete, reduce volatility. This is however only the cases when there is no aggregate risk. In the opposite situation, adding non-redundant assets to the market potentially increases price volatility. [Bhamra and Uppal \(2009\)](#) extend the analysis to a continuous time model with aggregate endowment risk and two agents that differ only in risk aversion. Introducing the derivative makes the discount rate stochastic, which will drive volatility above its fundamental value as long as the procyclical component of the discount rate (precautionary savings in the risk-free asset) is low. [Brock *et al.* \(2009\)](#), focusing on heterogeneous expectations and learning dynamics, also concludes that creating new hedging instruments can actually increase price volatility.

In our paper, we look at a specific case of market incompleteness. On Sundays, traders at the Tel Aviv Stock Exchange can buy and sell options on the dollar

denominated in shekels, even though for all practical purposes they cannot buy and sell dollars directly. We exploit the fact that it is impossible, on these days, to replicate the option's payoff in the cash market, so that delta hedging is not possible. From an informational perspective, currency option traders must make decisions without knowing the dynamics and level of the contemporaneous spot exchange rate on Sundays. We expect traders to adapt their behavior and strategies to the situation. From the analysis of their trading pattern, we then analyze look at how information and volatility are impact, and finally whether the market quality is affected.

2.1 Trading patterns

First, the closure of the spot market removes an important source of information for option trading. Information is known to permeate between the spot and option markets in both directions (Stephan and Whaley, 1990; Easley *et al.*, 1998). Contrary to the TASE options market which is centralized and where orders are public, the spot forex market is over the counter, information is not readily available even on flows, let alone inventories. Large dealers, however, get precious indications from their clients as well as the interdealer market, helping them forecast the spot exchange rate (Cao *et al.*, 2003).

As far as options are concerned, the price of the underlying and its dynamics are the major components of pricing. The spot market closure introduces uncertainty, forcing traders to make assumptions regarding the non-existing spot price. Information permeating on the options market is therefore likely to be watched ever more closely than usual, and traders therefore need.

Hypothesis 1: In response to incompleteness, traders split their orders.

This comes from two channels. First, traders need to limit market impact and information leakage even more than usual, and smaller orders are a way to do this. Second, traders need test the market and gather information on its reaction, which

also warrants smaller orders. Naturally, those two effects can be compounded by herding phenomena.

Splitting has long been identified as a way to limit market impact and information revelation (Kyle, 1985; Biais *et al.*, 1995). While the book is common knowledge on the TASE, the small, more frequent orders may be used to elicit orders on the other side, similarly to the strategy described by Biais *et al.* (1995): even though there are no hidden orders on the TASE, there is most likely hidden demand which not in the book.

However, the strategy of hiding the true demand is limited by the desire for immediacy and low execution risk. If informed traders still want to have their full demand fulfilled within a certain time frame but with smaller orders, these will have to be relatively more frequent.

Splitting is difficult to formally identify since we do not have data on trading account, but we can look at the number and size of individual orders. Chou and Wang (2009), who have trading account data for a sample from the Taiwan Futures Exchange, find that all types of traders tend to use splitting strategy, including less likely to be informed individual traders, although less markedly than foreign institutional traders and futures proprietary firms.

Hypothesis 2: In response to incompleteness, traders cancel more orders.

More splitting should result in more cancelations. Consistently with information collection, traders need to reposition themselves frequently.

In some respect, this also relates to the “exploratory trading” strategy described by Clark-Joseph (2013) for certain high-frequency traders, willing to make losses on small, aggressive orders, because they use them to gather information and follow them with larger, profitable orders. In our dataset, we do not have access to account identifiers and thus cannot analyze individual strategies, but this type of strategy seems very likely from uninformed traders, whether they trade at high frequency or not.

Hypothesis 3: In response to incompleteness, traders have to be more patient.

Incompleteness could arguably change the survival of order either way, depending on how much traders adjust the aggressiveness of their orders. If uninformed trading dominates, demand for immediacy should not increase.

Market incompleteness, to some extent, exacerbates the well-known trade-off between execution speed and execution cost (see e.g. [Boehmer, 2005](#) on the empirical side and [Foucault *et al.*, 2005](#), on the theoretical side). Generally, if the proportion of impatient traders increases, both the uninformed, who may have inventory concerns, and the informed, who may have time-sensitive information, will have to increase their order aggressiveness. Conversely, if there is less information and inventory risk does compensate, then we expect longer survival times.

2.2 Information and intraday volatility

To make sense of changes in the trading patterns, it is necessary to consider measures of informational efficiency and price volatility.

Hypothesis 4: Incompleteness actually reduces information asymmetry.

While one could argue that incompleteness might impact information asymmetry either way, a reduction seems more likely. Private information on the spot forex comes largely from dealers observing flows and inventory ([Cao *et al.*, 2003](#)), which are non-existent on Sundays. Furthermore, traders having different types of private information (giving them, e.g., a better estimate of the unobservable spot) might not be able to profit from this information if the level of noise trading is not sufficient.

[Collin-Dufresne and Fos \(2012\)](#), extending a [Kyle \(1985\)](#) model with stochastic noise traders, show that insiders will wait for high levels of noise trading before they submit their orders. Empirically, [Collin-Dufresne and Fos \(2013\)](#) show that

certain informed traders can execute such a ramp-up strategy over weeks if not months, trading in high-volatility days to hide their activity.

All in all, we expect less adverse selection under incompleteness, which would translate in lower quoted and effective spreads, lower price impact and return autocorrelation.

Inventory concerns could have a counteracting effect on spreads. Stoikov and Sağlam (2009) look at the impact of incompleteness on the bid-ask quoted by an option market maker. Under complete markets, when the underlying asset is perfectly liquid, the market maker can completely delta-hedge and only the option's liquidity matters for the optimal bid and ask. Under incompleteness due to partial illiquidity in the spot but if the market maker can set bid-ask quotes for it as well as the option, the optimal quotes depend on their relative liquidity and the net delta of the inventory (sensitivity to the spot price). Finally, under incompleteness due to stochastic volatility and jump risk, the liquidity of the option and the net vega (sensitivity to the volatility) and gamma (second-order sensitivity to the spot price) of the inventory determine the optimal quotes.

The periodic incompleteness phenomenon is, to some extent, akin to the extreme case of illiquidity of the underlying, and that there is a considerable amount of literature on pricing options with illiquid or non-traded underlying. To our knowledge, our case of a periodically (known in advance) non-trading day for the underlying is unique to our TASE experiment.

Hypothesis 5: Under incompleteness, intraday volatility is lower.

As previously discussed, the literature has reached ambiguous conclusions regarding volatility under incompleteness. We however expect it to come out lower, but not necessarily through the channels described in asset pricing models such as that of Bhamra and Uppal (2009) and Brock *et al.* (2009).

Information-driven volatility is expected to be lower. Information on the spot market price, order flow and inventories disappear altogether. There are most

certainly less fundamental news arriving on Sundays, but this should be at least partially captured by the difference-in-differences setting. Semi-fundamental information *à la Ito et al.* (1998) might still exist, but might be harder to act on.

Non-fundamental volatility, related to the trading process, should also be mitigated by the more careful trading strategies, especially order splitting, designed to limit price impact.

2.3 Market activity and quality

The consequence of changes in the information structure and volatility is that market quality may be negatively affected.

Hypothesis 6: Under incompleteness, volumes of orders and trades are reduced.

Traders, especially if uninformed, may not need to trade currency options on Sundays, and may be willing to wait until the spot market is open on the Monday morning. It is therefore likely that the market activity will be somewhat reduced under incompleteness. In the limit, the asymmetry of information may be strong enough, combined with the impossibility to delta-hedge, to discourage uninformed trading altogether, causing a market breakdown (as in [Biais and Hillion, 1994](#)).

However, if as previously argued information asymmetry does not increase, then a collapse should be avoided and the market should remain active.

Hypothesis 7: Despite incompleteness, trading costs do not increase significantly.

It is difficult to make strong prediction regarding non-informational trading costs. Especially since delta-hedging is impossible when the spot market is inactive, we expect traders to pay even closer attention to their inventories. Other costs entering in the realized spread should not be affected.

3 Data

3.1 The natural experiment of the Tel Aviv Stock Exchange

A setting that allows empirical estimation of the magnitude and significance of the microstructure responses associated to market incompleteness is difficult to find. We propose to study a natural experiment at the Tel Aviv Stock Exchange (TASE). The TASE is a modern limit-order market that is studied frequently (see, among others, Amihud *et al.*, 1997; Kalay *et al.*, 2002; Amihud *et al.*, 2003; Hauser and Lauterbach, 2003; Eldor *et al.*, 2006). The exchange's particularity is that it is open on Sundays and closed on Fridays, reflecting the Israel workweek. Thus, options on the foreign exchange rate with the dollar are traded on Sundays, even though the underlying forex market is closed that day. There is no inter-bank dealing because the Bank of Israel does not have a fixing of the exchange rate on Sundays, and the futures market, while open, barely registers a single trade on the typical day. Large spot forex interdealer trading platforms, such as EBS, open on Sunday night after the TASE has closed and trade until Friday night.

The Tel Aviv Stock Exchange is the only public securities exchange in Israel. Prices are quoted in New Israeli Shekels (NIS). The TA-25 index is the prominent market index; it is a capitalization-weighted index of the 25 highest market values stocks. It is highly correlated with the U.S. markets, more than 9% of companies even being cross-listed, as of August 2011. Derivatives on the TA-25 index were launched in 1993, joined by options on the NIS-USD exchange rate in 1994. The market has been fully automated since 1999 and the volumes have very significantly increased, and are still progressing. Apart from these two products, however, other derivatives remain to this day thinly traded, including the four single-name equity options launched in 2009.

The TASE is a fully-electronic, liquid market compared to other exchanges with similar opening days in the region (such as the Amman Stock Exchange, the Bahrain Stock Exchange, NASDAQ Dubai, open Sunday through Thursday;

the Saudi Stock Exchange is open Saturday through Wednesday). It is also worth noting that the New Israel Shekel has had a free-floating exchange rate for the whole sample period (2006-2010), although the Bank of Israel has occasionally intervened to correct perceived abnormal valuations. To the best of our knowledge, these interventions have always happened in the underlying forex spot market and never in the TASE options market.

3.2 Derivatives contracts traded on the TASE

3.2.1 Derivatives contract description

European options on the U.S. dollar began trading on TASE in October 1994. The unit is USD 10,000. There are monthly expiration dates, the expiration day being the last Wednesday of the expiration month. The last trading day is the Tuesday before the last Wednesday of the expiration month. The settlement price is the most recent NIS/USD exchange rate published by the Bank of Israel on a TASE trading day prior to the expiration date.

A new series of options is issued monthly, with three months to maturity (in January, February, April, May, July, August, October and November); six months (in March and September); or one year (in June and December). Five series of options are active simultaneously. The strike price increments are 2.5, 5 or 10 points, and the minimum price fluctuations are NIS 1 for prices up to NIS 20, NIS 5 for prices of NIS 21 to NIS 200, NIS 10 for prices of NIS 201 to NIS 2,000, and NIS 20 for prices above NIS 2,000 NIS. Position limits are 100,000 contracts. All in-the-money options are automatically exercised.

European options on the TA-25 index have been trading since August 1993. The unit is NIS 100 multiplied by the index level. There are monthly expiration dates, the expiration day being the last Friday of the expiration month. The last trading day is the Wednesday before the last Friday of the expiration month. The

settlement price is computed from the opening prices of the index constituents on the last trading day before the expiration date.

A new series of options is issued monthly with a three-month time to maturity. Three series of options are therefore active simultaneously. The strike price increment is 10 points, and the minimum price fluctuations are NIS 1 for prices up to NIS 20, NIS 5 for prices of NIS 21 to NIS 200, NIS 10 for prices of NIS 201 to NIS 2,000, and NIS 20 for prices above NIS 2,000. Position limits are 30,000 contracts. All in-the-money options are automatically exercised.

3.2.2 Opening hours

The Tel Aviv Stock Exchange is open from Sunday to Thursday, except for holidays. Tel Aviv is on the Israel Standard Time (IST, UTC+2) during winter and Israel Daylight Time (IDT, UTC+3) during summer. For derivatives, continuous trading starts at 9:30 and finishes at 16:30.

There are a number of holidays and mid-holidays which may vary slightly each year, and during which trading is suspended. In 2010, for example, there were 18 holidays (February 28, March 29-30, April 4, 5, 19 and 20, May 18-19, July 20, September 8, 9, 10, 17, 22, 23, 29, and 30) and five mid-holidays (March 31-April 1 and September 26-28). On mid-holidays, continuous trading stops at a random time between 14:29 and 14:30 for stocks, and at 14:45 for derivatives.

3.3 Sample

We are using five years of intraday data (2006-2010) of orders and transactions on the TASE options market. Two dates are missing from the transaction files in 2007: Sunday, October 7 and Monday, October 8. We exclude immediate-or-cancel (IOC), fill-or-kill (FOK), and adjusted orders (which are extremely rare in the sample). Open orders are automatically canceled at the end of the day, rather than kept open for the next day. Table 1 shows summary statistics for our dataset.

[Table 1 about here.]

Our sample covers 1228 trading days. The total number of orders on the forex options was stable between 3 and 4 millions of orders between 2006 and 2009 before a drastic decrease in 2010 to less than two million. More than 60% of the orders are canceled. Calls are on average more traded than puts during the sample period. Trading activity on the TA-25 is several orders of magnitude greater than the trading activity on the forex options. Since 2007, the number of orders was more than 100 million per years for the TA-25 options compared to 4 million at most for the options on the dollar. During this time period, transactions were close to 20 million for the index options, while they were about 0.74 million for the options on the dollar. Contrary to the forex options, index puts are more active (both in orders and transactions) than the corresponding calls.

3.4 Selected microstructure measures

From the five years of data on orders, transactions and the book we have at our disposal, we compute a number of microstructure measures. To be as comparable as possible, the measures are aggregated at the contract level (a contract being defined by its underlying, maturity date and strike) and the day-minute level. We always aggregate by the minute at which orders are placed within a given day, rather than that at which they are matched or canceled.

3.4.1 Trading patterns

To better understand how traders change their strategies to accommodate market incompleteness, we consider another set of measures:

1. Number of orders per minute;
2. Average size of orders;
3. Number of canceled orders relative to matched orders in a minute;

4. Size of canceled orders relative to matched orders;
5. Survival time of matched orders (used in survival analysis);
6. Survival time of canceled orders (used in survival analysis).

These measures allow us to test the predictions from Section 2. The frequency of orders and their average size can indicate strategic splitting. Canceled-to-matched ratios are helpful to determine a change in the trading pattern: more canceled orders can point to traders trying to gather information and repositioning their orders more often, as would a reduction in their size. Studying the survival time of matched and canceled orders, finally, serves to isolate whether different orders serve different purposes.

3.4.2 Information and intraday volatility

Market incompleteness could exacerbate trading costs, due to inventory costs and information asymmetries, and destabilize prices. To check whether this is the case, we compute the following measures:

7. Quoted bid-ask half-spread, defined as half the difference between the best bid and ask prices B_{it} and A_{it} in the book at time t for contract i (see for instance [Lin *et al.*, 1995](#)), relative to the quote midpoint $(A_{it} + B_{it})/2$:

$$\text{Quoted spread}_{it} = \frac{A_{it} - B_{it}}{A_{it} + B_{it}}; \quad (1)$$

8. Effective bid-ask half-spread relative to the midpoint at time t for contract i , defined as in [Bessembinder \(2003\)](#):

$$\text{Effective spread}_{it} = D_{it} \frac{P_{it} - M_{it}}{M_{it}}, \quad (2)$$

where P_{it} is the transaction price, M_{it} is the quote midpoint for the best bid-ask for contract i at time t , and D_{it} is an indicator variable of the trade

direction, which equals one for a buyer-initiated trade and minus one for a seller-initiated trade²;

9. Price impact, defined as in Bessembinder (2003, JFM):

$$\text{Price impact}_{itn} = D_{it} \frac{M_{i,t+n} - M_{it}}{M_{it}}. \quad (3)$$

For the number of period n , we consider 5-minute and 30-minute intervals as in Hendershott *et al.* (2011), as well as 1-minute and 10-minute lags. We report only the 5-minute lag here, since results were qualitatively similar;

10. First-order autocorrelation of log returns on the quote midpoints, in absolute value, sampled at the 30-minute frequency (Roll, 1984; Hasbrouck and Ho, 1987). This is computed daily, as opposed to the other minute-level measures;
11. Realized variance (RV), estimator of integrated variance (IV) in the absence of jumps (see for instance Andersen *et al.*, 2003), defined as the sum of squared returns and also computed daily:

$$\text{RV}_t = \sum_{i=1}^{M-1} r_{t,i+1}^2 \quad (4)$$

where the $r_{t,i}$ are intraday log-returns (with $i \in 1, \dots, M$) on day t . For this and the following volatility measures, we use a 5-minute sampling of the bid-ask midpoint.

12. Bipower variation (BPV), proposed by Barndorff-Nielsen and Shephard (2004), is a consistent estimator of IV in the presence of jumps (but without microstructure noise) :

$$\text{BPV} = \frac{\pi}{2} \left(\frac{M}{M-1} \sum_{i=1}^{M-1} |r_{t,i}| |r_{t,i+1}| \right) \quad (5)$$

² Note that we have access to individual orders so there is no ambiguity regarding who initiates the trade, and we therefore do not need to rely on a classification algorithm.

13. MedRV estimator of Andersen *et al.* (2012), designed to eliminate returns contaminated by a large jump, given by:

$$\text{medRV}_t = \frac{\pi}{6 - 4\sqrt{3} + \pi} \left(\frac{M}{M-2} \right) \sum_{i=2}^{M-1} \text{med}(|r_{t,i-1}|, |r_{t,i}|, |r_{t,i+1}|)^2. \quad (6)$$

The quoted spread reflects the liquidity available at the inside quote. However, it is an imperfect proxy of execution costs. First, it does not reflect where transactions actually occur, and so does not reflect actual transaction costs. Second, there are reasons to believe that trades taking place outside the spread have different characteristics than those taking place inside; for example, they could be larger on average (Lee, 1993). Effective spreads are more informative than quoted spreads because they reflect the price at which transactions actually occur.

The price impact is the market's reaction to the informational content embedded in a trade (Bessembinder, 2003). A reduction in the price impact signifies that the quotes midpoint moves less after a trade: the market finds less information in trades, or assigns less credibility to it. The autocorrelation of returns should be zero if market follow a random walk; on the other hand, informed trading is likely to be directional and induce autocorrelation.

The three estimators of intraday volatility give us a picture of price fluctuations under incompleteness, which also strongly relate to new information being incorporated.

3.4.3 Market activity and quality

In the limit, sufficiently large market incompleteness could trigger a market breakdown. To make sure this is not the case, we compute some standard measures of market activity and quality:

14. Total volume of orders per minute and contract, i.e. the sum of the quantities offered or requested in individual orders;

15. Total volume of transactions per minute and contract, i.e. the sum of the quantities exchanged;
16. Quoted depth, i.e. the sum of quantities available at the best bid and ask prices;
17. Realized bid-ask half-spread at time t for contract i , defined as in [Bessembinder \(2003\)](#):

$$\text{Realized spread}_{itn} = D_{it} \frac{P_{it} - M_{i,t+n}}{M_{it}}, \quad (7)$$

where $M_{i,t+n}$ is the quote midpoint considered n periods after the trade, a proxy for the security price after the execution of the trade. For the number of period n , we considered and report the same lags as for the price impact.

The realized spread, which goes back to [Stoll \(1985, 1989\)](#), allows us to measure the post-trade price reversal and can be viewed as a measure of trading costs net of the trade’s informational content.

For the effective spread, realized spread and price impact, if either side of the book is missing (at the time of the order, and after the lag for the realized spread and the price impact), the observation is ignored. If there is no transaction within a given minute, none of these spreads is computed.

Compared to most of the other measures used in this article, with the exception of autocorrelation, these three volatility measures are computed daily. They are derived from the returns on the quote midpoint for each contract, sampled at the 5-minute frequency.

3.4.4 Summary Statistics

Table 2 shows some summary statistics for our chosen measures.

[Table 2 about here.]

There is a decrease in the volume of the orders on Sundays, by 30% for the forex and only 13% for the TA-25. The number also decreases but at a lesser rate while the size of the order decreases substantially for the forex and is comparable on Sunday to the rest of the trading week. Quoted spread decreases by 11% for forex and by 4% for the index. Yet quoted depth does not change for the forex while it increases by almost 8% for the index. While the quoted depths are similar, quoted spreads for the forex options are more than three times the index ones.

Another symptom of the difference of activity between the two markets emerges when looking at the realized and effective spreads, as well as the price impact. The forex measures are almost twice the corresponding index measures. While the realized spread behavior on Sundays is similar to weekdays, the effective spread and the price impact are lower on Sundays for the forex.

The number of orders decreases on Sundays for both options, but the size of the orders decreases substantially for the forex, as does the size of the canceled orders relative to matched orders. These two measures stay stable across weekdays for the index. Finally, the survival time of the orders (canceled and matched) is much greater for the forex than for the index, and more so on Sundays.

Overall, two important microstructure characteristics emerge from Table 2: the first one is the clear difference between the two markets in terms of quantities and the second one is the difference between Sunday and other trading days.

4 Empirical strategy

4.1 Difference-in-differences estimation

To identify the impact of market incompleteness, we need to filter out the common factors affecting currency options between Sunday and the rest of the week, and also the common factors with regular options whose underlying is traded. To that effect, we use a difference-in-differences methodology with forex options as the treated group and options on the equity index as a control.

We are in a quasi-experimental setting, as opposed to a proper experimental setting which would require random assignment between the treated and control groups. Despite this inevitable flaw, the commonality in liquidity between forex and equity markets requires the use of the difference-in-differences setting to identify the impact of market incompleteness as cleanly as it is possible.

There is a considerable literature on commonality, both in prices and liquidity, across asset classes and across countries. Regarding price discovery, [Andersen *et al.* \(2007\)](#) find common dynamics at a high-frequency across forex, equity and bond markets. Regarding liquidity, [Chordia *et al.* \(2000\)](#) finds covariation in liquidity measures at the market and industry level, and [Hasbrouck and Seppi \(2001\)](#) in prices, order flows and liquidity. A recent paper by [Karolyi *et al.* \(2012\)](#) explores commonality in liquidity in equity markets across countries. For Israel, they find a relatively high level of commonality characteristic of modern, developed stock markets. [Mancini *et al.* \(2013\)](#) document strong commonality in market-wide liquidity of forex, equity, and bond markets. While these studies analyze spot assets, there is evidence that the liquidity patterns translate to the options ([Cao and Wei, 2010](#)).

To capture commonality, we use a classic difference-in-differences setting. Such a methodology has been used to identify causal effect in other recent papers on asymmetric information and liquidity, such as [Perotti and Rindi \(2010\)](#); [Hendershott *et al.* \(2011\)](#); [Kelly and Ljungqvist \(2012\)](#). The “treatment”, in our case, is the absence of trading on the underlying market, which is what happens every Sunday to the currency options. We need to identify the treatment effect to the treated series, the currency options, by using as control the index options, which always have a traded underlying. This is somewhat similar to the methodology used by [Kandel and Tkatch \(2009\)](#), also working with TASE data, which compares the liquidity of exchange-traded notes on local and U.S. indices on Sundays to estimate the link between the inventory cost and the bid-ask spread. They also use

weekday morning hours when European markets are still closed (which is not possible in our case, because the forex markets trade continuously during weekdays).

Our chosen microstructure measures are described in detail in subsection 3.4. For each measure y_{it} , aggregated by contract ID i and by minute of each day t , we set up a panel regression of the form:

$$y_{it} = \alpha + \beta \text{ sunday}_{it} + \gamma \text{ dollar}_{it} + \delta(\text{ sunday}_{it} \times \text{ dollar}_{it}) + \text{controls} + \epsilon_{it} \quad (8)$$

where sunday_{it} is an indicator variable for whether an observation is from a Sunday, and dollar_{it} is an indicator variable for whether it is from the currency options, as opposed to the equity index options. Our variable of interest is then δ , the difference-in-differences coefficient. Indeed, it is the incremental impact of the Sunday for the currency options, i.e. the average treatment effect for the treated series.

If δ is significantly different from zero, then something specific happens to the currency options on Sundays that is likely attributable to the underlying not being traded, since we filter out characteristics of currency options that exist over the whole week, as well as Sunday or first day effects that are common to both types of options.

It is likely that there is some (unknown) structure of dependence in the standard errors. In particular, we expect heteroscedasticity and serial correlation to influence our panel difference-in-differences results (Bertrand *et al.*, 2004). Following the recommendation from Petersen (2009), we use double-clustered standard errors as proposed by Cameron *et al.* (2011) and Thompson (2011). We cluster by day rather than by minute. This produces 1228 clusters, which seems sufficient. In the cross-section, we use the maximal number of cluster available, which depends on the measure. For most measures, we can use the almost 7500 clusters corresponding to the contract IDs, which should undoubtedly be enough to ensure asymptoticity. Our regressions control for the characteristics of

contracts: the underlying (exchange rate or equity index), the type of option (call or put), the moneyness (proxied by strike quintiles) and the maturity (proxied by the order to maturation), and an indicator variable for contracts that are in their week of maturity where trading behavior may be different. We provide results for unconditional regressions and models that include all the controls. In unreported work, we also estimate the regressions with different combinations of controls and the results are qualitatively identical.

4.2 Survival analysis

For two measures, the survival time of matched and of canceled orders, we use a slightly different estimation procedure. Rather than the OLS framework, we cast our difference-in-differences analysis in a Cox proportional-hazard model (Cox, 1972), better suited for time-to-event analysis. This semi-parametric model is of the form:

$$\lambda(t|X) = \lambda_0(t) \exp(\beta' X) \quad (9)$$

where λ is a hazard function left unspecified, λ_0 is the baseline hazard, and X is a vector of the covariates. The model is fitted by the method of partial likelihood. We report the exponential of the coefficients, which are the multiplicative coefficient of the hazard ratio, i.e. the rate of an event occurring in the group defined by X over the baseline rate of occurrence. A coefficient higher than 1 can be interpreted as a higher hazard rate than the baseline, and conversely for a coefficient lower than 1. We use the same controls and standard error adjustments as in the OLS panel regressions.

5 Empirical results

Results are reported in Tables 3 to 5. The main coefficients of interest are on the “Dollar \times Sunday” lines, which correspond to the marginal impact of incomplete-

ness (the spot market is closed on Sundays for options with the dollar underlying). When looking at the magnitude of the effect, it is useful to keep in mind that, when controls are excluded, the intercept is the average of the dependent variable for the equity index options on weekdays, and summing the coefficients for all four dummy variables (intercept, “Dollar”, “Sunday” and “Dollar \times Sunday”) gives the average of the dependent variable for the forex options on Sundays.

With controls, the reported coefficient corresponds to averages for put contracts in the middle strike quintile for the first series of options to mature, excluding the maturity week. In what follows, we generally discuss the coefficients without controls for the sake of simplicity. The results with controls serve to show the robustness of the effects, as discussed above.

5.1 Trading patterns

Table 3 shows results for the number of orders per minute and order size, the ratio of these two measures for canceled relative to matched orders, and the survival of matched and canceled orders (in a Cox proportional-hazard framework rather than the least square approach used for other measures).

[Table 3 about here.]

Under incompleteness, traders are submitting significantly smaller and significantly more orders (panel A). Without controls, the average order size declines substantially by 6.61 units, compared to an average weekday size of 14.3 contracts for the index options and 33.1 contracts ($14.3 + 18.8$) for the forex options. The number of orders per minute increases by 2.61 units, still without controls, from a weekday average of 17.3 and only 2.5 units for the index and dollar underlying respectively. Submitting smaller, more frequent orders is consistent with more order splitting by forex option traders.

The canceled-to-matched ratio is consistent with the increase in order splitting. Canceled orders become relatively more frequent than matched orders, and their

relative size is much smaller. Under incompleteness, there are 0.276 additional canceled contracts relative to matched contracts per minute, with a relative size reduced by 2.46 units, without controls. On average, canceled orders are much larger than matched order (on weekdays, 4.75 times for TA-25 options and 10.52 times for forex options). Such a reduction in size with an increase in cancellation is to be expected if many of the canceled orders are small exploratory orders, that periodically need to be repositioned.

Finally, the survival analysis reveals that filled orders execute significantly faster, by 2% (corresponding to a multiplicative factor of 1.02), under incompleteness, while canceled orders are canceled more slowly, by 16.8% (multiplicative factor of 0.832), all without controls. Note, of course, that whether an order ends up in one group or the other is determined endogenously.

These results suggest that the increased order splitting leads to faster executions and later cancellations, indicating a quite substantial change in order submission strategy. Depending on their objective, traders become more patient with respect to their resting orders that provide liquidity (because cancels are less frequent) but are less patient regarding their executions (because they happen relatively faster). Note that the faster matching is a marginal impact; as is apparent from Table 2, the survival time increases on Sunday relative to other days for matched orders, but less so for forex options than equity index options.

All in all, it appears that in response to incompleteness, traders split their orders more and cancel more orders. The survival results are slightly more complex, but suggests that some traders still demand immediacy. Higher demand for immediacy may translate into more order aggressiveness. We therefore need to look at a different set of variables to see whether the impact of immediacy-demanding traders dominates.

5.2 Information and intraday volatility

As discussed above, there is a usual trade-off between immediacy of execution and price. Table 4 shows the quoted and effective bid-ask spreads, price impact and autocorrelation, as well as intraday variance.

[Table 4 about here.]

Under incompleteness, the quoted spread is declines quite dramatically by 1.45%, to be compared to weekdays averages of 4.62% and 15.1% for the TA-25 and forex options respectively, excluding controls. The effective spread is also tightened under incompleteness by a relatively small amount (-0.36%), but which needs to be compared to weekdays averages of 1.75% for TA-25 options and 4.51% for forex options. This lower spread is what is expected from a context of lower demand for immediacy, most likely dominated by uninformed traders.

There is a significant reduction in the informational component of the spread, the price impact, which shows that overall the informational content of trades is lower under incompleteness. It is reduced by 0.69%, from a weekday average of 1.25% and 3.51% for index and forex options respectively. This favors the interpretation that a large part of the trading activity is uninformed and about managing inventory risks, and/or that the smaller, more frequent orders successfully hide the private information.

In this context, market efficiency seems to be improved, with a reduction in autocorrelation of almost 3%, from a weekday average of 20% for forex options, and 19.4% for TA-25 options. Returns are closer to a random walk, which likely confirms less informed trading activity: information tends to be directional and induce autocorrelation.

Volatility consistently declines under incompleteness. On weekdays, daily RV is 0.84 for forex options and 0.52 for equity index options. Under incompleteness, RV is significantly reduced by a large magnitude (-0.24). Volatility estimated

using bipower variation is generally lower, but the pattern is the same. Under incompleteness, bipower variation is lower by 0.14, compared to a 0.18 average for TA-25 options and 0.27 for forex options on weekdays. Finally, medRV, which filters out large jumps, also shows a significant reduction to 0.20 from 0.44 on weekdays for currency options and 0.27 for equity options.

These results substantiate the side of the literature arguing that incomplete markets can be less volatile. However, the channel through which this happens is very likely to be information: the spot market is the main source of information for forex option traders.

5.3 Market activity and quality

Having made earlier the hypothesis that incompleteness was likely to discourage part of the trading activity, we consider measures of market activity and quality. Table 5 shows the difference-in-difference results for order and transaction volumes, quoted depth, and realized spread.

[Table 5 about here.]

Order volumes are significantly lower on Sundays for forex options, with, when excluding controls, 6.14 fewer contracts per minute and contract ID, up to 11.3 fewer contracts traded with controls. The magnitude is quite large compared to the rest of the week for the control group, or 153 units on average.

The effect is even more marked for the volume of transaction. Excluding controls, 4.82 less units are exchanged, from a baseline of 29.76 for the equity index options on weekdays.

As expected, there is a non-trivial reduction in volumes. However, these results do not suggest that incompleteness leads to a market breakdown.

Quoted depth is not significantly affected by incompleteness: despite a negative coefficient, there is a lot of variability. The order splitting strategy does not lead to

a reduction in the quantities available at the best bid and ask. Non-informational trading costs, measured by the realized spread, are not significantly changing either, and the market therefore seems to be absorbing the changes of trading strategies well.

6 Conclusion

In this paper, we use the natural experiment of the Tel Aviv Stock Exchange (TASE) to analyze how order submission patterns, trading and hedging strategies, and overall market impact are affected by market incompleteness. Options on the dollar are traded on Sundays on the TASE, while their underlying is not, which we use in a difference-in-differences setting, with options on the equity index as control.

Overall, our evidence suggests that market incompleteness has two major effects on traders behaviors. First, likely because of expected higher adverse selection, traders change their patterns, resorting to higher strategic order splitting, nonetheless somewhat reducing their overall trading volumes. Second, because of actually lower information caused by the spot market closure, prices are in fact more efficient and volatility is lower, and aggregate trading costs during periods of incompleteness are slightly reduced, suggesting that informed trading plays a lesser role.

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Table 1: Summary statistics of the raw dataset

This table shows summary statistics for the raw dataset we use to compute the selected measures. For each underlying, it reports the number of dates in the orders and transactions database, and the number of individual orders and transactions for these dates, grouped per year. A very large majority of orders are limit orders, even though fill-or-kill (FOK) orders and immediate-or-cancel (IOC) orders, which we exclude from our analysis, are also allowed. Unit calls are call contracts with a strike of 1, and are therefore always exercised. Since they behave rather differently than other series, and have only small volumes, we choose to exclude them. Adjusted orders and transactions, and canceled transaction are also excluded. Note that open orders are automatically canceled at the end of the day, rather than kept until the next day.

	2006	2007	2008	2009	2010	Total
# trading days	248	243	245	248	244	1,228
Options on the dollar						
# orders	3,471,431	3,352,543	3,118,451	4,055,307	1,886,083	15,883,815
o/w calls	1,884,889	1,808,672	1,839,704	2,350,713	1,120,435	9,004,413
o/w puts	1,586,542	1,543,871	1,278,747	1,704,594	765,648	6,879,402
o/w FOK	172	188	281	131	62	834
o/w IOC	8,213	6,408	33,357	25,567	15,012	88,557
o/w unit calls	6,700	6,711	5,784	3,373	2,948	25,516
o/w adjusted	9,340	1,735	0	0	0	11,075
o/w canceled	2,876,370	2,511,063	1,845,360	3,034,559	1,298,086	11,565,438
o/w open	160,068	196,560	223,645	201,015	124,173	905,461
# transactions	321,240	465,974	740,529	577,625	330,855	2,436,223
o/w calls	222,867	287,963	479,428	348,660	200,697	1,539,615
o/w puts	98,373	178,011	261,101	228,965	130,158	896,608
o/w unit calls	1,086	982	1,254	654	638	4,614
o/w adjusted	2,424	2,482	2,833	4,005	5,947	17,691
o/w canceled	6	56	60	64	27	213
Options on the TA-25 equity index						
# orders	62,556,574	110,659,667	158,046,525	117,585,573	120,289,029	569,137,368
o/w calls	32,163,151	55,049,637	76,903,475	58,350,359	58,213,508	280,680,130
o/w puts	30,393,423	55,610,030	81,143,050	59,235,214	62,075,521	288,457,238
o/w FOK	5,518	3,644	4,236	9,848	3,933	27,179
o/w IOC	71,519	2,084,168	4,790,161	4,177,960	5,937,922	17,061,730
o/w unit calls	360,993	69,120	79,658	74,691	93,365	677,827
o/w adjusted	18,605	2,389	0	0	0	20,994
o/w canceled	46,653,157	87,782,933	130,550,589	93,852,308	93,235,175	452,074,162
o/w open	773,781	839,315	809,850	792,157	898,741	4,113,844
# transactions	12,917,088	18,602,501	21,677,809	18,406,382	21,186,218	92,789,998
o/w calls	6,891,374	9,623,518	11,055,723	9,564,684	10,692,703	47,828,002
o/w puts	6,025,714	8,978,983	10,622,086	8,841,698	10,493,515	44,961,996
o/w unit calls	4,855	5,837	4,070	4,191	3,805	22,758
o/w adjusted	1,753	1,316	2,264	2,361	2,676	10,370
o/w canceled	47	59	48	54	269	477

(o/w: of which)

Table 2: Summary statistics of the selected measures

This table shows the mean of our selected measures on Sunday vs other days for the forex options and TA-25 options, with the p -value of a simple t -test. The measures' labels match those of Subsection 3.4, which details the way each measure is constructed.

Measure	Forex options			TA-25 options		
	Sunday	Other days	p -value of t -test	Sunday	Other days	p -value of t -test
1. Number of orders	2.11	2.49	0.00	14.31	17.30	0.00
2. Size of orders	26.28	33.11	0.00	14.13	14.34	0.00
3. Number of canceled to matched orders	1.40	1.61	0.00	5.10	5.58	0.00
4. Size of canceled to matched orders	8.11	10.52	0.00	4.79	4.75	0.00
5. Survival of matched orders (min.)	4.97	3.57	0.00	1.71	1.22	0.00
6. Survival of canceled orders (min.)	15.32	7.62	0.00	1.75	1.15	0.00
7. Quoted spread	13.43%	15.09%	0.00	4.41%	4.61%	0.00
8. Effective spread	4.04%	4.51%	0.00	1.63%	1.75%	0.00
9. Price impact (5 min.)	2.72%	3.51%	0.00	1.13%	1.25%	0.10
10. Autocorrelation (30 min.)	17.6%	19.95%	0.00	19.7%	19.4%	0.00
11. Realized variance (5 min.)	0.60	0.84	0.00	0.52	0.52	0.90
12. Bipower variation (5 min.)	0.12	0.27	0.00	0.17	0.18	0.13
13. MedRV (5 min.)	0.20	0.44	0.00	0.26	0.27	0.24
14. Volume of orders	59.72	86.09	0.00	133.15	153.37	0.00
15. Volume of transactions	26.91	34.96	0.00	26.52	29.76	0.00
16. Quoted depth	85.38	85.29	0.63	70.07	64.99	0.00
17. Realized spread (5 min.)	1.26%	0.89%	0.12	0.50%	0.49%	0.89

Table 3: Trading patterns

Panel A and B summarize the panel regressions results for the order size and the number of orders, the ratio of canceled to matched orders for the order size and the number of orders. Panel C summarizes the Cox proportional hazard regression for matched and canceled orders. In Panel C, the exponential of the coefficients are reported, i.e. are the multiplicative coefficient of the hazard ratio. All measures are aggregated per day-minute and contract. The standard error estimates are clustered by group and time. Controls are booleans for contract type (put or call), strike quintiles, order to maturity and maturity week (full results are reported in the appendix). Group clusters are based on contract ids. Time clusters are based on individual days. The star symbols (***, **, *, .) denote corresponding p -value lower than 0.1%, 1%, 5% and 10% respectively.

Panel A. Number and size of orders

	Order size		Number of orders	
Intercept	14.3***	17.8***	17.3***	15.4***
(S.E.)	(0.213)	(0.417)	(0.322)	(0.466)
Dollar	18.8***	19.2***	-14.8***	-15.2***
(S.E.)	(0.647)	(0.645)	(0.324)	(0.424)
Sunday	-0.215	-0.193	-2.99***	-3.48***
(S.E.)	(0.211)	(0.2)	(0.249)	(0.312)
Dollar \times Sunday	-6.61***	-6.18***	2.61***	1.56***
(S.E.)	(0.857)	(0.861)	(0.249)	(0.347)
Controls	None	All	None	All
Obs.	39,464,604	39,464,604	39,464,604	39,464,604
p of F stat.	0***	0***	0***	0***

Panel B. Canceled-to-matched ratio of the number and size of orders

	Canceled-to-matched (order size)		Canceled-to-matched (number of order)	
Intercept	4.75***	8.05***	5.58***	4.87***
(S.E.)	(0.067)	(0.276)	(0.0745)	(0.191)
Dollar	5.77***	5.71***	-3.97***	-4.09***
(S.E.)	(0.168)	(0.172)	(0.0784)	(0.0978)
Sunday	0.0452	0.163**	-0.489***	-0.527***
(S.E.)	(0.0556)	(0.0603)	(0.0707)	(0.0723)
Dollar \times Sunday	-2.46***	-2.45***	0.276***	0.295***
(S.E.)	(0.193)	(0.196)	(0.0751)	(0.0767)
Controls	None	All	None	All
Obs.	14,340,435	14,340,435	14,340,435	14,340,435
p of F stat.	0***	0***	0***	0***

Panel C. Survival of matched and canceled orders

	Survival of matched orders		Survival of canceled orders	
Dollar	0.669***	NA	0.379***	NA
(S.E.)	(0.00207)	NA	(0.00318)	NA
Sunday	0.944***	NA	0.915***	NA
(S.E.)	(0.00226)	NA	(0.00345)	NA
Dollar \times Sunday	1.020***	NA	0.832***	NA
(S.E.)	(0.00461)	NA	(0.00730)	NA
Controls	None	All	None	All
Obs.	1,850,615	1,850,615	5,198,471	5,198,471

Table 4: Information and intraday volatility

Panel A summarizes the panel regressions results for the average quoted spread and effective spread, aggregated per day-minute and contract. Panel B summarizes the panel regressions results for the price impact (5-minute lag), aggregated per day-minute and contract, and the autocorrelation of returns on quote midpoint in absolute value, sampled at a 30 minute frequency and aggregated per day and contract. Panel C summarizes the panel regressions results for the realized variance, bipower variation and medRV computed on the quote midpoint returns, sampled at a 5-minute frequency and aggregated per day and contract. The standard error estimates are clustered by group and date. Controls are booleans for contract type (put or call), strike quintiles, order to maturity and maturity week (full results are reported in the appendix). Group clusters are based on contract ids. Time clusters are based on individual days. The star symbols (***, **, *, .) denote corresponding p -value lower than 0.1%, 1%, 5% and 10% respectively.

Panel A. Quoted and effective spread

	Quoted spread (%)		Effective spread (%)	
Intercept	4.62***	8.38***	1.746***	0.818***
(S.E.)	(0.0867)	(0.403)	(0.0361)	(0.0382)
Dollar	10.5***	9.8***	2.761***	2.769***
(S.E.)	(0.411)	(0.376)	(0.0924)	(0.0879)
Sunday	-0.208**	-0.285**	-0.112***	-0.257***
(S.E.)	(0.07)	(0.101)	(0.0320)	(0.0360)
Dollar \times Sunday	-1.45***	-1.2***	-0.359***	-0.307***
(S.E.)	(0.33)	(0.281)	(0.0553)	(0.0537)
Controls	None	All	None	All
Obs.	37,587,530	37,587,530	13,967,773	13,967,773
p of F stat.	0***	0***	0***	0***

Panel B. Price impact (5 min.) and midpoint returns autocorrelation (30 min.)

	Price impact (5 min., %)		Autocorrelation (30 min., %)	
Intercept	1.25***	1.25***	19.357***	19.671***
(S.E.)	(0.0699)	(0.0699)	(0.168)	(0.244)
Dollar	2.27***	2.27***	0.595*	1.787***
(S.E.)	(0.208)	(0.208)	(0.278)	(0.262)
Sunday	-0.111	-0.111	0.347	0.342
(S.E.)	(0.0827)	(0.0827)	(0.373)	(0.370)
Dollar \times Sunday	-0.686*	-0.686*	-2.698***	-2.758***
(S.E.)	(0.304)	(0.304)	(0.477)	(0.486)
Controls	None	All	None	All
Obs.	14,353,576	14,353,576	274,651	274,651
p of F stat.	0***	0***	0***	0***

Panel C. Realized variance, bipower variation and medRV

	Realized variance		Bipower variation		MedRV	
Intercept	0.52456***	0.9331***	0.1822***	0.2878***	0.2744***	0.4487***
(S.E.)	(0.0245)	(0.0561)	(0.00812)	(0.0198)	(0.0138)	(0.0332)
Dollar	0.31980***	0.5109***	0.0961***	0.1593***	0.1618***	0.2623***
(S.E.)	(0.0442)	(0.0493)	(0.01697)	(0.0195)	(0.0286)	(0.0328)
Sunday	-0.00188	-0.0116	-0.0107	-0.0155	-0.0147	-0.0208
(S.E.)	(0.0327)	(0.0331)	(0.01331)	(0.0133)	(0.0224)	(0.0224)
Dollar \times Sunday	-0.24438***	-0.2377***	-0.1441***	-0.1427***	-0.2242***	-0.2214***
(S.E.)	(0.0471)	(0.0471)	(0.02035)	(0.0202)	(0.0348)	(0.0346)
Controls	None	All	None	All	None	All
Obs.	295,270	295,270	294,520	294,520	293,847	293,847
p of F stat.	0***	0***	0***	0***	0***	0***

Table 5: Market activity and quality

This table summarizes the panel regressions results for the volume of orders, the average quoted depth and average realized spread (5-minute lag). Measures are aggregated per day-minute and contract. The standard error estimates are clustered by group and time. Controls are booleans for contract type (put or call), strike quintiles, order to maturity and maturity week (full results are reported in the appendix). Group clusters are based on contract ids. Time clusters are based on individual days. The star symbols (***, **, *, .) denote corresponding p -value lower than 0.1%, 1%, 5% and 10% respectively.

Panel A. Volume of orders and transactions

	Volume of orders		Volume of transactions	
Intercept	153***	165***	29.76***	24.67***
(S.E.)	(2.56)	(4.82)	(0.487)	(1.085)
Dollar	-67.3***	-68.6***	5.20***	4.89***
(S.E.)	(2.79)	(3.37)	(0.950)	(0.947)
Sunday	-20.2***	-22.8***	-3.24***	-4.47***
(S.E.)	(2.59)	(3.01)	(0.547)	(0.602)
Dollar \times Sunday	-6.14*	-11.3**	-4.82***	-5.06***
(S.E.)	(3)	(3.7)	(1.271)	(1.207)
Controls	None	All	None	All
Obs.	39,464,604	39,464,604	14,431,755	14,431,755
p of F stat.	0***	0***	0***	0***

Panel B. Quoted depth and realized spread (5 min.)

	Quoted depth		Realized spread (5 min., %)	
Intercept	65***	72.7***	0.492***	-0.417
(S.E.)	(1.13)	(17.5)	(0.0692)	(1.06)
Dollar	20.3***	21.5.	0.398*	0.412*
(S.E.)	(2.03)	(11.9)	(0.2)	(0.201)
Sunday	5.09***	3.71**	0.00976	-0.0723
(S.E.)	(1.28)	(1.40)	(0.0841)	(0.0875)
Dollar \times Sunday	-4.99.	-6.13	0.364	0.338
(S.E.)	(2.98)	(4.01)	(0.3)	(0.304)
Controls	None	All	None	All
Obs.	39,296,924	39,296,924	14,353,576	14,353,576
p of F stat.	0***	0***	0***	0***