How does Price Discovery Take Place in the Option Market? Evidence from S&P 500 Index Options

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Abstract

We propose a novel methodology to quantify the price discovery contribution of options to the underlying asset value. Using options on the S&P 50 index, we show fundamental changes in this market during the sample period between 2004 and 2018. We find an important shift in price discovery from call to put options, and from long-term contracts to short-term contracts. We show that volatility and jump risks have different effects on the information share of options, and that these effects vary across years, contract types, and maturities. Our results suggest that information flows in the option market change across time and depend on option characteristics, implying that these contracts are actively used for risk-sharing opportunities in this market.

Keywords: Price discovery, Index option, Information Share, Market Completeness, Market Efficiency

JEL classification: G14, G23.

1 Introduction

Financial markets play a distinctive role in the economy as venues where asset prices incorporate new information through trading. This price discovery process is crucial for market participants wishing to invest at fair valuations and at low costs. Never simple, price discovery is particularly challenging in modern financial markets, where a multiplicity of security contracts implies that information is spread across many sources. In particular, technological advances and market innovations have made option markets a venue in which hundreds and even thousands of contracts are available to trade, all of them linked to the same underlying security.

Given the large number of option contracts available, which span several maturities and exercise values, it emerges the question of how to compute the relative efficiency among this large number of contracts in the price discovery process of the underlying asset value. Moreover, if options cause traders to migrate across markets, how is information impounded among these contracts? Do investors, if given the opportunity, rapidly use new derivative contracts to tailor to their financial needs? The goal of this paper is to propose a methodology to answer these types of questions, characterizing the information share of each contract, and to study the main drivers of these quantities. We use prices of all traded options associated to a particular underlying asset, in our case the S&P 500 index, to quantify the individual contribution of an option with respect to the underlying asset value.

Option contracts derive their value from the underlying asset's future states, making them a unique source to isolate informative price movements about this asset. The importance of option markets in the price discovery process of the underlying asset value hinges on several elements. First, Black (1975) argues that the embedded leverage in option contracts facilitates trading for informed traders facing capital constraints. Second, options enhance welfare by completing markets Ross (1976), so increasing the availability of option contracts to informed traders allows them to select different contracts and construct complex strategies from these securities. As documented in Chakravarty et al. (2004) and Rourke (2013), option contracts of diverse characteristics impound differently new information related to future stock prices. Moreover, the recent emergence of options, featuring sequential issuance of contracts expiring one week apart, has allowed investors to control exposure to specific risks associated with price jumps Andersen et al. (2017). Third, Figlewski and Webb (1993) and Lin and Lu (2015) argue that trading in options can relax short-sale constraints by allowing investors to take positions in options, thus enabling informed traders to circumvent such restrictions in the underlying asset.

A methodological complication for price discovery analyses in option markets is the size of the panel. Standard methodologies to account for the information share of a security, like the one proposed in Hasbrouck (1995), are not suited to handle this large cross-section of contracts. These methodologies decompose price changes into innovations in the fundamental value (a permanent component) and in a noise component (a temporary shock). The information share (IS) of different price series is then determined by looking at the share of common innovation variance that is explained by each price series. The IS parameters are typically computed from reduced form errors of a vector error correction model (VECM), which relies on a Cholesky factorization. This step makes the computation of IS dependent on the ordering of the series, so with a large set of observations, the number of possible orderings increases exponentially and the calculations become infeasible. Nonetheless, there is an extensive literature that has successfully used large-dimension common factor models (see Bai and Ng (2008) for a complete review on the topic) to adapt the computation of IS from a large cross-section of price series.

We build on the work of Westerlund et al. (2017) and use a factor analytical approach to isolate the amount of variation explained by individual time-series in a panel of option prices. The advantage of this method lies in the estimation of an unobservable factor from a large cross-section of observations, which is perfectly suited for the large dimensional nature of option panels. To estimate the information share of an option for a given day, we first employ intraday option data to obtain an imperfect proxy of the underlying's unobservable efficient price, similar in spirit to the martingale restriction used in Longstaff (1995). From these option-implied prices, we construct a balanced panel and use the factor analytical approach of Westerlund et al. (2017) to compute the daily information share of each option in the panel. By pooling hundreds of observations across maturities and moneyness, our approach offers a first-time view of the information flow structure in an option market.

Using this method, we estimate daily IS from July 2004 to December 2018. Our results evidence two significant changes in the incorporation of information through option contracts. First, there is a marked shift in information from calls to puts: at the start of the sample, we observe a relative balanced distribution of information between the two types of contracts, with about 51% of the total information contained in call options. Across the sample, we observe how this proportion steadily moves towards put options, which impound over 70% of the total information in the panel by the end of the sample. Second, there is an important transfer of information from long-term contracts to short-term contracts. At the beginning of the sample, long-term contracts (contracts with more than 60 days to maturity) account for 52% of information, while short-term contracts (contracts expiring in 30 days or less) do so for only 22%. These proportions gradually move over time, and during the last year of the sample, we observe that only 20% of the information comes from long-term contracts, while 55% comes from short-term contracts. The previous structural changes are not observable when we use existent market measures such as volume, number of contracts, and number of option maturities, which speaks about the economic importance of the proposed methodology to understand price dynamics in the option market.

To further shed light on the structural changes that have affect option markets, we use the introduction of new contract expirations to investigate the effects of market completeness on price discovery. Ross (1976) shows theoretically that introducing new options contracts enhances market completeness, leading to an increase in market efficiency. However, empirical studies on how information content changes during the market completion process are scarce. We fill this void by pinpointing the dates for the introduction of 4 types of SP500 index options: weeklys introduced in 2005, quarterlys introduced in 2007, end-of-months introduced in 2014, and Monday/Wednesday weeklys introduced in 2016 (details provided in Appendix). Overall, we do not observe immediate structural changes of information shares after the introduction dates. Instead, we observe a slow and gradual process that takes years for IS to shift from existing contracts to new type of contracts. For instance, Weekly contracts are introduced in 2005, but they do not see significant change in their information share until 2010, when it starts to grow from 2% IS to 48% in 2018. This indicates that changes in the incorporation of new information from market completion is not immediate, but rather, that it is a process that happens progressively and depends on the transactional efficiency of the market.

Next, to understand what type of information is impounded in option contracts, we conduct a year-by-year beta regression of our IS measure on several variables that capture important aspects of the underlying asset price behaviour. We find that increments of the S&P 500 index volatility are generally associated with a decrease in the IS of options throughout the sample, showing that shocks of this type are less likely to be incorporated through a particular type of option. In contrast, we find that the relation of information shares and the leverage effect, as measured by the correlation between the underlying volatility and its return, depends on the characteristics of the option. This is also observed when we regress on jump risk innovations. For all these variables, the magnitude and significance of the relation varies substantially across time. These results reveal that information about underlying asset dynamics are distinctly incorporated in option prices.

Price discovery studies using option data typically ignore how information is distributed across option contracts, and center the discussion on whether the option market leads or lags the underlying asset market (e.g. the stock). The methodologies used in this literature vary greatly, and results are mixed. On one hand, several studies employ quantities computed from option markets to study subsequent information about underlying asset values. For instance, variables such as abnormal trading volume and order imbalance can predict future stock returns (see for instance, Johnson and So, 2012; Lin and Lu, 2015; Ge et al., 2016). In Amaya et al. (2022), variables from intraday option prices are used to explain future volatility and returns on the S&P 500 index. On the other hand, a different group of studies explicitly quantify where price discovery occurs, some of them finding a small or even negligible role to equity option prices (see Muravyev et al., 2013) and others finding considerable information in these prices (Chakravarty et al., 2004; Rourke, 2013; Patel et al., 2020). We add to this literature by investigating how price discovery happens within the option market, and documenting structural changes across time, thus providing a complementary view to the existent literature.

We also contribute to the literature that studies the measurement of price discovery in financial markets. The term we use, information share, originates from the breakthrough work of Hasbrouck (1995) and has been applied in many empirical studies. For instance, Harris et al. (2002) and Hupperets and Menkveld (2002) use this metric with US equities and European equities cross-listed in the US market, De Jong et al. (1998) and Covrig and Melvin (2002) employ it to analyze foreign exchange markets, Mizrach and Neely (2008) study the US Treasury market, and Dittmar and Yuan (2008) employ it to analyze corporate and sovereign bonds in emerging markets. Despite its popularity, Hasbrouck information share measure is not without its drawbacks: it is difficulty to obtain standard errors for inference, and it is subject to overparametrization since it requires suitable identifying restrictions due to the VECM model setting (Karabiyik et al., 2021). As a remedy, Harris et al. (2002) recommend an alternative measure, known as component share, which offers several advantages over Hasbrouck (1995)'s information share. Although this method enables asymptotically standard inference, it still suffers from overparametrization. Recent papers propose alternatives methodologies that offer several advantages by casting the problem in terms of a factor model estimation. Among them, we find Westerlund et al. (2017), which incorporates the latest advances in factor model literature for large dimension data to develops a simple method that works with large number of prices. This method solves the overparametrization problem in Hasbrouck's information share, while making the computation of information shares feasible for a large panel data. We build our framework on this method, providing a new application of these methods in the study of price discovery for large-dimension panel of option prices.

Our paper differs from previous studies on market completeness, as these works are mainly theoretical (see Staum, 2007). A market is complete when all risk factors are traded and perfect risk transfer is possible. Classic theories assume a complete market yet in practice, markets are never complete. Thus, many studies focus on relaxing the classic complete market assumption, such as option valuation in incomplete markets (e.g., El Karoui and Quenez, 1995; Henderson, 2007) and portfolio optimization in incomplete markets (see Skiadas, 2006). Empirical studies on options market completion have studied the impact of option listing on the spot market volatility (e.g., Damodaran and Lim, 1991; Mayhew, 1999; Mayhew and Mihov, 2004) and spot market quality (Kumar et al., 1998). In this paper, we revisit the classic work of Ross (1976), and look at a series of market completion events to understand changes in market efficiency. In particular, the way information in incorporated in newly introduced contracts. Does market efficiency responds immediately to new contract introduction, or does it take time to happen? This is by nature an empirical question that we answer in this paper. Our result suggests that market participants do not immediately use new contracts, but that their adoption, and the gains in efficiency associated with their use, are slow to materialize.

The rest of this paper is organized as follows. Section 2 introduces the institutional background of the market completion process for S&P500 index options. Section 3 introduces our price discovery model that derives information share measure. Section 4 presents our dataset and the estimation method of our information share measure. Section 5 lays out the empirical analysis and findings and Section 6 concludes the paper.

2 Institutional Background: New Options Introduction for S&P500 Index Options Market

In this section, we document the introduction of new option contracts for SP500 index. We illustrate such the events in Figure 1, where the total volume of SP500 index options from 2004 to 2018 is represented by the blue line, and the event dates are represented by the vertical lines. The data include all available SP500 index options from Option Metrics.

The nowadays very popular SPX weeklys were initially introduced on October 28, 2005 [1]. They were created for customers who target opportunities tied to specific market

[1]The exact date for weekly introduction, Oct 28, 2005, is found by first collecting the rough range of the time of the introduction, i.e. Oct 2005, from CBOE (Cboe Global Markets, Inc.) website and anecdotal evidence, and then from this range checking Option Metrics data for the exact date. Specifically, we download all available SPX options data on Option Metrics and group the data by date and maturity. We observe that one additional maturity shows up in Oct 28, 2005 compared to the previous day, Oct 27, 2005, and this added one has 7 days to maturity, perfectly matching the definition

events, such as earnings and government reports[2]. However, they didn't draw much attention upon introduction, as we can see in Figure 1 there is only a small increase in overall volume around October 2005.

As the standard SP500 index options (i.e. the monthly-traded SPX), the weeklys traded solely in open outcry initially. It's not until the December 2, 2010[3] that weeklys transit from AM-settled to PM-settled, and from solely open outcry to a hybrid trading model, which incorporates electronic and open outcry trading on one exchange. Note that two events happened at the same time. First, the transition to a hybrid trading model enabled electronic trading which catered the point-and-click customers[4]. Second, the transition from AM-settlement to PM-settlement helped reduce the gap risk arising from overnight price change[5]. In Figure 1, we don't see an immediate increase in overall trading volume on December 2010, but we do see a substantial rise in the following semi-year.

Weeklys have also seen more maturities available over time. When weeklys are first introduced in 2005, they were all listed on Fridays and would expire on the following Friday. On July 1, 2010[6], CBOE expands weekly options by one day (that is, weeklys were listed on Thursdays instead of Fridays, and would still expire on the following Friday), which allows traders to more easily "roll" from one weekly expiration to another.

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of a weekly option. We use this way to pin down other dates too when the news source does not provide a specific event date.

[2]CBOE 2012Q3 earnings call:
https://ir.cboe.com/sites/cboe-ir-v1/files/cboe/financial-information/quarterly-results/2012-3/cboe-holdings-3q12-prepared-remarks.pdf

[3]CBOE Regulatory Circular:
http://www.cecouncil.com/media/2607/ae1ba790-4f87-4493-93cd-3420d24683af.pdf

[4]CBOE 2012Q1 earnings call:
https://ir.cboe.com/sites/cboe-ir-v1/files/cboe/news-and-events/events/cboe-1q-2012-earnings-call-remarks.pdf

[5]The down side to European options is that they settle on the morning following their last trading day – which creates overnight risk: if the underlying being used were to gap at the open from where it closed the night before – it is possible that option traders who carried open positions overnight could get burned and suffer trading losses.

[6]CBOE press release:
https://ir.cboe.com/news-and-events/2010/06-30-2010/cboe-expands-weekly-options-one-day-allows-traders-more-easily-roll-one-weekly-expiration-another

Still, weeklys were only available roughly 1 week before expiration, and that's in stark contrast with weeklys nowdays that list up to 12 consecutive weeks. When did that expansion happen? We were not able to find the exact dates from the typical news source, and thus we turned to Option Metrics data to pin down the dates. Specifically, we list the dates on which more maturites are observed than the previous day, and then manually check those days and then find the first day when an additional Friday listing is observed compared to the previous day. The specific event dates we find are as follows: On May 31, 2012, available listing expanded from 1 week to 5 weeks; On January 16 and 29 , 2014, available listing expanded to 7 and 8 weeks, respectively; From September 4 to November 13, 2014, available listing further expanded from 9 to 12 weeks. This is not the end of the increasing availability for weeklys as weeklys became increasingly popular. In addition to these initial Friday-expiration weeklys, Wednesday-expiring and Monday-expiring weeklys were introduced in February 23 and Aug 15, 2016, respectively[7], allowing investors to fine-tune their trading time frames with even greater precision and flexibility. Back to Figure 1, the expansion in listing weeklys one day earlier in July 2010 did not make much difference, while the expansion of available listings in May 2012, January 2014 and September-November 2014 all happened with a jump in total trading volume. The overall volume around the introduction of Monday and Wednesday weeklys fluctuated and is not clear how it responded to the events.

Compared to the quick growth of new contracts for short-dated options, the very-long-dated options have also added available expirations but only slightly. SPX LEAPS (Long-term Equity AnticiPation Securities), options contracts with expiration dates that are longer than one year, listed only 2 expirations throughout 2004, and this number increased only to 3 or 4 in 2018. I haven't found specific events from the news source.

[7]CBOE press release:
https://ir.cboe.com/news-and-events/2016/02-01-2016/cboe-list-spx-wednesday-expiring-weeklys-options
CBOE press release:
https://ir.cboe.com/news-and-events/2016/07-11-2016/cboe-list-spx-monday-expiring-weeklys-options

From the data, the increase seems to be an outcome of 1) adding new expiration before one is about to expire 2) adding January expiration to the existing June and December expiration.

Another type of new contracts introduced are End-of-Quarter and End-of-Month contracts, complementing the regular SPX options that typically expire on Fridays. On February 21, 2007[8], SPX End-of-Quarter Options (or quarterlys) were introduced. As the name has suggested, the quarterlys expire on the last trading day of each quarter to coincide with end-of-quarter accounting practices, and have since become popular with money managers who use options to rebalance or settle portfolios on the last day of each quarter[9]. In similar spirit, on July 7, 2014, SPX End-of-Month Options (or EOMs) launched[10] in response to requests from asset managers who need instruments matching end-of-month fund cycles and fund performance periods. Upon completion of this change, all PM-settled SPX option series, including those which expire at the End-of-Week, End-of-Month and End-of-Quarter, all transacted on the Hybrid trading platform under the symbol SPXW[11]. In Figure 1, we can see a big increase in total trading volume concurring and in the month following the introduction of quarterlys in February 2007, and a small increase around the launch of EOMs in July 2014.

3 Model and Information Share Measure

This section lays out the price discovery model and our measure of information share of option prices. We first show how the underlying asset price in the options can be characterized from observed option prices. Based on the option implied prices we then

[8]The date is found by checking Option Metrics data.

[9]CBOE information circular:
http://otp.investis.com/generic/sec/sec-show.aspx?Type=pdfhaspdf=1cik=0001374310FilingId=5686685

[10]CBOE press release:
https://ir.cboe.com/news-and-events/2014/05-29-2014/cboe-launch-spx-end-month-options-july

[11]CBOE regulatory circular:
https://cdn.cboe.com/resources/regulation/circulars/regulatory/RG14-081.pdf

we present our model for of price discovery and propose a measure of information share of an option regarding the underlying asset price.

3.1 Option Implied Index Price

A common restriction that arises in no-arbitrage option pricing models is that, under the risk-neutral pricing measure, the expected price of the underlying asset must equal its current value. This restriction is referred to as the martingale restriction (Longstaff, 1995), and it holds true in a frictionless market without arbitrage opportunities. If restrictions are present, the expected price does not necessarily equal the current price of the underlying asset, and the extent of this divergence depends on the size of the friction affecting the option market. An implication of the martingale restriction, whether binding or not, is that the price of a given option provides information about the current price of the underlying asset. We build on this intuition to construct implied index prices from options, which are obtained by inverting an option pricing model.

Denote by S_t the efficient value of the underlying asset at a given point in time t and by V_t its volatility. Under the usual conditions, the arbitrage-free price on a European option at time t is given by

$$O_t = O_t(S_t, V_t) = E^Q \left[e^{-r(T-t)} F(S_T, K) \,|S_t, V_t \right], \tag{1}$$

where F is the payoff function at maturity T of the option, K the strike price, r the constant risk-free rate, and Q a risk-neutral probability measure. Assuming that the observed option price is o_t and that V_t is the underlying's asset volatility, the asset value inverted from these two values can be written as:

$$\tilde{S}_t = O_t(o_t, V_t)^{-1}. \tag{2}$$

3.2 Information Share of Option Prices

In this section we introduce our model for price discovery and our measure information share of option prices. The measurement of price discovery requires isolating informative price movements from noise. Let $\tilde{S_{it}}$ be the price for the underlying asset implied from option $i = 1, ..., N$ in period $t = 1, ..., T$ as described in the previous section. Changes in $\tilde{S_{it}}$ may be driven by two different reasons. First informed traders may decide to trade option i, so $\tilde{S_{it}}$ will reflect a permanent price change due to such new information. Second, noise trading, temporary order imbalances and other trading frictions in option i market can also cause changes in price. Therefore in the short term $\tilde{S_{it}}$ will not necessarily coincide with the underlying efficient (true) price of the asset (S_{it}). Let E_{it} be the option specific noise capturing the difference between the true index price and the option implied price, then we can express this relation as :

$$\tilde{S_{it}} = S_t + E_{it}, \tag{3}$$

Equation 3 can be used to represent a very intuitive price discovery process.[12]. The option implied price $\tilde{S_{it}}$ has two sources of innovation, shocks to the true index price S_t and shocks to the option-idiosyncratic price E_{it}. Shocks to the efficient price have a permanent effect on the option implied price, but the effect of option-specific shocks is transitory, so $\tilde{S_{it}}$ will adjust to the fundamental value over time. An option market is relatively efficient in the price discovery process if it incorporates a larger amount of fundamental shocks than other option markets. In terms of equation 3 , a given option market is more informative about the true price if its given option implied price co-moves (or is highly correlated) with the index's true price. Additionally, such option market will be less informative if the option market -specific shocks E_{it} have large variability.

[12]This model is similar to a standard model of price discovery as the ones of Hasbrouck (1993) or Frank and Schotman (2010), where the asset prices are observed in different markets

Our measure of information share is based on this intuition.

In order to construct our measure of information share we start by expressing the model 3 as a factor model:

$$X_{it} = \lambda_i F_t + E_{it}, \tag{4}$$

where $X_{it} = \tilde{S_{it}}$, $\lambda_1 = \lambda_2 = ... = \lambda_n = 1$, and $F_t = S_t$. In factor model notation, X_{it} represents the response variable, λ_i the factor loading's, F_t the common factors, and E_{it} the idiosyncratic noise. The dynamics of the model are governed by $F_t = F_{t-1} + \eta_t$ and $E_{it} = \rho_{it} E_{it} + \epsilon_{it}$ where $\rho \in (-1, 1]$ and ϵ_{it} is an i.i.d. error. Notice that the model in equation 4 is not restricted to $\lambda_i = 1$. In the model 4 the co-movement of a given option implied price and the index's true price will be captured by λ_i , and the variability of the option-specific shocks will be can be measured by the variance of E_{it}.

The option contribution to to price discovery, or its information share, can be can be estimated as the proportion of the efficient price innovation variance that can be attributed to that option [13] Specifically, in the context of our model in equation 4 we propose that information share of the option i can be estimated as follows:

$$IS_i = \frac{\lambda_i^2 \sigma_\eta^2 \sigma_{E,i}^{-2}}{\sum_{n=1}^{N} \lambda_n^2 \sigma_\eta^2 \sigma_{E,n}^{-2}} \tag{5}$$

where $\sigma_\eta^2 = E[\eta_t^2]$ and $\sigma_{E,i}^2 = E[E_{it}^2]$. IS_i in equation 5 represents the contribution of the option i (numerator) with respect to the total variation of the true efficient price (denominator). It is straightforward to see that this measure intuitively captures an option market level of information in the price discovery process. First, information share of a given option market (IS_i) is positively related λ_i^2 which captures the degree of association between the implied option price and the true option price in 4 . Then, option

[13] In a similar setting Hasbrouck (1995) proposes that the market's contribution to price discovery, or its information share, can be estimated as the proportion of the efficient price innovation variance that can be attributed to that market.

markets with implied prices that are highly correlated with the true index price will be more informative about the true price. Second, IS_i is positively related to the ratio between the common innovation's variability σ_η^2 and the variability of option-specific shocks $\sigma_{E,i}^2$. Thus, option markets with large variability of idiosyncratic (transitory) shocks will be less informative in the price discovery process.

First, market frictions and micro-structure effects noise can that render both prices different. Second, the volatility V_t in the option pricing model has to be estimated, which could introduce a different source of uncertainty. Third, any option pricing model only provides a partial description of observed prices, so there is always the possibility of model error.

4 Data

The prices used in this study are for the S&P 500 index European options traded at the Chicago Board Options Exchange. Our sample starts in July 2004 and ends in December 2018, covering some important changes in terms of availability of expiration date cycles at the short and medium expiration spectrum. In particular, our sample contains the introduction in 2005 of weekly options with Friday expirations, which was later extended to Monday and Wednesday expirations in 2016. In addition, the sample also includes the addition of quarterly options in 2007, whose last day of trading corresponds to the end-of-quarter accounting practice. These events, together with different market and economic conditions, constitute a rich sample to study and understand the information share associated with option contracts of different maturities and moneyness.

We construct our sample from option contracts available on Option Metrics that have positive volume for a given trading day. Then, we retrieve level I quote data for each option from Tick Data, who sources information from the Options Price Reporting

Authority (OPRA), to construct one-minute midquotes for each day an option trades in our sample period. We only use quotes that have bid prices higher than zero and lower than the ask price, have timestamps between 9:30 a.m. and 4:00 p.m. Eastern Time, do not have any condition code, and are not eligible for automatic execution.

We apply several filters. First, we validate data by keeping only the observations with positive volume, positive open interest, positive implied volatility, positive bid price that is lower than its ask price. Second, for monthly options on the same day with the same moneyness and maturity, we use AM-settled contracts[14]. Finally, we filter out non-active options by keeping only option-day observations with trading volume larger than 5, open interest larger than 5, and option price larger than 0.5. The total number of option-day observations in our final sample is 2,336,917.

Table 1 presents the descriptive statistics of our dataset. We report total and average daily number of contracts traded, average daily volume and average daily percentage spread per maturity and moneyness throughout our sample period. The way we define maturity and moneyness groups are as follows. Two types (put or call) and three maturity ranges (ST, MT and LT) compose the six maturity groups, where ST refers to short-term contracts with date-to-maturity (DTM) $\leq$ 30 days, MT refers to medium-term with DTM$\in$(30,60] days, and LT refers to long-term contracts with DTM$>$ 60 days. Two types (put or call) and three moneyness ranges (OTM, ATM and ITM) compose the six moneyness groups, where moneyness is defined based on the standardized moneyness measure (m) following Anderson et al (2017);

$$m = \frac{ln(K/F_\tau)}{\sqrt{\tau} IV_{ATM,\tau}} \tag{6}$$

[14]The non-AM settled monthly contracts, i.e. pm-settled monthly SPX contracts, were not introduced until 2011 under a separate symbol SPXpm. We don't use them as they have the same characteristics as the conventional AM-settled monthly contracts except only for the settlement time but have much less volume.

where K denotes strike price, τ denotes years to maturity, F_τ denotes the forward price for transactions τ years into the future, and $IV_{ATM,\tau}$ denotes the (annualized) implied volatility of the option with strike price closest to F_τ. Using this standardized moneyness measure, OTM (out-of-money) options are defined as puts with $m < -1$ and calls with $m > 1$, ATM (at-the-money) options are calls and puts with $-1 \leq m \leq 1$, and ITM (in-the-money) options are puts with $m > 1$ and calls with $m < -1$.

Panel A of Table 1 presents the statistics of the six maturity groups. We can see that for both calls and puts, ST contracts have the largest number of contracts traded, while MT and LT contracts have similar number of contracts traded. Similarly for average daily volume, ST contracts show the highest volume, followed by MT and LT contracts.For liquidity cost (measured by average percentage spread), however, ST puts, MT puts and MT calls rank the highest (0.18, 0.17 and 0.16), while ST calls, LT puts and LT calls are lower (0.13, 0,12 and 0.12). Panel B of Table 1 presents the statistics of the six moneyness groups. OTM puts show the largest number of traded contracts, followed by ATM calls and ATM puts. The number of contracts for these three groups significantly outnumbers the other three groups of contracts. However, the average daily volume for OTM puts, ATM puts and ATM calls are roughly the same. For both calls and puts, the average percentage spread is largest for OTM options (0.37 and 0.23), much larger than ATM and ITM options (all less than 0.10).

To have a rough sense how different types of options grow over time, in Figure 1 we present total trading volume each year for each type of options. For maturity groups, the volume of all six groups starts off similar in 2004, yet diverges over time. Comparing puts and calls with the same maturity range (that is, put-ST vs. call-ST, put MT vs. call MT, and put-LT vs. call-LT), in all three cases we can see puts grow faster than calls in volume. Comparing the three maturity ranges within the same general type (puts or calls), we find that for both puts and calls, volume increases most rapidly for

ST contracts, then MT contracts, and lastly LT contracts (for instance, volume of ST puts goes from 4 million in 2004 to 93 million in 2018, while volume of LT puts only grows from 5 million in 2004 to 36million in 2018). For moneyness groups, OTM puts see the largest volume increase (from 6 million in 2004 to 97 million in 2018), while OTM calls see much less volume increase (from 0.93 million in 2004 to 25 million in 2018). ATM puts and ATM calls both show significant volume increase over time. The volume evolution for ITM puts and ITM calls, however, is almost a flat line and their volume increase neglectable compared to other types of options. Comparing puts and calls with similar moneyness, we see from the graph that the volume grows in similar speed for both ATM and ITM contracts, but not for OTM contracts (OTM puts have much larger volume increase over time than OTM calls).

Though we see some type of options have larger volume increase than others, it's not immediately clear whether these options also impound more information or contribute more to price discovery, and that's when information share comes in.

5 The Information Share of Index Option Prices

5.1 Estimation of Information Share (IS)

To estimate the information share of an option for a given day, we first compute one-minute implied asset prices as follows. First, for every minute during the trading day, we use the observed midquote of an option and the S&P 500 index value to invert the Black-Scholes model and compute the option's implied volatility. Next, to construct the conditional implied volatility estimate $\tilde{V}_{i,t}$ required in Equation 2, we use the average of the previous 30 implied volatilities to time t. Then, using the conditional volatility estimate and the midquote of the option at time t as the two inputs in the Black-Scholes model, we proceed to invert this model and obtain the implied index price $\tilde{S}_{it}$. This procedure is repeated for each minute between 10:00 am and 4:00 pm (the times for which estimates of the conditional volatility are available), providing intraday implied index values associated to each option in a given day. The resulting time series $\{\tilde{S_{i,t}}\}_{t=1,\ldots,360}$ are used to construct the option's information share for the day using the methodology as described below.

Estimation of the parameters in equation 5 requires transforming the factor model of equation 4 into a static factor model as follows:

$$x_{it} = \lambda_i f_t + e_{it}, \tag{7}$$

where x_{it}, f_t and e_{it} are the first differences of X_{it}, F_t and E_{it} .Model **??** is a standard static linear factor model, and therefore the parameter of the model can be estimated using principal components methods developed by Bai (2003). Specifically we obtain an estimate of loadings $\hat{\lambda_i}$ and the factor $\hat{f_t}$ by principal components, then since $f_t = \eta_t$ we can estimate σ^2_η as $\hat{\sigma^2_\eta} = T^{-1}\sum_{t=2}^{T}\hat{f_t^2}$. We will obtain an estimate of e_{it} by $\hat{e_{it}} = x_{it} - \hat{\lambda_i}\hat{f_t}$ and compute $\hat{E_{it}} = T^{-1}\sum_{t=2}^{T}\hat{e_{it}^2}$ to get an estimate of $\sigma^2_{E,i}$ as $\hat{\sigma^2_{E,i}} = T^{-1}\sum_{t=2}^{T}\hat{E_{it}^2}$. Westerlund et al. (2017) show that under standard assumptions, this information shares estimator is consistent as N and $T \to \infty$.

Having established the estimation method for information share (IS), we next demonstrate the findings with our IS measure.

5.2 IS across Moneyness and Maturity

Table 2 presents the descriptive statistics of IS across moneyness and maturity groups. Notice that not all groups have contracts trading every single day. The total number of days in our sample is 3,603, and missing values exist for ST puts, MT puts, ST calls, MT calls, ITM puts and ITM calls. We then look at each panel separately:

Panel A of table 2 shows the statistics for the maturity groups. We can see that ST puts and LT puts have largest average IS (22% and 20%). ST puts also have the most volatile IS (SD=0.13). Also notice that LT puts have no missing values and yet accounts for minimum 2% IS, while other contracts all have days with nearly 0% IS – despite LT puts' slow increase in volume, they always play a part in the market.

Panel B of table 2 presents the statistics for the moneyness groups. We see that ATM puts and ATM calls have largest average IS (37% and 36%), and they're also most volatile in IS (SD = 0.15 and 0.16, respectively). In addition, Despite the relatively small informational role of ITM puts, ITM calls and OTM calls (average IS are 7%, 3% and 1% respectively), the distribution of IS is right-skewed: the maximum daily IS is surprisingly high (max IS are 72%, 60% and 21%, respectively), indicating that these normally unimportant contracts can play a big role in specific days.

To have a general sense of which type of options overall contributes more to price discovery or how distribution of IS across different type of options is like, we also present in Figure 2 the pie charts of average IS in 2004 (the beginning of our sample) and 2018 (the end of our sample) per moneyness and maturity. The comparison for maturity groups shows a substantial IS increase for ST puts (from 10.1% in 2004 to 40.5% in 2018), and a huge decrease in IS for both LT puts (from 26.7% in 2004 to 13% in 2018) and LT calls (24.9% in 2004 and 6.7% in 2018). For moneyness groups, OTM puts see a big increase in IS (from 9.4% in 2004 to 28.3% in 2018) while ATM calls lose IS (from 40.6% in 2004 to 22.5% in 2018).

5.3 IS Evolution

5.3.1 Trends from Conventional Measures

Before we show the evolution of IS, we first present the trends observable from conventional market measures as a benchmark. Besides the volume measure shown in Figure 1, we hereby add another two easily-available measures that can also be used to track the evolution of different types of contracts: number of contracts and number of maturities available.

Figure 3a shows the year-by-year plots for average daily number of contracts. We can see that number of contracts grows exponentially for all maturity groups but in different speed. All six maturity groups start off at similar level of number of contracts in 2004, yet diverge increasingly after that (ST puts the fastest, then MT puts, LT puts and ST calls, lastly LT calls and LT puts). For moneyness groups, however, Only OTM puts, ATM puts and ATM calls grow exponentially. Their increase in number of contracts significantly outnumbers the other three types. Overall, the growth pattern shown in number of contracts is similar to that of volume.

Figure 3b shows the year-by-year plots for average daily number of maturities. For maturity groups, different from volume and number of contracts, the six groups do not start off at similar level and the LT contracts ranks the highest throughout the sample. This is understandable given that longer period to maturity renders wider range of feasible number of maturities for LT contracts. That said, the number of maturities of MT contracts does not outnumber that for ST contracts over time despite their longer time to maturity. Number of maturities for ST contracts start off almost the same as MT contracts but ST contracts prevail after 2010 and especially after 2015. This echos the dramatic growth for ST contracts that we also observe in volume and number of contracts. For moneyness groups, contracts do not start off at similar level and end up at different levels. ATM puts, ATM calls and OTM puts always have the largest number of maturities (and these three lines almost completely overlap), OTM calls rank the second, then ITM calls, and lastly ITM puts.

Figure 1 and Figure 3 taken together, the three measures in general agree on these trends for different types of options: 1) for maturity types, ST puts grow fastest, followed by MT puts, LT puts, ST calls, and lastly MT and LT calls, and 2) for moneyness types, OTM puts, ATM puts and ATM calls grow the fastest, followed by OTM calls, and lastly ITM puts and ITM calls.

5.3.2 Trends from IS

Now we show the IS evolution, and compare that with the pattern from the benchmark measures to see whether IS can indeed provides more insight than those easily-available market measures.

Figure 4 presents the year-by-year plots for IS per moneyness and maturity. For maturity groups, we see that ST puts are indeed the unicorn: they start off the lowest information share in 2004 (10%), and end up the highest information share in 2018 (41%). However, distinct from the evolution of volume and number of contracts, the informational role for MT puts and ST calls does not significantly increase (from 2004 to 2018, IS for MT puts only increase from 12% to 18%, ST calls from 12% to 15%) despite their significant growth in trading volume and number of contracts. For LT puts, their information share even almost halves over time (27% → 14%) despite their similar number of contracts over time as ST calls. For moneyness groups, OTM puts gain the biggest increase in IS, However, again different from the benchmark measures, its IS is always smaller than that of the ATM puts. ATM calls, despite similar growth in volume, number of contracts and number of maturities as ATM puts, significantly lose IS over time (41% → 23%) while ATM calls do not. OTM calls, despite gaining more increase in all three benchmark measures than ITM puts and ITM calls, actually play the smallest informational role almost all the time (the only exception is 2013).

Back to the price discovery questions, we are interested in seeing which type of options lead the price discovery process and whether the leaders change over time. From the IS evolution shown in Figure 4, we notice two general structural changes that happen in our sample period, which is made more evident in Figure 5:

First, the rise of puts and fall of calls. Figure 5 shows that IS for puts and calls are almost the same in 2004, yet they diverge over time (mainly after 2010) and puts end up carrying the majority of information content in 2018 (IS for puts grows from 49% to 72% from 2004 to 2018), while calls only account for the rest less than 30% of information share.

Second, the rise of ST contracts and fall of LT contracts. Figure 5 shows that the IS for MT contracts larges stay the same over time (slightly over 20%). However, IS for LT and ST contracts has almost switched if we compare the year 2004 and 2018. IS for ST contracts rise from 22% in 2004 to 55% in 2018, while IS for LT contracts falls from 52% to 20% in 2018. The trend is especially evident after 2010.

Overall, Figure 4 and Figure 5 illustrate that IS do provide more insights in the relative importance among different types of options that the easily-observable benchmark measures cannot fully capture. We also document two noticeable structural change in the options information structure during the period of 2004 to 2018.

5.4 Market Completeness and Information Share

One conjecture for why IS for ST contracts rise rapidly is the introduction of a specific type of ST options currently widely used, weeklys. Weeklys are, as its name indicates, short-dated contracts expiring one-week apart. Prior to its introduction, the typical SPX options are much longer-dated monthly options. Andersen et al. (2017) acknowledges the emergence of active trading in the weeklys as a step toward market completion, as they improves market participants' ability to acquire or lay off exposure to volatility and jump price risks. An interesting question follows: how does information structure changes after the introduction of new types of options? From the market completion perspective, we are investigating how information structure changes in the process of market completion.

Ross (1976) shows that increased market completeness should be followed by enhancement in market efficiency. We thus expect that the introduction of new options is followed by IS increase in relevant options groups. Specifically, the null hypotheses are

(a) After introduction of weeklys in 2005 (or new weeklys in 2016), IS for puts remain unchanged or drop.

(b) After introduction of weeklys in 2005 (or new weeklys in 2016), IS for ST contracts remain unchanged or drop.

(c) After introduction of new weeklys in 2016, IS for weekly contracts remain unchanged or drop.

(d) After introduction of quarterlys in 2007 (or EOMs in 2014), IS for MT contracts remain unchanged or drop.

(e) After introduction of EOMs in 2014, IS for end-of-quarter or end-of-month contracts remain unchanged or drop.

In Appendix 7.1 we list a timeline of important dates that are more or less related to SP500 index options. Among them, 4 events are introduction of new types of SP500 index options: 1) introduction of (Friday) weeklys in 2005, 2) introduction of quarterly or end-of-quarter options in 2006, 3) introduction of end-of-month (EOM) options in 2014, and 4) introduction of Monday and Wednesday weeklys in 2016.

In Figure 8 we mark these four years on the graphs of IS evolution. From the graph, other than that the introduction of Monday and Wednesday weeklys in 2016 coincide with larger information gap between puts and calls, these event years do not seem to coincide with the general structural change in the informational structure. In particular, notice that weeklys are initially introduced in October 2005 (the leftmost red dash line), and for both plots no obvious IS trend seems to take place until 2010. Its implication for the conjecture mentioned at the beginning of this section is, although it's possible that weeklys contributes to the rise of ST contracts, merely the introduction of weeklys doesn't.

To make it more explicit whether and when information starts to be impounded into new types of options, we label the types of options based on their expiration dates, and then quantify their IS accordingly. To be specific, contracts that expire on the 3rd Friday of each month are labelled as monthly options (the typical options traded before the introduction of other new types of options), contracts that expires on the last trading day of either a quarter or a month are labelled as quarterly or EOM, that expire on other Fridays than the 3rd Friday of a month are labelled as (Friday) weeklys, and contracts that expire on either Mondays or Wednesdays are labelled as Mon/Wed weeklys. We manually process specific cases in which holidays affect the expiration dates.

Figure 8 presents the IS evolution for new and old contracts with new options introduction years marked in vertical dash lines.

We first compare weeklys with non-weeklys. The plot shows that weeklys are first introduced in 2005, yet its information role does not significantly rise until 2010. Though we do see an apparent turning point in 2010, the information share for weeklys overall grow gradually and steadily throughout the sample period. Notice that the IS rise in weeklys coincide with the rise in ST options. This result demonstrates that 1) the information structure does change in the market completion process as new types of options contracts are introduced, and 2) such change in information structure does not happen overnight, and it could take a long time for changes to start to happen (nearly 5 years in this case), and even after that the increase in information share can still happen only gradually and progressively, which adds to our understanding that market completion does *not* lead to an immediate gain in efficiency.

Now we turn to the plot comparing four types of contracts. For Monday and Wednesday weeklys introduced in 2016, different from Friday weeklys, they immediately gain informational importance, and IS for Friday weeklys decrease accordingly. This is probably because Monday/Wednesday weeklys are very similar products as Friday weeklys and are thus substitutive. For quarterly options introduced in July 2007 or End-of-Month options (EOMs) introduced in July 2014, however, they show similar pattern as (Friday) weeklys. We see a time gap of around 2 years before the end-of-quarter options start to play a part in the information structure, and gradually rise over time, illustrating the same progressive feature. The introduction of End-of-Month options, however, do not followed by further rise in the informational role of these types of options. It could be that their role is overshadowed by the rapid growth of weekly options.

Overall, we observe that the informational structure in the option market changes with the emergence of new contracts, illustrating the transactional efficiency achieved by a more complete market. We also observe that the change in informational structure tend to happen gradually and progressively, rather than overnight.

5.5 Further Analysis

In this section, we further explore what type of information is impounded in options contracts.

To investigate that, we look at factors that have been shown to have an impact on option prices, risk and liquidity. Risk is viewed as the sole pricing factor in classic theories. We differentiate volatility risk and jump risk as their importance has been widely acknowledged in option pricing literature (for example, Duffie et al., 2000). The widely-documented implied volatility smirk reflects the asymmetry feature in risk pricing, and we thus include leverage to capture it. On the other hand, liquidity, the extensively studied factor in market microstructure literature, has also come into asset pricing (e.g., Cetin et al., 2006) and more recently, studies on options market (e.g., Melanie and Wei, 2010; Feng et al., 2014). They relax the assumption that investors are price takers, complementing the classic theory by allowing investors' trades to affect price. We capture liquidity from its two common dimensions, transaction cost and market depth. Specifically, transaction cost is measured by percentage spread of options' price, and market depth is measured by options' trading volume and open interest. We also control for number of contracts.

We run the following beta regression year-by-year for each maturity group g:

$$
\begin{aligned}
IS_{g,t} =& \beta_0 + \beta_1 volatility_t + \beta_2 jump_t + \beta_3 leverage_t \\
& + \beta_4 spreadA_{g,t} + \beta_5 ln(volumeS_{g,t}) + \beta_6 ln(openinterestS_{g,t}) \\
& + \beta_7 ln(Ncontract_{g,t}) + \epsilon_{g,t}
\end{aligned} \tag{8}
$$

where $IS_{g,t}$ is the total information share for all contracts in the maturity group g on day t. $volatility_t$ and $jump_t$ are volatility risk and jump risk of the underlying SP500 index on day t using oxford dataset [15]. Specifically, volatility is measured by the bipower variation (i.e. estimator bv_ss with symbol .SPX in the oxford dataset), and jump is measured by the part of realized variance that excesses (if it excesses) bipower variation (i.e. max(rv5_ss – bv_ss,0) using oxford bipower variation estimator, bv_ss, and realized variance estimator, rv5_ss). $leverage_t$ is the leverage effect measured by an integrated correlation between SP500 index return and change of VIX for day t, computed using 1-minute intraday data following the method in Kalnina and Xiu (2017) [16]. $spreadA_{g,t}$ is the average percentage spread across all contracts in group g on day t, where percentage spread is defined as $(ask_{i,t} - bid_{i,t})/midprice_{i,t}$ for each contract i. $ln(volumeS_{g,t})$ is the logarithm for the total trading volume of all contracts in group g on day t. $ln(openinterestS_{g,t})$ is the logarithm for the total open interest (number of options positions that has not been closed out or exercised) of all contracts in group g on day t. $ln(Ncontract_{g,t})$ is the logarithm of the number of contracts in group g on day

[15]Data source (the Oxford-Man Institute's realised library):
https://realized.oxford-man.ox.ac.uk/documentation/estimators

[16]Detailed parameter and code used for the calculation are available upon request

t.

To estimate the coefficients, we use beta regression, a technique more suitable than OLS here as the dependant variable, IS, is limited to the range of [0,1]. We first run the beta regression, then for coefficients that are statistically significant at 95% confidence level, we obtain the marginal effect of a standard deviation change in that explanatory variable on IS. We run this regression year-by-year for all 15 years and thus obtain 15 numbers of marginal effect for each variable for each of the six maturity groups. The regressions are only conducted on maturity groups as the two general trends observed in the previous section does not involve moneyness groups. We present the estimation results in Figure 6.

Figure 6 shows that all factors considered have more or less impact on IS. None of the subplots is a flat line of a consistent zero (number assigned to statistically insignificant coefficients) marginal effect throughout the 15 years in our sample. Regarding magnitude of the impact, *volatility* and $ln(Ncontract)$ demonstrate larger impact IS per 1 standard deviation change than other variables: 1 standard deviation change in *volatility* can associate with 10% IS change and $ln(Ncontract)$ can lead to 8.4% IS change, while other variables rarely see over 4% impact on IS. Regarding frequency of the (statistically significant) impact, *volatility*, *leverage*, *volume*, *spreadA* influence IS almost throughout the sample, while $Ncontract$, *jump* and *openinterest* only affects IS in fewer specific years.

For specific variables, notice that *volatility* overall decreases IS for all call options throughout the sample, especially in 2010 and 2015, both of which coincide with the time when puts gain larger IS than calls. *jump* tends to have the opposite effect of *volatility*. For example, in 2015 jump is associated with 10% IS decrease in ST puts but volatility is associated with 10% IS increase in the same type of contracts.. This validates the differentiation of volatility risk and jump risk. Judging from the direction of the impact, volatility risk contributes to the IS trend of rise in puts and fall in calls, while jump risk attenuates this trend. $leverage$ shows an overall consistent negative association with IS for ST puts and positive association with IS for MT and LT puts. Since $leverage$ measures the correlation between SP500 index return and VIX change and is typically negative (market downturns tend to show higher volatility than in market upturns), this means that the more negative the $leverage$ (the larger the leverage effect), the more information is impounded in ST puts the less in MT or LT puts. This effect is consistent with the IS trend of rise in ST contracts and fall in LT contracts. The effect of $spread$ on IS is overall consistently negative, which is expected: the higher the liquidity cost, the less the informed trading and the lower the information content. $volume$ and $openinterest$, if having significant impact, are all negatively associated with IS. This is surprising from the liquidity perspective (we expect contracts that are more liquid can impound more information). It could be that these market depth measures confound with the amount of noise trading, which will decrease IS, or it could be that $Ncontract$ absorbs the positive effect from liquidity. We see that $Ncontract$ positively impact ST contracts (both calls and puts) during 2004-2007 and 2010-2012 in large magnitude, but no impact on LT contracts. This is consistent with the IS rising trend for ST contracts especially for the period of 2010-2012 when IS of ST contracts accelerates and exceeds that of LT contracts.

Overall, the beta regression result suggests that volatility is related to the IS trend of the rise (fall) of puts (calls), and number of contracts and leverage effect associate with the IS trend of the rise (fall) of ST (LT) contracts.

6 Conclusion

In this paper, we propose a methodology to compute the relative efficiency of option contracts in the price discovery process of the underlying asset value. Our method differs from existing method used in options price discovery literature in the way that it accommodates large-dimension data. The large-dimension feature is critical for the current era where huge number of contracts are easily created and traded thanks to technology advancement. In particular, we show in this paper that this method enables price discovery study for thousands of options with the same underlying.

Using intraday option prices of the SP 500 index, we quantify the individual contribution of an option in a panel of available contracts for a given day. We document how the information share of options has significantly changed during the period of 2004 to 2018 across option types, maturities, and moneyness. Puts and calls start off sharing similar amount of information, yet over time puts become the major player. Long-term contracts start as the information leader, yet over time that leader role is shifted to short-term contracts.

We use the introduction of new contract expirations to investigate the effects of market completeness on price discovery. We observe that the informational structure in the option market changes with the emergence of new contracts, illustrating the transactional efficiency achieved by a more complete market. We also observe that the change in informational structure tend to happen gradually and progressively, rather than overnight.

Finally, we explore what type of information is impounded in options contracts using beta regressions. We find that volatility can potentially explain the rise of puts and fall of calls, and number of contracts and leverage associate with the rise of short-term options and fall of long-term options.

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7 Tables and figures

Table 1: Sample Description: Total and Average Daily Number of Contracts Traded, Average Daily Volume and Average Daily Percentage Spread in 2004M7-2018M12

This table reports the descriptive statistics for the options data. Number of contracts ($Ncontract$), trading volume ($volume$), and percentage spread ($spread$) defined as (ask-bid)/midprice are originally data for each options contract each day, and then aggregated (summation or average) to the group level. Groups are divided in two ways: maturity (Panel A) or moneyness (Panel B). Two types (put or call) and three maturity ranges (ST, MT and LT) compose the six maturity groups, where ST refers to short-term contracts with date-to-maturity (DTM)≤30 days, MT refers to medium-term with DTM ∈(30,60] days, and LT refers to long-term contracts with DTM>60 days. Two types (put or call) and three moneyness ranges (OTM, ATM and ITM) compose the six moneyness groups, where moneyness is defined based on the standardized moneyness measure (m) in equation (6) following Anderson et al (2017). OTM are out-of-money options composed of puts with $m < -1$ and calls with $m > 1$, ATM are at-the-money options composed of calls and puts with $-1 \leq m \leq 1$, and ITM are in-the-money options composed of puts with m¿1 and calls with $m < -1$.

Panel A: Maturity Groups				
	$Ncontract$	$Ncontract$/day	$volume$/day	$spread$
Put-ST	589,832	170	189157.2	0.18
Put-MT	418,345	120	109404.8	0.16
Put-LT	466,082	129	104600.0	0.12
Call-ST	359,412	104	116446.2	0.13
Call-MT	240,474	69	66230.5	0.17
Call-LT	262,766	73	59201.5	0.12
Panel B: Moneyness Groups				
	$Ncontract$	$Ncontract$/day	$volume$/day	$spread$
Put-OTM	861,992	239	195753.4	0.23
Put-ATM	583,696	162	194806.8	0.06
Put-ITM	28,571	9	2254.5	0.05
Call-OTM	184,565	51	39066.4	0.37
Call-ATM	593,970	165	189070.0	0.09
Call-ITM	84,117	24	7352.3	0.03

Table 2: Descriptive Statistics for Daily IS in 2004M7-2018M12

This table reports the descriptive statistics for the daily information share (IS) measure per maturity (Panel A) and moneyness (Panel B). Two types (put or call) and three maturity ranges (ST, MT and LT) compose the six maturity groups, where ST refers to short-term contracts with date-to-maturity (DTM)$\leq$30 days, MT refers to medium-term with DTM $\in$(30,60] days, and LT refers to long-term contracts with DTM>60 days. Two types (put or call) and three moneyness ranges (OTM, ATM and ITM) compose the six moneyness groups, where moneyness is defined based on the standardized moneyness measure (m) in equation (6) following Anderson et al (2017). OTM are out-of-money options composed of puts with $m < -1$ and calls with $m > 1$, ATM are at-the-money options composed of calls and puts with $-1 \leq m \leq 1$, and ITM are in-the-money options composed of puts with m¿1 and calls with $m < -1$. IS ranges from 0 to 1.

Panel A: Maturity Groups								
	N(days)	Mean	SD	Min	P25	P50	P75	Max
Put-ST	3,463	0.22	0.13	0.00	0.12	0.20	0.31	0.77
Put-MT	3,498	0.16	0.08	0.00	0.11	0.15	0.21	0.59
Put-LT	3,603	0.20	0.10	0.02	0.12	0.18	0.25	0.94
Call-ST	3,463	0.16	0.09	0.00	0.10	0.15	0.22	0.58
Call-MT	3,498	0.12	0.07	0.00	0.07	0.11	0.16	0.63
Call-LT	3,603	0.16	0.11	0.00	0.07	0.14	0.23	0.68
Panel B: Moneyness Groups								
	N(days)	Mean	SD	Min	P25	P50	P75	Max
Put-OTM	3,603	0.17	0.11	0.01	0.09	0.14	0.22	0.86
Put-ATM	3,603	0.37	0.15	0.06	0.27	0.35	0.45	0.93
Put-ITM	3,298	0.03	0.04	0.00	0.01	0.01	0.03	0.60
Call-OTM	3,603	0.01	0.01	0.00	0.00	0.01	0.01	0.21
Call-ATM	3,603	0.36	0.16	0.00	0.24	0.36	0.46	0.88
Call-ITM	3,571	0.07	0.06	0.00	0.02	0.05	0.09	0.72

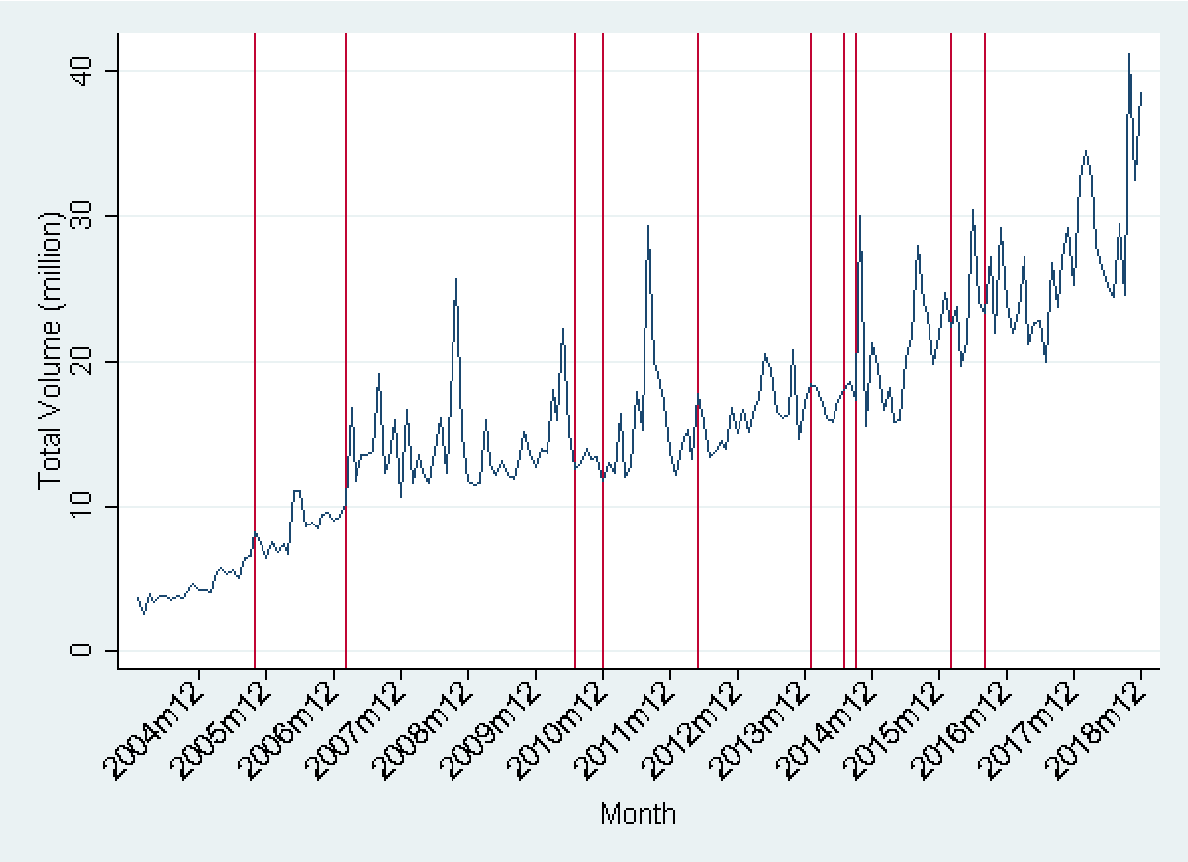
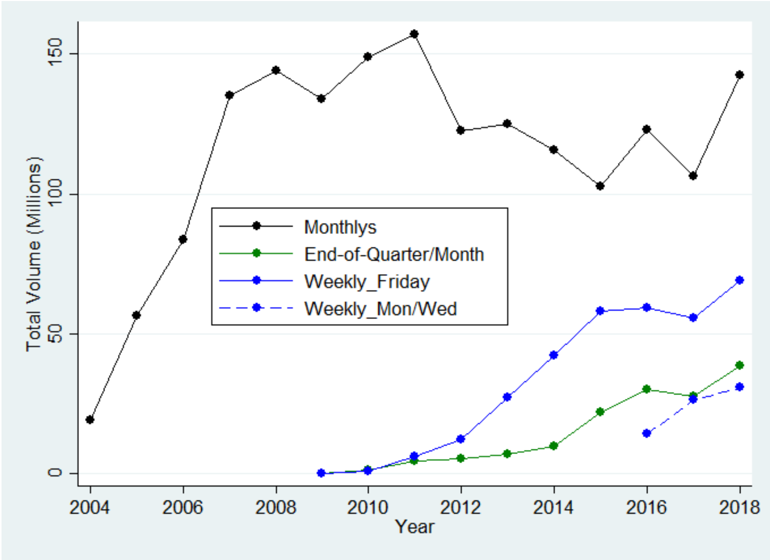
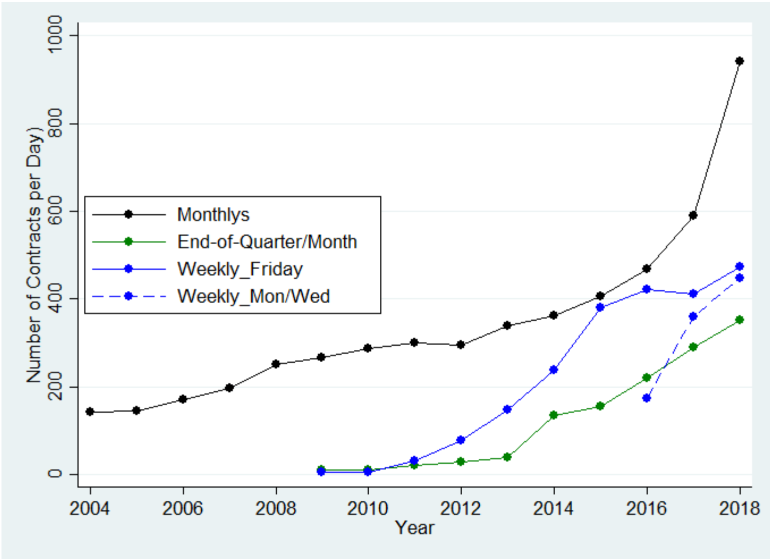


Figure 1: Total Volume of SP500 Index Options of 2004-2018

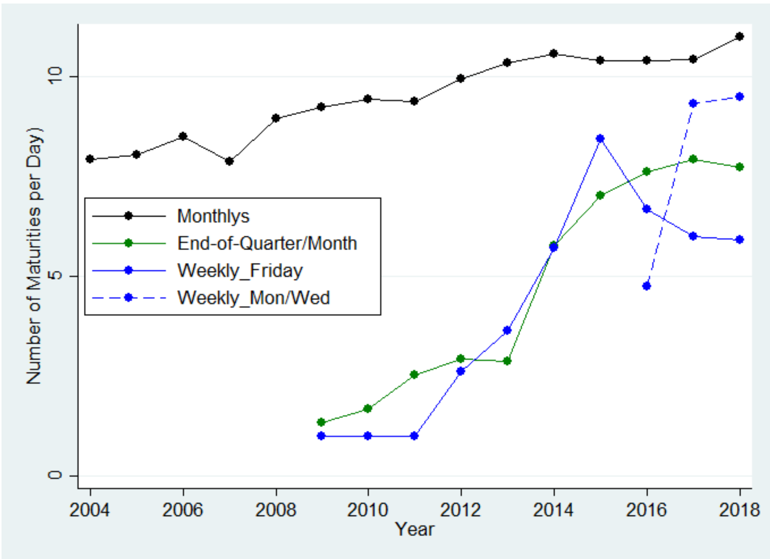
Note: This figure shows the total volume of SP500 Options for each month during 2004 to 2018. The data comes from Option Metrics. The red vertical lines represent event months (listed below). More accurate event dates are listed in Appendix.
2005m10: Introduction of SPX weeklys
2007m2: Introduction of SPX quarterlys
2010m7: Weeklys availability expands by 1 day
2010m12: Weeklys transition: AM → PM; open outcry → hybrid
2012m5: Weeklys listing expanded (from 1 week) to 5 consecutive weeks
2014m1: Weeklys listing expanded (from 5 weeks) to 8 consecutive weeks
2014m7: Introduction of SPX End-of-Month Options (EOMs)
2014m9: Weeklys listing expanded to 12 consecutive weeks from Sep-Dec 2014
2016m2: Introduction of SPX Wednesday-expiring weeklys
2016m8: Introduction of SPX Monday-expiring weeklys



(a) Trading Volume by Year



(b) Average Daily Number of Contracts by Year



(c) Average Daily Number of Maturities by Year

Figure 2: Benchmark Measures by Year

Note: This Figure shows the year-by-year (a) trading volume (b) average daily number of contracts and (c) average daily number of maturities per maturity and moneyness.

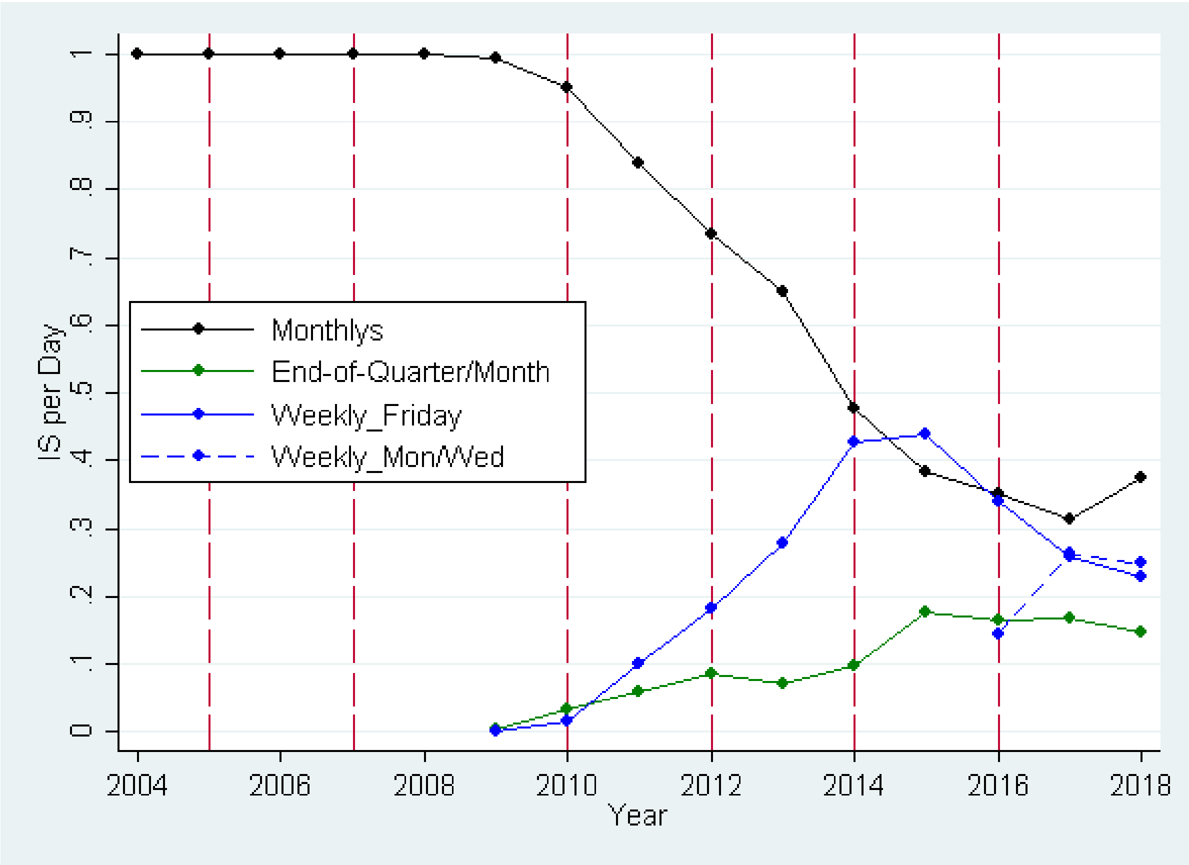
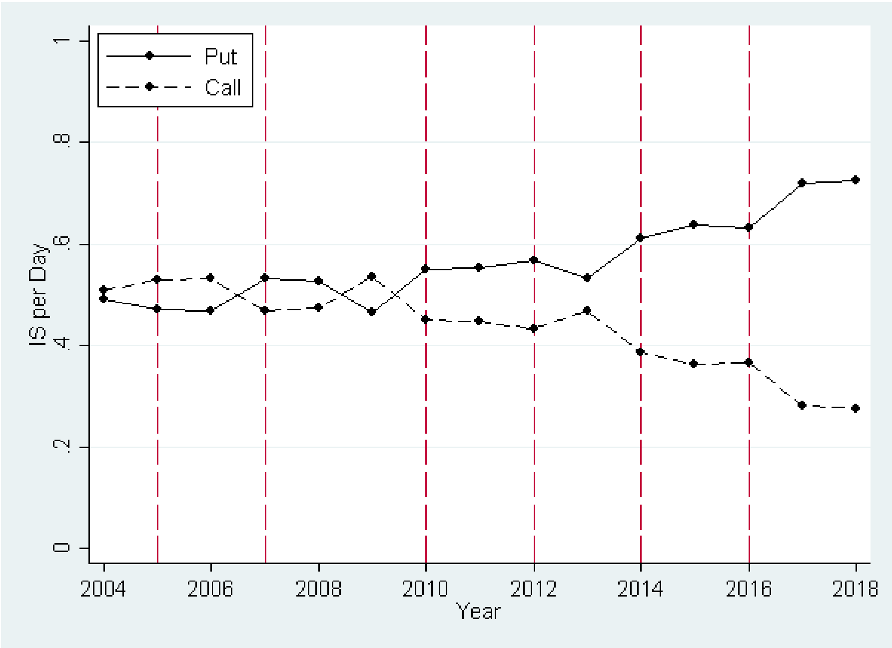
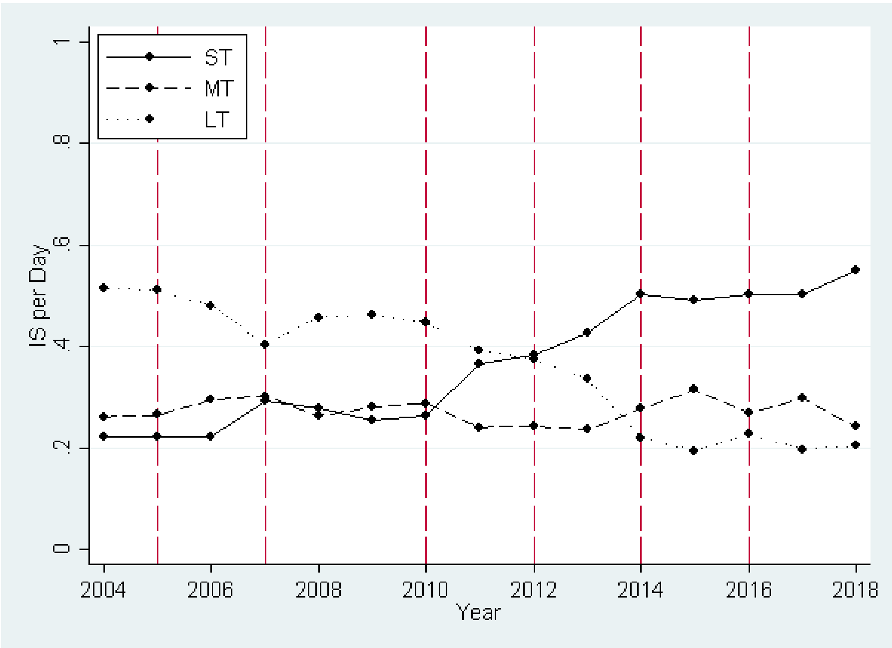


Figure 3: IS for Old and New Options

Note: This figure presents information share (IS) evolution for old options ("Non-weeklys" in (a) and "Monthlys" in (b)) and new options. The event years for new options are marked in red vertical lines.
2005: introduction of weeklys
2007: introduction of quarterlys
2010: weeklys transition: AM → PM; open outcry → hybrid
2012: expansion of weekly listing (from 1 week) to 5 consecutive weeks 2014: introduction of End-of-Months (EOMs); expansion of weekly listing to 12 consecutive weeks
2016: introduction of new weeklys (Monday and Wednesday expiration)



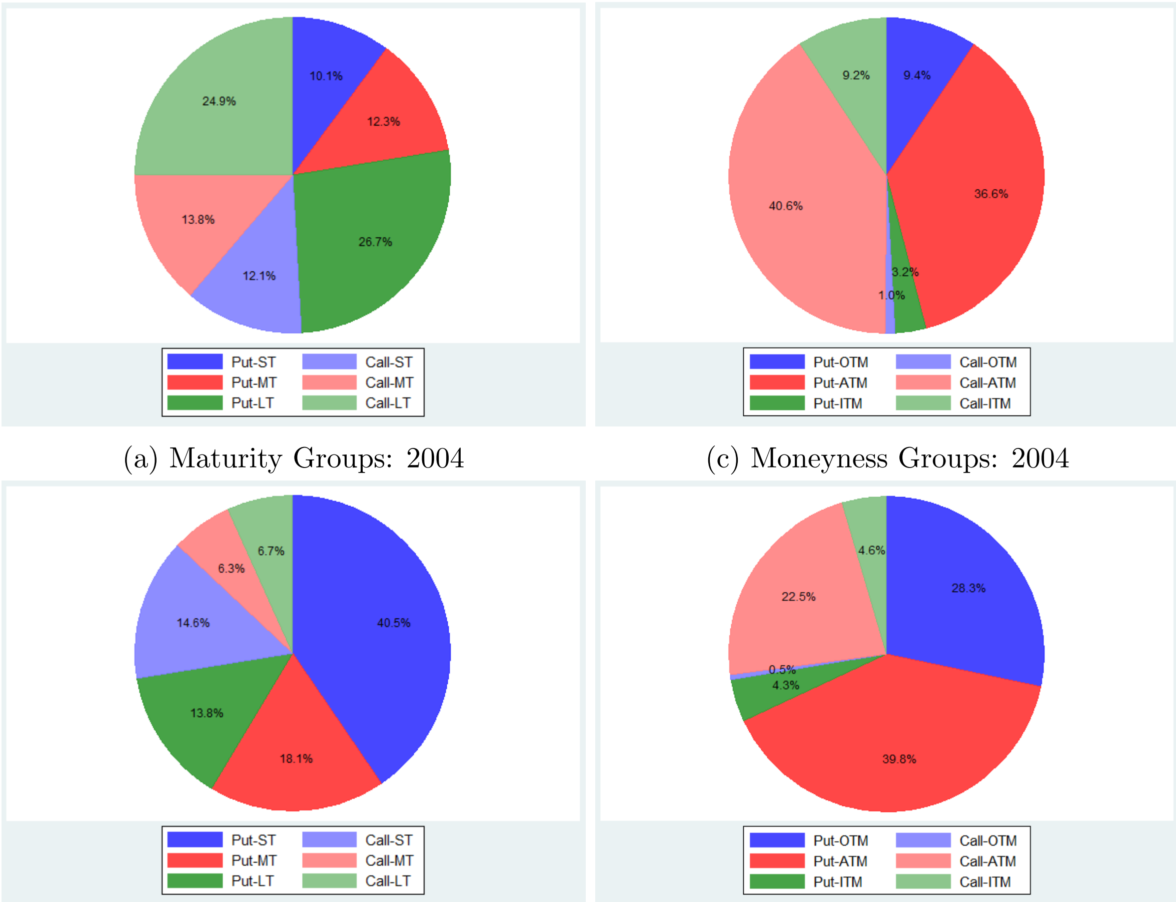
(a) Put vs. Call



(b) ST vs. MT vs. LT

Figure 4: IS Evolution with Introduction Dates for New Options

Note: This figure presents information share (IS) evolution as in Figure 5 with the introduction years for new options marked in red vertical lines.
2005: introduction of (Friday) weeklys
2007: introduction of quarterlys
2010: weeklys transition: AM → PM; open outcry → hybrid
2012: expansion of weekly listing (from 1 week) to 5 consecutive weeks 2014: introduction of End-of-Months (EOMs); expansion of weekly listing to 12 consecutive weeks
2016: introduction of new weeklys (Monday and Wednesday expiration)



(a) Maturity Groups: 2004

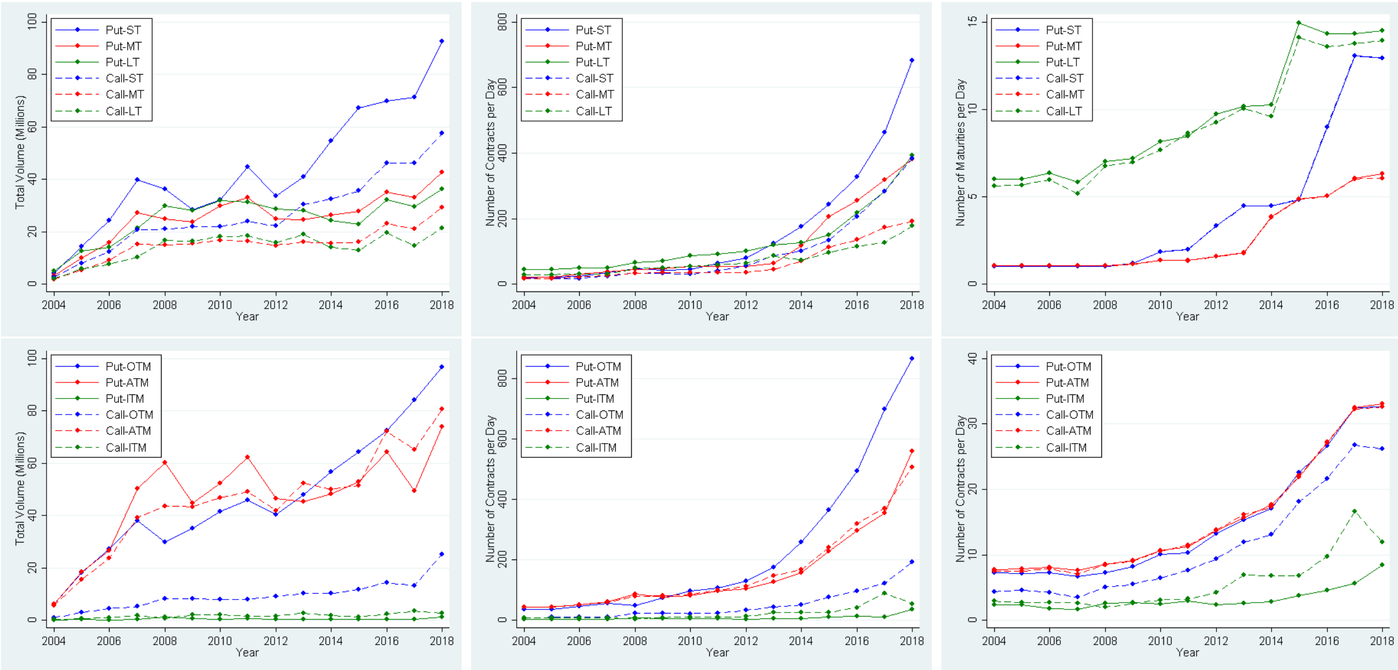
(c) Moneyness Groups: 2004

(b) Maturity Groups: 2018

(d) Moneyness Groups: 2018

Figure 5: IS: 2004 vs. 2018

Note: These pie charts present the comparison of information share (IS) in 2004 and 2018 for maturity groups (a and b) and moneyness groups (c and d). Group definitions are the same as in Table 1.



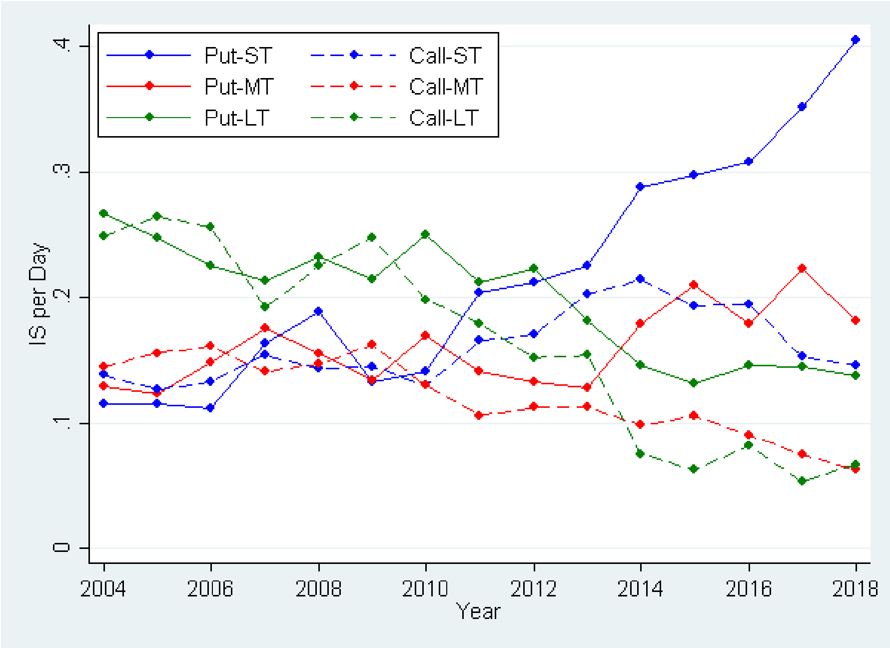
(a) Trading Volume by Year

(b) Average Daily Number of Contracts by Year

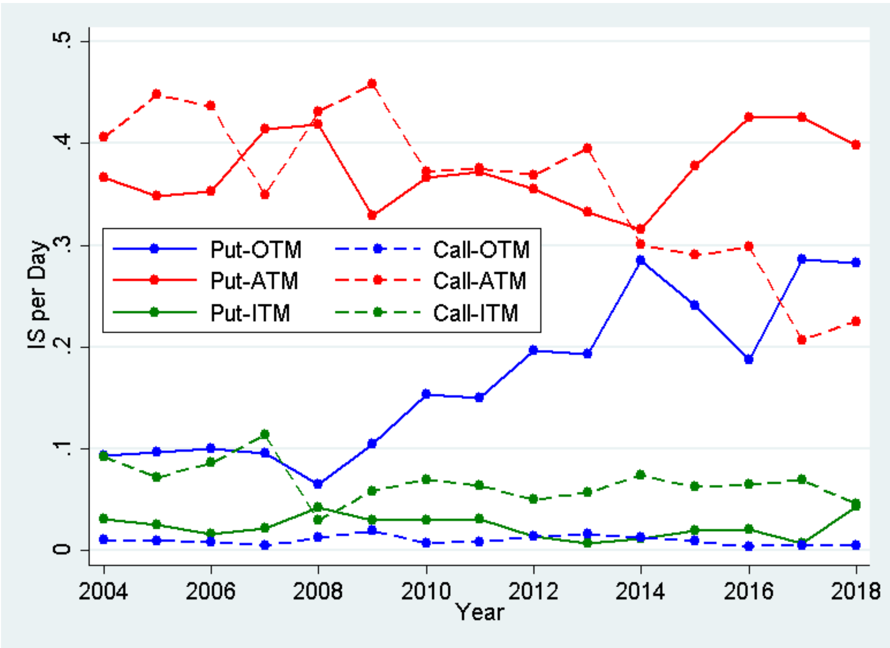
(c) Average Daily Number of Maturities by Year

Figure 6: Benchmark Measures by Year

Note: This Figure shows the year-by-year (a) trading volume (b) average daily number of contracts and (c) average daily number of maturities per maturity and moneyness. Group definitions are the same as in Table 1.



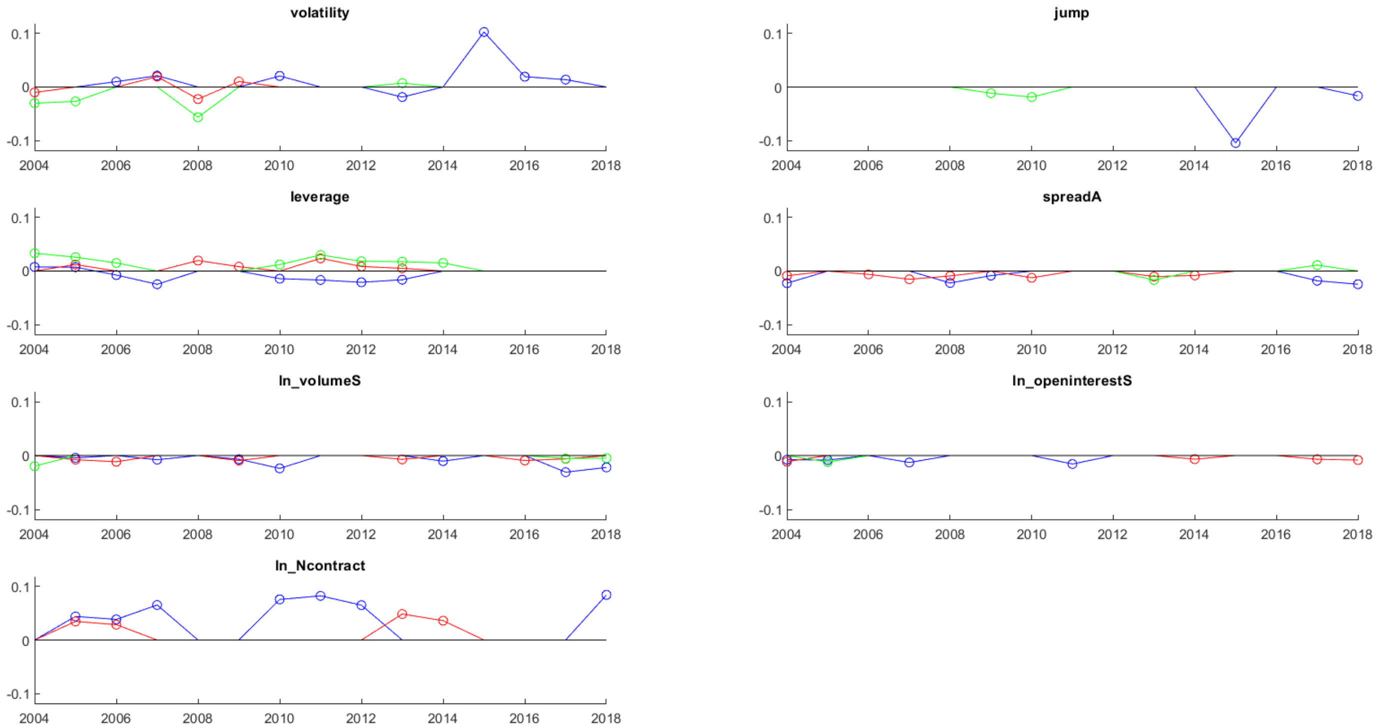
(a) Maturity Groups



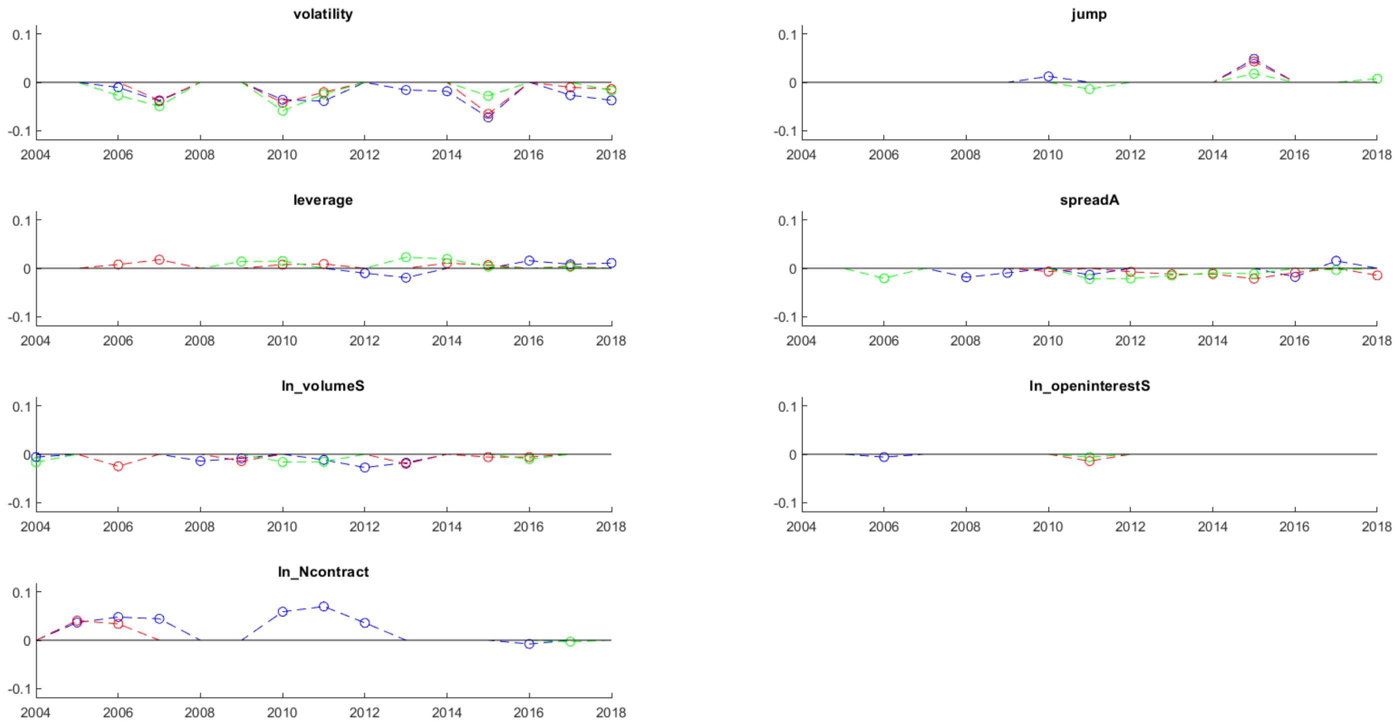
(b) Moneyness Groups

Figure 7: IS by year

This Figure demonstrates the year-by-year information share (IS) in each (a) maturity and (b) moneyness group. Group definitions are the same as in Table 1.



(a) Puts



(b) Calls

Figure 8: Beta Regression: Effect of 1σ Change in x on IS

This Figure demonstrates the estimated marginal effect of 1σ change in each explanatory variable on IS from 90 beta regression of equation (8) (year-by-year regression for 15 years and 6 maturity groups). We only report marginal effects that are statistically significant at 95% level the insignificant marginal effect is shown to be zero. See section 4.4 for variable definition.

8 Appendix

8.1 Market Completion Process of SP500 Index Options

2005/10/28 Introduction of **SPX (End-of-Week) weeklys**:
2007/02/21 Introduction of SPX **End-of-Quarter** options (**quarterlys**)
2010/07/01 Weeklys availability expands by 1 day (listed on Thursday instead of Friday) for trades' ease of roll-over.
2010/12/2 Weeklys transit from **AM-settlement to PM-settlement** (to reduce gap risk) and from **open outcry to hybrid trading** (enabling both open outcry and electronic trading).
2012/05/31 Weeklys listing expanded (from 1 week) to **5 consecutive weeks**.
2014 Jan Weeklys listing expanded (from 5 weeks) to **8 consecutive week**s
2014/07/07 Introduction of SPX **End-of-Month** Options (**EOMs**)
2014 Sep-Nov Weeklys listing expanded (from 8 weeks) to **12 consecutive weeks**
2016/02/23 Introduction of SPX **Wednesday**-expiring Weeklys.
2016/08/15 Introduction of SPX **Monday**-expiring Weeklys.