Retail Option Traders and the Implied Volatility Surface

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Abstract

Retail option traders are typically net purchasers of short-dated options, especially out-of-the money contracts, whereas they frequently sell long-dated options. Using retail brokerage platform outages as shocks to trading, we find that outages are associated with commensurate demand shocks to implied volatility. Outages produce lower implied volatility on average, with stronger reductions for options that tend to be purchased by retail investors. In contrast, implied volatility increases for long-dated options during outages, consistent with reduced retail writing activity. The findings suggest that retail demand pressure can have important effects on the implied volatility term structure, moneyness curve, and call-put spread.

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1. Introduction

Options traders are traditionally regarded as sophisticated, and past research finds evidence of informed trading in options markets (e.g., Johnson and So, 2012; Hu, 2014; Ge, Lin, and Pearson, 2016). In recent years, reductions in trading commissions, greater work flexibility, and increased attention from social media and the financial press have led to dramatic increases in options trading by retail investors.[1] Individual investors are often inexperienced and prone to herding and gambling behavior (e.g. Barber, et al., 2022; Kumar, 2009),[2] and widespread retail option trading could have important financial market implications. In this article, we analyze retail option trading data and rely on brokerage platform outages to study the effects of retail investors on options markets.

Options market makers cannot perfectly hedge their trades with retail investors due to transaction costs and other market frictions, and they are sensitive to inventory risk due to capital constraints and agency issues (Muravyev, 2016). As a result, demand pressure can have effects on option prices and implied volatility (Bollen and Whaley, 2004; and Garleanu, Pedersen, and Poteshman, 2009). A well-developed literature has established several stylized facts regarding implied volatility. In particular, the call-put volatility spread has been shown to predict future stock returns and macro conditions (e.g. Bali and Hovakimian, 2009; Cremers and Weinbaum, 2010; An et al., 2014; Han and Li, 2021). A second stream of literature analyzes how implied volatility varies across strike prices, and the volatility moneyness smile/smirk has been attributed to an aversion to price jumps (Dennis and Mayhew, 2002; Pan, 2002; Xing, Zhang, and Zhao, 2010; Yan, 2011). Other work focuses on the term structure of implied volatility and finds an association between

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[1] For example, Banerji (2021) reports a fourfold increase in retail option trading over a five-year period.
[2] Past work suggesting that retail investors trade options in uninformed ways includes Poteshman and Serbin (2003), Bauer, Cosemans, and Eichholtz (2009), Li, Subrahmanyam, and Yang (2021), and Choy and Wei (2022).

future returns and volatility (Mixon, 2007; Vazquez, 2017). While existing work emphasizes the role of fundamentals, hedging demands, and informed trading, in recent years speculative trading by retail investors may play a key role in shaping the implied volatility (IV) surface.

Capturing the effects of retail investors on options markets is challenging since trading is endogenously related to market conditions. Our identification approach exploits retail brokerage outages to isolate the effects of retail trading on financial markets (Barber et al., 2022; Eaton et al., 2022; Bryzgalova, Pavlova, and Sikorskaya, 2023a). We employ a difference-in-differences type approach that contrasts option volume and implied volatility during outages with similar times of day during the previous week, and we use indicator variables to compare options favored by retail investors to a set of control options. In addition, we perform several robustness tests, including event-time plots, to help alleviate concerns that outages are endogenously determined.

Our outage analysis studies how shocks to retail investor trading impact option prices without the need for direct trading measures. However, we begin by characterizing individual investor option trading preferences to generate predictions for their effects on implied volatility. Specifically, we rely on the retail options trading algorithm of Bryzgalova, Pavlova, and Sikorskaya (2023a) (BPS) and data from the Options Price Reporting Authority (OPRA) to examine individual investor's proclivity to purchase or sell options of different maturities and moneyness levels. Consistent with BPS, we find that retail option demand is concentrated in short-dated options. For example, about half of retail option trading occurs in contracts that expire within one week. Retail investors also favor calls over puts and prefer out-of-the-money over in-the-money options.

The effect of individual investors on implied volatility depends on the nature of their options trading. In an environment with imperfect market maker hedging and inventory risks, widespread purchasing of options (either calls or puts) will create upward pressure on prices that manifests as higher implied volatility. On the other hand, if retail investors tend to sell options, this will create downward pressure on prices and reduce implied volatility. Empirically, we show that retail investors' tendency to purchase vs write options varies considerably across contracts. In aggregate, we find evidence that retail investors are more likely to purchase options than write them, consistent with anecdotal evidence,[3] and retail net option purchases are strongest for short-dated out-of-the-money options. On the other hand, retail traders show a net tendency to write long-dated options. Taken together, we therefore hypothesize that retail investors will have an upward effect on short-horizon implied volatility, whereas they may have a downward effect on implied volatility at longer horizons. We take these predictions to the data in the context of retail broker outages.

We confirm that retail brokerage platform outages have a significant impact on option trading activity, particularly those with high retail interest. For example, retail option dollar volume is nearly 13% lower during outages for options on high retail stocks, as proxied by stocks with high retail option volume in the previous five days. In contrast, we find no evidence that non-retail option trading changes during outages, which helps mitigate concerns that outages are directly caused by market conditions. We also note that options favored by retail investors are actively traded. For example, the 15-minute mean (median) of the number of retail trades in the high interest group is roughly 1,600 (700) contracts per stock, with a corresponding average option dollar volume of $80K, suggesting our setting does not focus on options that rarely trade.

The evidence that retail broker outages are associated with reduced retail option trading corroborates Eaton et al. (2022)'s evidence of lower retail stock trading. Thus, retail broker outages

[3] For example, Bogousslavsky and Muravyev (2024) find that long option positions outnumber option writing 7-1 in their sample of retail option traders.

can be viewed as creating negative shocks to retail investor participation in both stock and option markets. Analyzing the effects of retail broker outages on the implied volatility surface, and in particular the call-put spread, the moneyness smile/smirk, and the term structure of volatilities, provides an opportunity to isolate the effect of retail investors on the option market.

Retail investors' impact on implied volatility is shaped by their net proclivity towards purchasing vs. writing options, and we next examine the effects of outages on net retail option dollar volume. We find that retail broker outages are associated with a drop in net retail purchasing activity on average across contracts, yet we find evidence suggesting a decline in retail writing behavior for long-dated options, consistent with the trading preferences described above. Having confirmed that brokerage outages significantly impact retail investors' ability to trade options, we next analyze the effects of retail broker outages on implied volatility.

We find that when retail investors are unable to trade during platform outages, average implied volatility for options that are favored by retail investors falls by 0.019, which translates to a drop of 4% relative to the median of 0.47. The negative effects of outages on implied volatility are significantly stronger for calls than puts (-0.036 vs -0.024), which is consistent with retail traders' preferences for purchasing call over put options. Broker outages are also associated with shifts in the implied volatility moneyness curve. Specifically, we find that out-of-the-money options experience a significant drop in implied volatility, while outages have an insignificant effect on IV for in-the-money options. The impact of outages suggests that retail investor option demand flows serve to strengthen the moneyness smile.

Retail broker outages have the most dramatic effect on the term structure of implied volatility. In particular, implied volatility falls by 0.061 for options with less than or equal to seven days to maturity and 0.044 for options with intermediate maturities of between 8 and 20 days. In contrast, implied volatility for long-dated options significantly rises by a value of 0.026 during brokerage outages. The overall outage effect is a significant increase of the slope of the implied volatility maturity structure for options on stocks favored by retail investors. The impact of outages on the term structure of implied volatility matches the observed net trading behavior, in particular retail investors' proclivity towards purchasing short-dated options and writing long-dated options, which provides convincing support for the interpretation that retail investors impact implied volatility.

We conduct several additional analyses and robustness checks. For example, we find that the results continue to hold if we exclude the 30 stocks with the most actively traded options, which suggests that meme stocks are not driving the findings. We consider variations of the BPS algorithm and also consider an alternative measure of retail trading using small customer trades on Nasdaq and find similar results.

In order to address concerns that market conditions directly cause outages, we create event-time plots to examine the periods immediately before and after outages. Event-time plots show that the trends in implied volatility for both the high retail and control option groups are similar in the hour prior to the outages, yet implied volatility abruptly falls during the outages for the high retail interest group only, particularly for the types of options favored by retail investors, such as short maturity or out of the money options. The drop in implied volatility quickly reverts in the post-outage period. We also plot the implied volatility surface for many moneyness-maturity bins before, during, and after broker outages. This approach illustrates the effects of the outages on IV for various fixed moneyness-maturity groups. The figures confirm the previous findings, with implied volatility dropping markedly for short-maturity options, particularly out-of-the-money options, during outages, but only for the high retail interest stocks.

We also consider whether changes in implied volatility can be fully explained by changes in underlying stock volatility during outages. Eaton et al. (2022) show that outages at Robinhood are associated with reductions in stock volatility, whereas outages at other retail brokers correspond with volatility increases. We confirm the cross-broker differential stock volatility pattern in our context, yet we find reductions in IV during both Robinhood and non-Robinhood outages, which suggests the option market effects we observe are not merely a direct manifestation of changes in the underlying stock market.

Our work contributes to several strands of literature. One area of research emphasizes the role of demand pressures on option markets. For example, Bollen and Whaley (2004) argue that buying pressure helps explain differences in the shape of the moneyness curves between index and stock options. Garleanu, Pedersen, and Poteshman (2009) models demand-pressure effects and finds that proxies for option demand are related to the moneyness smirk. In other work, Muravyev (2016) highlights the effects of demand pressures on dealer risk and finds evidence that inventory risk accounts for a sizable portion of option order imbalances.[4] Our study provides novel evidence by focusing on the demand-pressure effects of a specific option trading clientele that has grown substantially in recent years, and our setting allows us to isolate the effects of retail investors on option markets.

The findings also contribute more broadly to studies that seek to understand the shape of the implied volatility surface, including the term structure (e.g., Mixon, 2007; Vazquez, 2017), and the moneyness smile or smirk (e.g., Dennis and Mayhew, 2002; Pan, 2002; Xing, Zhang, and

[4] Our findings also connect with the broader literature that relates demand shocks to asset prices (Koijen and Yogo, 2019). For example, van der Beck and Jaunin (2021) show that household demand shocks can have important price effects due to the inelastic response of institutional investors, and Gabaix et al., (2022) find evidence that household demand elasticity is higher among low-wealth investors, magnifying the role of retail investors. Our evidence suggests that correlated trading by retail investors has important effects on options markets, and the impact of individual investors is concentrated in certain segments of the moneyness-maturity spectrum.

Zhao, 2010; Yan, 2011). Our analysis highlights the key role of individual investors in determining the IV surface, with speculative demand pressure from retail investors having distinct effects on the call-put volatility spread, the implied volatility smile, and the term structure of volatility. The findings suggest that caution is warranted when interpreting the implied volatility surface as reflecting information about underlying firm cash flows or the risk environment of the firm.

Our results add to contemporaneous work on the microstructure of options markets and how retail investors trade. Ernst and Spatt (2023) highlight that payment for order flow arrangements create incentives for retail brokers to encourage option trading, and Hendershott, Khan, and Riordan (2022) find evidence of cream skimming of retail option trades. Bryzgalova, Pavlova, and Sikorskaya (2023a) propose a retail option trading algorithm and characterize how individual investors trade, Bogousslavsky and Muravyev (2024) study retail option trading performance, de Silva, So, and Smith (2022) and Beckmeyer, Branger, and Gayda (2023) find evidence that retail option traders lose money around earnings and in short-dated options. Bryzgalova, Pavlova, and Sikorskaya (2023b) find evidence that retail investors suboptimally exercise options, Naranjo, Nimalendran, and Wu (2023) find that retail option losses increase with trade complexity, and Allen et al., (2023) suggest that retail investors played a role in the 2021 meme stock short squeezes.[5] Our analysis also provides evidence that retail traders play an increasingly important role in options markets, yet our emphasis is on studying the effects of retail investors on the implied volatility surface, a fundamental summary statistic that emerges from option markets.

Other recent work relates option trading to volatility in the underlying assets. Lipson, Tomio, and Zhang (2023), Brogaard, Han, and Won (2023), and Dim, Eraker, and Vilkov (2024)

[5] In early work, Lakonishok et al., (2007) also characterize retail option trading and document that discount broker customers tend to trade speculatively and are more likely to buy and write calls than puts.

find mixed evidence that option trading influences underlying stock volatility. Our outage setting provides broad exogenous shocks to retail trading in stock and option markets, which allow us to shed light on the role that individual investors play in determining the shape of the implied volatility surface. Moreover, we find evidence that some broker outages have the opposite effect on implied vs underlying stock volatility, which suggests that retail option traders have impacts on option markets that are distinct from their role in stock markets.

2. Data and Descriptive Statistics

2.1 Data Sources, Construction of the Sample, and Key Variables

Our sample covers option trades reported by the Option Price Reporting Authority (OPRA). Motivated by Bryzgalova, Pavlova, and Sikorskaya (2023a), we proxy for retail trading using transactions that are flagged by OPRA as either single-leg auctions trades or transactions that are automatic executions with sizes less than five contracts.[6] Trades are signed as buys and sells as in Muravyev (2016), where buys (sells) are trades executed above (below) the NBBO midpoint. In addition, we repeat the analysis using an alternative proxy for retail trading based on small (less than 50 option contracts), non-professional customer trades in the NASDAQ NOTO and PHOTO databases. Although the Nasdaq sample captures only a portion of option trading, it has the benefit of being able to identify whether trades open or close positions and whether the positions purchase or write options. More details on the Nasdaq option sample are available in the Internet Appendix in Section IA.1.

2.1.1 Computing Implied Volatility

[6] We confirm in the robustness analysis (Table 7) that the results are similar when using a more restrictive retail proxy based only on single-leg auction trades.

We calculate implied volatility for each option chain in the sample using the Black-Scholes option pricing model. We obtain option prices from the NBBO mid-quotes from OPRA and underlying spot prices are measured as the prevailing NBBO midprices from TAQ. We use the quote midpoints in lieu of transaction prices to avoid bid-ask bounce from obstructing the measure of implied volatility, though our main conclusions continue to hold if we instead use option transaction prices (Panel A of Table IA6). Time to expiration is measured as minutes to the expiration date's market close, and we use end-of-day 3-month Treasury bills for the risk-free rate. Implied volatility across option chains is aggregated by option dollar volume to the stock level at fifteen-minute horizons.

One concern with inferring volatility from intraday option prices is that market frictions could influence implied volatility. Option markets tend to be less liquid than equity markets, and option quote staleness may influence observed implied volatility. We address this issue by requiring an option chain to have 500 trades reported in OptionMetrics over the 5 days before the outage event, and we also require the option to have nonzero midquote variance during the intraday outage time window (i.e. active quote changes). Nonetheless, the results continue to obtain if we relax these filters (Panel B of Table IA6). We also note that our conclusions are similar if we analyze option prices directly instead of implied volatility (Table IA5).

We merge the data with CRSP for information on security types, and stock-day price and volume. We focus on options for individual common stocks (share codes 10 or 11 in CRSP), and we consider options with moneyness between -35% and 35%, where moneyness is the ratio of the strike price to the stock price, minus one, for put options and one minus the ratio of the strike price to the stock price for call options. We also exclude LEAPS (options with maturities greater than one year).[7]

2.2 Descriptive Statistics

Figure 1 plots total option dollar volume and retail volume, using the BPS measure, from November 2019 through June 2021, which corresponds to the broker outage sample period. Days with brokerage outages are denoted with gray bars. The figure shows that retail trading has grown in recent years and represents a considerable portion of option volume. We observe that brokerage outages are also distributed throughout the sample period.

Table 1 presents descriptive statistics for the sample. Panel A reports option-day level dollar-volume-weighted averages, and Panel B details option trading at fifteen-minute intervals separately for high and low retail interest stocks. We define high retail interest stocks as those with option dollar volume in the top quintile over the last five trading days, with low-retail interest capturing the remaining set of optionable stocks that meet the option liquidity filters. For high interest stocks, retail investors execute approximately 1,583 options trades on average, totaling $39,261 dollar volume every 15 minutes. Table IA1 in the Internet Appendix shows similar patterns for outage versus non-outage periods, although as expected there is less retail trading during broker outages. The descriptive statistics indicate that options with high retail-interest tend to be well traded.

3. Characterizing Retail Option Trading

[7] LEAPS account for a low fraction of retail volume (1.2% during our sample period). We also exclude options with less than one day to maturity since the prices of out of the money options become extremely volatile as the time value collapses to zero and implied volatility becomes difficult to estimate. However, we show in Table IA7 that the prices of zero-day options are lower during brokerage outages, consistent with the evidence for other options with short maturities.

We anticipate that the effects of retail investors on option markets will be concentrated in the types of contracts that they favor, and we begin by characterizing retail option trading. Individual investors are often inexperienced and have been shown to be prone to gambling and herding behavior (e.g. Kumar, 2009; Boyer and Vorkink, 2014; Byun and Kim, 2016; and Barber, et al., 2022) and influenced by sentiment (Lemmon and Ni, 2014). Thus, we conjecture that retail investors speculative trading will concentrate in options with strong lottery-like features, such as purchases of short-dated, out-of-the-money options.

3.1 Retail Option Trading Contract Characteristics

How do retail investors trade options? The top row of Figure 2 plots cumulative retail volume partitioned by maturity and moneyness levels. In particular, we aggregate retail dollar volume within each maturity-moneyness category and then scale each bin by total retail dollar volume across bins. Additional plots show calls and puts separately, again scaling by total retail volume. The most prominent trading feature emerging from the plots is that retail option traders emphasize short-dated options. For both calls and puts, maturities of one week account for a large fraction of overall trading, although there is nontrivial trading in options with maturities greater than four months. We also see that retail investors emphasize near-the-money and out-of-the money options over deep in- or out-of-the money options.[8] The retail option trading patterns are largely consistent with discount broker trading documented in Lakonishok et al. (2007).

3.2 Retail Option Trading Implications for Implied Volatility

[8] In Table IA2 in the Internet Appendix, we regress retail dollar volume on firm and option contract characteristics in the Nasdaq sample. Consistent with the plots in Figure 2, we find that retail option trading is significantly higher in call contracts, in short maturity contracts, and for near- and out-of-the-money options. Regarding firm characteristics, we observe that retail option traders tend to trade options on large stocks that have high volatility, idiosyncratic skewness, and previous week returns.

The effect of retail investor option trading on implied volatility depends on their proclivity toward different types of trading. Trading demand that pushes option prices up, without changes in underlying firm fundamentals, will have the effect of increasing implied volatility. Analogously, trades that exert downward pressure on option prices will have the effect of reducing implied volatility. There are eight distinct option trade types: purchasing calls, closing purchased calls, writing calls, closing written calls, and the same four positions for put options. While each retail trade may potentially create price pressure that can influence implied volatility, some categories of trades are likely to exert greater influence than others.

Anecdotal evidence suggests that retail investors are net purchasers of options. Many retail brokers require special authorization and additional capital requirements to write options. For example, Robinhood prohibits naked option sales, and E-trade and TD Ameritrade more than double the margin requirements for uncovered option writing relative to option purchases. Bogousslavsky and Muravyev (2023) find that long option positions are seven times more common than option writing in their sample of retail option traders. In our Nasdaq sample (details in the Internet Appendix), we find that small customer open option purchases are roughly three times more common than open written option positions (Table IA3).

On the other hand, option positions are often unwound before expiration, which potentially creates offsetting price pressure. However, to the extent that option market makers are net sellers on average, as evidenced in past work (e.g. Pan and Poteshman, 2006; Baltussen, et al., 2021; Eraker and Osterrieder, 2023), option purchases will add to inventory risk while offsetting sales will reduce it. Consistent with the view that open option purchases create more price pressure than closing sales, Eraker and Osterrieder (2023) find that option ask prices are more sensitive to market shocks than option bid prices. Thus, a pattern of retail traders purchasing options and later unwinding is likely to have a net upward effect on implied volatility. More generally, variation in retail investors' proclivity to purchase vs write options by moneyness or maturity can have important implications for the implied volatility surface.

In the OPRA sample, retail option trades that open purchase positions or close written positions will be classified as buys, whereas close purchase and open writing positions will be classified as sells. To explore retail investors' tendency toward net buying, for each stock-day we calculate the fraction of dollar volume that is signed as buy, sell, and at the midquote. Averaging across stock-days, we observe 47.6% of volume is designated buy, 45.5% is sell, and 6.9% is at the mid-quote and therefore hard to sign.[9] Although the net tendency towards purchasing appears relatively modest on average, as argued above the tendency for open positions to be purchases likely creates net upward pressure on option prices and implied volatility.

We next consider the extent to which net retail volume varies by maturity and moneyness. In the bottom row of Figure 2, we plot average stock-day buy dollar volume less sell dollar volume, scaled by total retail net dollar volume. We observe that the tendency to purchase options is considerably stronger for short-dated options, which suggests retail investor demand will have upward pressure on short-dated options. On the other hand, the net trading of long-dated options is negative on average, suggesting retail investors are more likely to write these options than purchase them, which can create downward pressure on long-maturity implied volatility. The patterns are evident for both calls and puts, though they are more pronounced for call options. The

[9] Although BPS emphasize contract-weighted volume, in their Internet Appendix they report a slight tendency towards net sales when dollar-weighting retail volume. Based on their posted code, the discrepancy with our small positive net volume result can be attributed to differences in winsorizing. BPS winsorize option prices and contract volume separately at 99.5% before constructing dollar volume, whereas we winsorize dollar volume directly at 99.5% ($22,431). We note that the general net volume patterns we observe in Figure 2 hold using contract-weighting or dollar-weighting using BPS's winsorization approach.

distinct pattern of strongly purchasing short-dated options and writing long-dated options offers clear testable hypotheses regarding their effects on implied volatility.

4. The Effects of Retail Trading on Option Markets

The preceding evidence suggests that retail trading accounts for a considerable portion of overall option market activity. Retail investors specifically prefer to purchase short-dated, near- and out-of-the-money call options, while they tend to write long-dated options. Since option market makers cannot hedge perfectly due to market frictions and are sensitive to inventory risk (Muravyev, 2016), demand pressure can have effects on option prices and implied volatility (Bollen and Whaley, 2004; and Garleanu, Pedersen, and Poteshman, 2009). In this section, we examine retail trading pressure and its impact on implied volatility.

4.1 Identification Approach

Option trading varies with market conditions, which makes it difficult to isolate the effects of retail option trading on implied volatility. Our approach relies on retail brokerage platform outages, in which option markets are open for trading but a considerable number of retail investors are unable to trade due to technical difficulties at their broker (Eaton et al., 2022). We identify brokerage outages using Downdetector.com, a web platform that compiles user complaints. Outage information on the website is updated at 15-minute time intervals and reflects both external user reports and internal verification checks.

We focus on outages during market hours, and to ensure that the scale of an outage is material, we require a minimum of at least 200 outage reports during each 15-minute window. We restrict the sample to outages unique to one broker at a time to alleviate concerns that outages may be driven by market-related factors. The brokers in our sample include Charles Schwab, E-Trade, Fidelity, Robinhood, and TD Ameritrade. We do not include other major brokers (such as

Interactive Brokers) because they do not have sufficient outages reported on Downdetector. Our sample brokers experienced a total of 73 outages with at least 200 complaints from the beginning of 2019 through June 2021, when the Downdetector data is no longer available. The median length of outages is 45 minutes. Figure 1 plots the timing of platform outages using grey vertical lines. We see that broker outages are distributed throughout the sample period.

Analyzing the effects of brokerage outages on option markets requires an assessment of which options retail investors would have traded in the absence of the outage. Our approach is to identify options that are heavily traded by retail investors in the days prior to the outage. We measure high retail interest using the top quintile of retail stock option trading measured over the 5 days prior to the day of the outage, while options in the other four quintiles of retail trading are considered to have relatively low retail interest.[10] Our approach involves performing a difference-in-differences type analysis to examine the effects of retail option trading on option market outcomes. The time dimension compares the effects during outages to similar times of day during the previous five trading days, and the cross-sectional difference uses indicator variables to compare the options with high retail interest to those with lower retail interest.

One potential concern is that market conditions may have caused the broker outage. As an additional robustness check, we plot intraday event-time figures to assess market conditions immediately before and after outages. Event-time figures also help address concerns that implied volatility may change mechanically as the time to maturity falls, which could influence comparisons of outages to the previous five-day benchmark period.

4.2 Brokerage Outages and Option Volume

[10] We sort into high and low retail interest groups based on overall retail volume. For robustness, in Table 8 we find similar results if we instead use the retail share of overall option volume.

We begin by exploring whether retail brokerage outages impact option trading volume. Our approach relies on the following regression model:

$$Trd_{i,t} = \alpha + \beta_1 Retail_{i,d-1} + \beta_2 Outage_t + \beta_3 Retail_{i,d-1} \times Outage_t + \gamma_i + \delta_d + \varepsilon_{i,t}. \quad (1)$$

The sample consists of fifteen-minute intervals, *t*, for options aggregated up to each stock *i* during the outage window on day *d*, matched with fifteen-minute intervals for the same stock and time for each of the five trading days preceding the outage date (ending on day *d-1*). We include firm, γ_i, and day, δ_d, fixed effects in the model. The $Retail_{i,d-1}$ variable represents an indicator variable that takes a value of one if the underlying stock is in the top quintile of retail option trading and zero otherwise. The $Outage_t$ variable is an indicator variable equal to one during the outage period and zero otherwise.

We consider both total and retail option volume measures ($Trd_{i,t}$), which are aggregated across the option chain for each stock at 15-minute intervals. Volume is measured using the natural log of dollar volume, and we also calculate volume for calls and puts separately. Table 2 reports the results. The findings confirm that brokerage outages have a significant impact on option trading. For example, overall option volume drops by 8.4% during outages for options on stocks favored by retail traders, relative to options on less favored stocks. As expected, the drop is even stronger for retail trading, as retail option volume drops by 12.9%. Retail volume also falls for both calls and puts, though the decrease is larger for calls (13.1% vs. 10.0%). In Table IA4 in the Internet Appendix, we analyze the effects of retail broker outages on non-retail (non-BPS) option trading. Consistent with outages uniquely influencing retail trading, we find no evidence that outages significantly affect non-retail volume, which helps further alleviate endogeneity concerns that market conditions directly cause retail broker outages.

The effects of retail traders on implied volatility depends on their relative tendency to purchase and sell options, and Table 3 presents the outage evidence for net retail dollar volume, which measures retail option buying net of selling (as in the bottom row of Figure 2). In addition to splitting the sample into calls and puts, we also partition the option sample by maturity and moneyness. We observe that net retail option dollar volume significantly falls overall during the brokerage outages for options favored by retail investors. The significant drop is especially salient for the types of options that Figure 2 suggests retail investors trade the most, such as calls and options that are short-dated and out-of-the-money. In contrast, long-maturity options exhibit an increase in net dollar volume during broker outages, consistent with retail investors tendency to write rather than purchase long-dated options as evidenced in Figure 2.

4.3 Brokerage Outages and Implied Volatility

The previous section documents that broker outages have a significant negative impact on retail option activity and in particular on net retail demand pressure. As a result, outages have clear testable implications for implied volatility. Specifically, we anticipate a drop in implied volatility overall during outages, as well as variation across the maturity/moneyness surface based on the relative tendency of retail investors to purchase rather than write options. We test these predictions using the following OLS model:

$$IV_{i,t} = \alpha + \beta_1 Retail_{i,d-1} + \beta_2 Outage_t + \beta_3 Retail_{i,d-1} \times Outage_t + \gamma_i + \delta_d + \varepsilon_{i,t}. \quad (2)$$

The dependent variable, $IV_{i,t}$, represents implied volatility, and the sample, subscript notations, and independent variables are the same as in Equation (1).

Table 4 presents regression results for the aggregate option sample as well as subsamples of call and put contracts only. We see that overall implied volatility significantly drops for options favored by retail investors when they are unable to trade. The estimated effect for the decrease in implied volatility of 0.019 corresponds to a drop of roughly 4% relative to the median of 0.47 (from Table 1).

The call-put volatility spread has been shown to predict future stock returns and macro conditions (e.g. Bali and Hovakimian, 2009; Cremers and Weinbaum, 2010; An et al., 2014; Han and Li, 2021), consistent with informed trading. Our evidence suggests that demand pressure from retail investors, who do not appear to be informed on average, may also play a role, and we next consider whether retail broker outages impact implied volatilities for calls differently than puts. Consistent with stronger retail pressure in call options, we observe in the last three columns of Table 4 that implied volatility decreases more during outages for calls than for puts, and this difference is statistically significant.[11] The stronger evidence for calls align with the evidence in Table 3 that the outage decline in net retail trading is stronger for calls than puts. Overall, the evidence in Table 4 is consistent with price pressure decreasing when retail investors leave the market.

We next consider how the impact of outages on implied volatility varies with option moneyness. Previous research documents an implied volatility smile or smirk in stock options, and some authors argue that demand pressure may help explain the variation in implied volatility across strike price (Bollen and Whaley, 2004; Garleanu, Pedersen, and Poteshman, 2009; Xing, Zhang, and Zhao, 2010). Our analysis focuses on the effects of retail investor demand pressure on the implied volatility moneyness curve, and our setting provides plausibly exogenous shocks to trading.

[11] The sample of only calls (puts) requires calls (puts) to be traded for a given stock during the outage and the control periods, whereas the test for the difference between call and put implied volatility requires both calls and puts to be traded for each stock. In other words, the call analysis examines the set of stocks with liquid calls, the put analysis examines the smaller set of stocks with liquid puts, and the call/put difference requires both for an apples-to-apples comparison.

Table 5 presents the regression estimates of the effects of retail broker outages on implied volatility separately for out-of-the-money, at-the-money, and in-the-money options. For options on stocks favored by retail investors, implied volatility significantly drops for ATM and, particularly, OTM options, while the implied volatility for ITM options is not significantly different during the outages. The last column formally compares OTM to ITM options and confirms that implied volatility drops significantly more for OTM options. The evidence suggests that retail option demand pressure impacts how implied volatility varies with moneyness and helps inform studies that link the smirk to underlying jump risk (e.g., Xing, Zhang, and Zhao, 2010; Yan, 2011).

As with the other observed cross-sectional option characteristics, the Black and Scholes (1973) assumptions predict that implied volatility should be flat across option maturities. However, evidence suggests that implied volatility does vary by maturity and that the term structure of implied volatility fluctuates over time (Mixon, 2007). Existing research on the IV term structure emphasizes index options rather than individual stock options, and little is known about the role of individual investors. In particular, retail investors' trading styles vary considerably by maturity, which could have important implications for the IV term structure.

Table 6 estimates Equation (2) separately for options of different maturities. We observe large variation in the broker outage effects on implied volatility across option term-to-maturity. In particular, implied volatility significantly decreases during outages for short- and mid-term options favored by retail investors. In stark contrast, implied volatility significantly increases during outages for long-dated options. The specific pattern of shifts in implied volatility is again consistent with the net option buying results in Table 3. Buying (selling) pressure lessens during outages for short-dated (long-dated) options favored by retail investors, which leads to decreases (increases) in implied volatility.

4.4 Event-time Plots

An important concern in our setting is that market conditions may directly cause outages. We shed light on this issue by creating event-time plots that examine the trends immediately before and after outages. Specifically, for the subset of 26 outages with a 30-minute duration, we track implied volatility in 5-minute intervals from one hour before to one hour after outages. For each 5-minute window and stock in the sample, we calculate the difference between IV on the outage day and the average IV for the same stock during the same 5-minute window over the five previous trading days. Similar to Tables 4-6, we assess statistical significance by regressing the abnormal IV measures on firm and day fixed effects.

As above, we separately consider options in the top quintile of retail interest and the remaining four quintiles, and we partition the sample by maturity and moneyness. The resulting IV plots for each 5-minute regression are presented in Figure 3. The figures report abnormal implied volatility on the outage day relative to the control period with statistical significance indicated by a 5% confidence interval band. During the pre-outage window, we see that regardless of the option sample being considered, IVs are similar and near zero for both low- and high-retail interest options, suggesting that implied volatilities measured during the pre-outage period are not materially different from IVs during the previous five days.

Implied volatility changes abruptly during the outage period, but only for options favored by retail investors. Consistent with the evidence in Tables 4-6, the negative IV outage effect is especially dramatic for out-of-the-money options and short-dated options, and we also observe a slight increase in IV for long-dated contracts. The IV patterns in Figure 3 match the net retail volume trading evidence in Figure 2 and Table 3, and together they are consistent with retail option traders pushing up IVs for options with net demand and exerting downward pressure on IV for options with net supply. Moreover, the lack of a pre-trend and the evidence that implied volatility quickly returns to normal levels supports the view that brokerage outages have a causal effect on implied volatility.

To further illustrate the effects of retail brokerage outages on the implied volatility surface, we construct 3-dimensional figures that capture variation in both maturity and moneyness. One benefit of this approach is that it illustrates how IV is impacted for fixed moneyness-maturity levels. In particular, we more finely partition options into narrow maturity and moneyness bins and plot separate implied volatility surfaces for the outage period, the post-outage period beginning one hour after the outage ends, and the control period measured during outage time windows over the previous five days. Implied volatility for each maturity-moneyness bin is computed by volume-weighting across option chains for each stock-day and then averaging across stock-days. As before, we compare options on stocks in the top quintile of retail option activity, measured over the previous five days, to options on stocks in the lower four quintiles of retail interest.

Figure 4 confirms and fleshes out the evidence from Tables 5 and 6. The top three panels show that retail brokerage outages have minimal effects on implied volatility inferred from options on stocks with relatively low retail option interest. Specifically, the implied volatility surface estimated during outage periods is relatively similar to the shapes measured during control periods and post-outage periods. In contrast, the bottom three panels of Figure 4 illustrate that outages have dramatic effects on the implied volatility surface for options on stocks with high retail option interest.

The effect of retail brokerage outages on IVs for retail-oriented stocks is most notable in the maturity dimension. Outages are associated with markedly lower short-horizon implied volatility, whereas IVs marginally increase at longer horizons. Together, the outage evidence suggests that retail investor demand increases the negative slope on the term structure of implied volatility, and their absence during outages is associated with a considerably flatter surface. The plots also illustrate the effects of retail traders on the IV moneyness smile. We observe that brokerage outages coincide with a less V-shaped pattern, as implied volatility flattens across the moneyness axis. The plot evidence is consistent with retail investors contributing to the strength of the IV moneyness smile, particularly for short-horizon options which tend to be the most heavily traded. Notably, the IV surface during the post-outage period is quite similar to the surface estimated during the previous five days, consistent with brokerage outages representing temporary shocks to implied volatility.

4.4 Robustness Tests

In this section, we perform several additional analyses and robustness checks to address concerns that the findings may be spurious. We begin by repeating the analysis on a number of data subsamples. The results are presented in Table 7, where for brevity we present only estimated coefficients and *t*-statistics on the interaction of the high retail interest and outage indicator variables. Specifically, we report the estimated effects on net retail dollar volume and then provide implied volatility results for all options as well as cross-sectional splits between calls and puts, OTM and ITM, and long-dated and short-dated options.

To address concerns that the findings are driven by a small number of meme stocks, Panel A of Table 7 removes the top 30 stocks by option volume proceeding each outage. In particular, it is possible that a few popular companies are subject to a flurry of retail option trading that creates an outage. However, the resulting outage would also lead to a (relatively exogenous) negative shock to trading in options with low amounts of news, and we can study the effect of outages for this subsample. We find that the results remain robust after excluding 30 stocks with the highest option volume before each outage, which suggests that the findings are not driven by a small number of actively traded options. We next consider the possibility that outages may be particularly susceptible to after-hours market news by excluding outages that begin before 9:45am in New York. Panel B shows that the results are unchanged if we remove morning outages, which alleviates concerns that our findings are driven by volatility after the market opens.

We also consider alternatives to our primary retail trading measure. Although the implied volatility outage results do not directly rely on a measure of retail volume, the choice of retail trading algorithm will influence the volume analysis and also the classification of which stocks have high retail option interest. In Panel C of Table 7, we drop auto executions when proxying for retail option trades, which BPS consider to be a more conservative approach. In Panel D, we identify retail interest using the retail share of total option dollar volume for each stock rather than the level of retail option volume. These results are similar to earlier findings.

Another concern is that our dollar-volume-weighting approach may spuriously influence the results. In particular, outages may affect which types of options are traded, and the resulting variation in volume by moneyness and maturity could possibly drive the observed IV results (i.e. IV does not change, while the volume composition does). In Panel E, we equal-weight across option contracts and find similar results.[12]

We also consider a measure of retail trading constructed using the Nasdaq option database, which provides information on open and close volume by trader type at ten-minute frequencies.

[12] A related concern is that illiquid options could influence the findings. We use a variety of data filters in Section 2.1.1 to ensure the option prices we analyze are relatively liquid, as evidenced in Panel B of Table 1.

We measure retail trading using non-professional customer orders with an average trade size less than 50 option contracts during a 10-minute interval. The Nasdaq data has the advantage that trades are identified as opening or closing position and information is also included regarding whether the trade was long or involved writing options. We therefore are able to explore investors relative tendency to purchase vs write options. The limitations are that the non-professional customer trades may contain some non-retail trades, and the data are only available for 2 of the 16 option exchanges. More details on the sample and net volume construction are available in Section IA.1 in the Internet Appendix. In Panel E of Table 7, we find similar net volume and implied volatility results using the Nasdaq sample.

4.5 Implied Volatility and Stock Volatility During Outages

Eaton et al. (2022) find evidence that outages at Robinhood are associated with reductions in stock volatility, suggestive of liquidity-demanding herding by Robinhood investors. In contrast, outages at other retail brokers correspond with volatility increases, consistent with liquidity provision by non-Robinhood retail investors. Thus, if the option market implied volatility evidence we observe during outages is fully explained by shifts in the underlying stock market, we would expect to see differences in the option market effects of outages at Robinhood relative to other retail brokers.

We separate the retail broker outage sample into Robinhood and non-Robinhood brokers, namely Charles Schwab, E-Trade, Fidelity, and TD Ameritrade. For each broker type, we then estimate the effect of outages on stock market volatility and option implied volatility for the set of stocks in our option trading sample. We use the same high-retail firm indicator for both stock and options regressions, which is based on option trading over the past five days (as in the rest of the analysis).

Stock return volatility is measured from transaction prices over five-minute windows as in Eaton et al. (2022). We confirm the different effects of broker outages on stock volatility in our sample. For example, stock return volatility significantly falls during Robinhood outages but significantly increases during non-Robinhood outage for the high retail-interest stocks. However, we find reductions in implied volatility during outages at both Robinhood and non-Robinhood brokers. The findings suggest that retail investors have distinct effects on option markets that extend beyond their role in the underlying stock market. Moreover, while stock traders appear appreciably different at Robinhood than at other retail brokers, retail option investors trade in similar ways across brokers.

5. Conclusions

Option market volume has dramatically increased in recent years, driven by an influx of retail investors. This paper examines the trading behavior of retail traders and the effects they have on option markets. We show that the retail option trading is particularly concentrated in short-dated, out-of-the-money call options.

Our main analysis examines the effects of retail trading on option market volume and implied volatility, using brokerage outages as exogenous shocks to retail option trading. We find that net buying volume by retail investors significantly drops during outages for the types of options retail investors prefer, such as call, short-dated, and OTM options. In contrast, net buying volume increases during outages for long-dated options, suggesting that retail investors tend to write rather than purchase longer maturity options.

The paper's central finding is that retail investor demand pressure significantly impacts option implied volatility. We find that implied volatility significantly decreases during retail brokerage outages, and in particular for call, OTM, and short-dated options. In contrast, implied volatility significantly increases for long-dated options. The effect of retail brokerage outages on implied volatility aligns with the shifts in net retail volume and points towards a significant role for retail investors in shaping the IV surface. Additional robustness analysis indicates that the outage results are unique to the outage period, are not driven by a small number of the most actively traded options, and continue to hold for alternative option trading data.

A growing literature studies the effects of demand shocks on financial markets and argues that individuals can have an outsized effect on asset prices due to the elastic nature of household demand (e.g. Koijen and Yogo, 2019; Gabaix et al., 2022; and van der Beck and Jaunin, 2021). Individual investors account for a relatively large fraction of trading in option markets, which suggests their role in explaining option prices may be even more prominent than in stock, currency, or bond markets. Our brokerage outage analysis indicates that retail investors' impact on the IV surface varies with contract type, moneyness, and maturity, which can help inform future research that attempts to measure the price elasticities associated with different option trading clienteles.

Appendix A: Variable Definitions

A.1 Key Explanatory Variables

- *$Retail_{i,d\text{-}1}$* – An indicator variable that is equal to one for stock options in the top quintile of retail option dollar volume over the five trading days preceding the outage day *d*. Source: OPRA.
- *$Outage_t$* – An indicator variable that denotes brokerage platform outage periods and is equal to 1 if an outage occurs during 15-minute period *t* and 0 otherwise). Source: Downdetector.com

A.2 Outcome Variables

- $Trd_{i,t}$ – An option volume measure sampled at 15-minute intervals, *t*, for options aggregated up to each stock *i*
    - *Option Dollar Volume* – the sum of the dollar value of all option trades. Source: OPRA.
    - *Retail Option Dollar Volume* – The sum of the dollar value of all option trades which are identified as single leg auction trades of automatic executions with less than five contracts. Source: OPRA.
    - *Net Retail Option Dollar Volume* – The sum of buy retail dollar volume minus the sum of sell retail dollar volume, where buy (sell) orders are trades above (below) the NBBO midpoint. Source: OPRA.
- $IV_{i,t}$ – the implied volatility inferred using the Black-Scholes option pricing model given the option characteristics, option NBBO midquote price, and the prevailing stock NBBO midquote price. Time to expiration is measured as minutes to the expiration date's market close, and we use end-of-day 3-month Treasury bills for the risk-free rate. Implied volatility is volume-weighted across contracts to 15-minute horizons, *t,* for stock *i*. Source: OPRA and NYSE TAQ files.
- *Stock Return Volatility* –The trade-based standard deviation of returns during 15-minute periods, requiring a minimum of 10 trades. Winsorized at 1% tails. Source: TAQ.

A.3 Key Option Characteristics

- *Short Maturity* – An indicator variable equal to 1 if the maturity of the option is less than or equal to 7 days and 0 otherwise.
- *Mid Maturity* – An indicator variable equal to 1 if the maturity of the option is between 8 days and 20 days and 0 otherwise.
- *Long Maturity* – An indicator variable equal to 1 if the maturity of the option is greater than 20 days and 0 otherwise.
- *Moneyness* – The ratio of the strike price to the stock price, minus one, for put options and one minus the ratio of the strike price to the stock price for call options.
- *Out of the Money* (OTM) – An indicator variable equal to 1 if *Moneyness* is less than -0.025.

- *At the Money* (ATM) – An indicator variable equal to 1 if *Moneyness* is between -0.025 and 0.025.
- *In the Money* (ITM) – An indicator variable equal to 1 if *Moneyness* is greater than 0.025.

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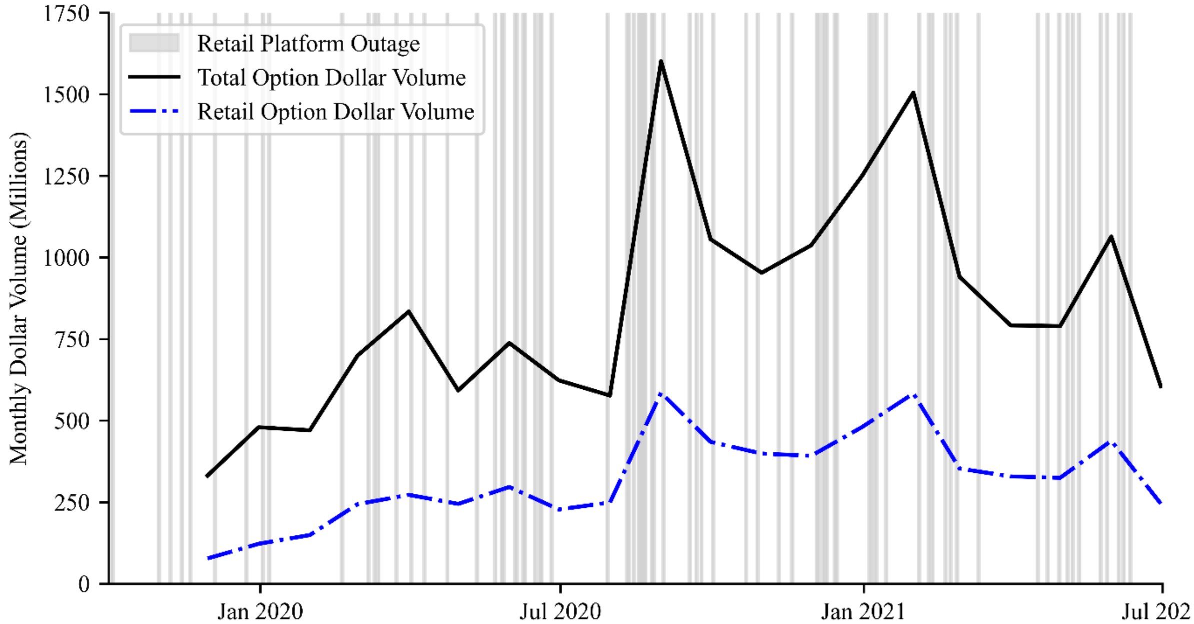

Figure 1. Monthly Option Trading and Broker Platform Outage Dates

The figure illustrates monthly option dollar volume and brokerage outages. The black solid line plots monthly option dollar volume and the blue dashed line plots the measure of retail option volume. Gray bars denote days in which a retail broker (Robinhood, Ameritrade, E-trade, Fidelity, or Schwab) experienced an outage during the regular trading hours of 9:30 to 16:00 EST. Platform outages are defined as having at least 200 outage reports on Downdetector.com.

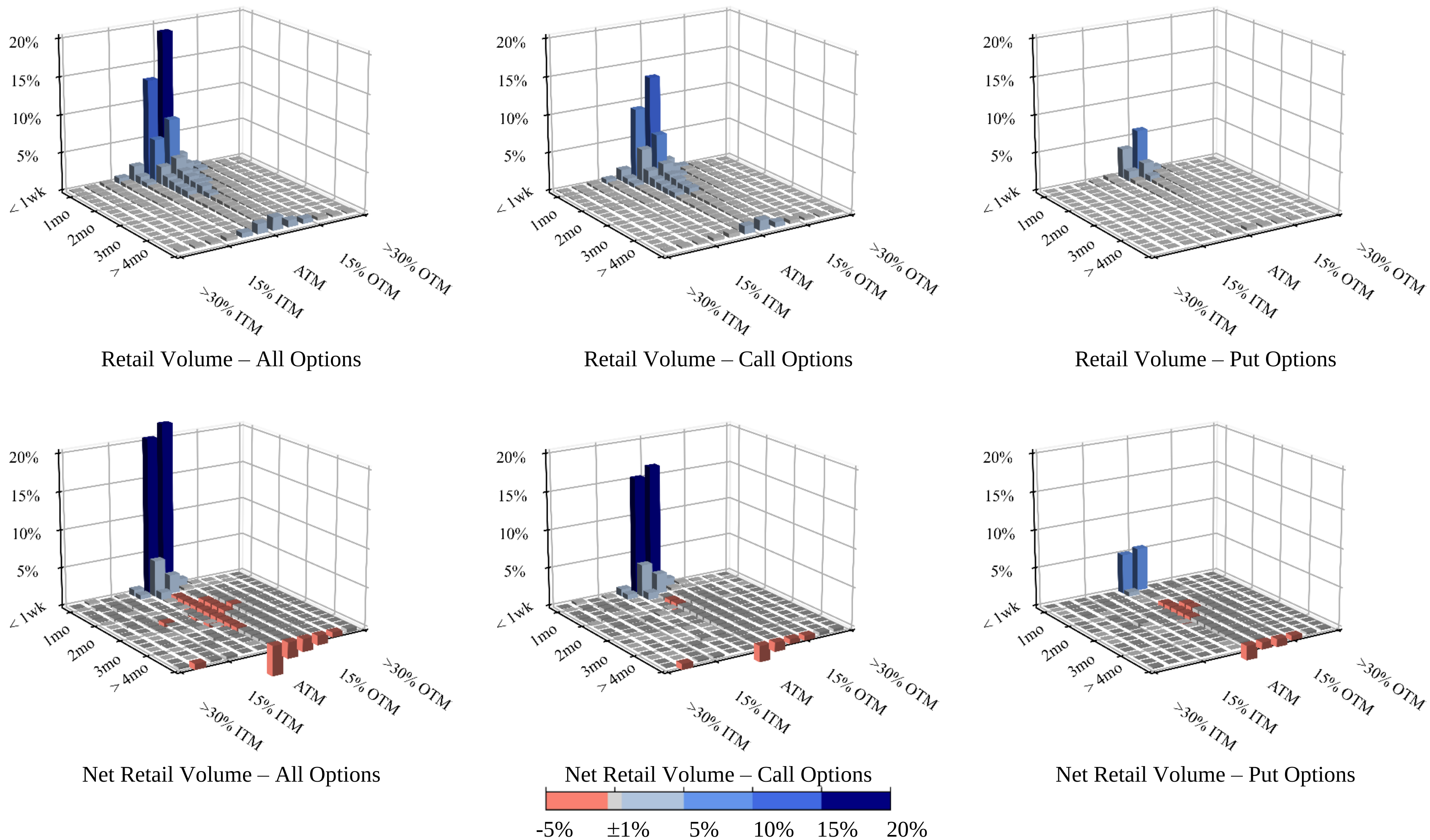

Figure 2. Retail Option Volume by Expiration and Strike level

The figure plots retail dollar volume share and net retail volume share for different moneyness and maturity categories. Net Retail Option Volume adds open-buy-call, open-buy-put, close-write-call, and close-write-put and subtracts close-sell-call, close-sell-put, open-write-call, and open-write-put dollar volume, and then scales by total retail dollar volume. Additional plots show volumes for calls and puts separately, scaled by total retail dollar volume. The volume measures for each maturity-moneyness bin are constructed by aggregating across option chains for each stock-day and then averaging across stock-days.

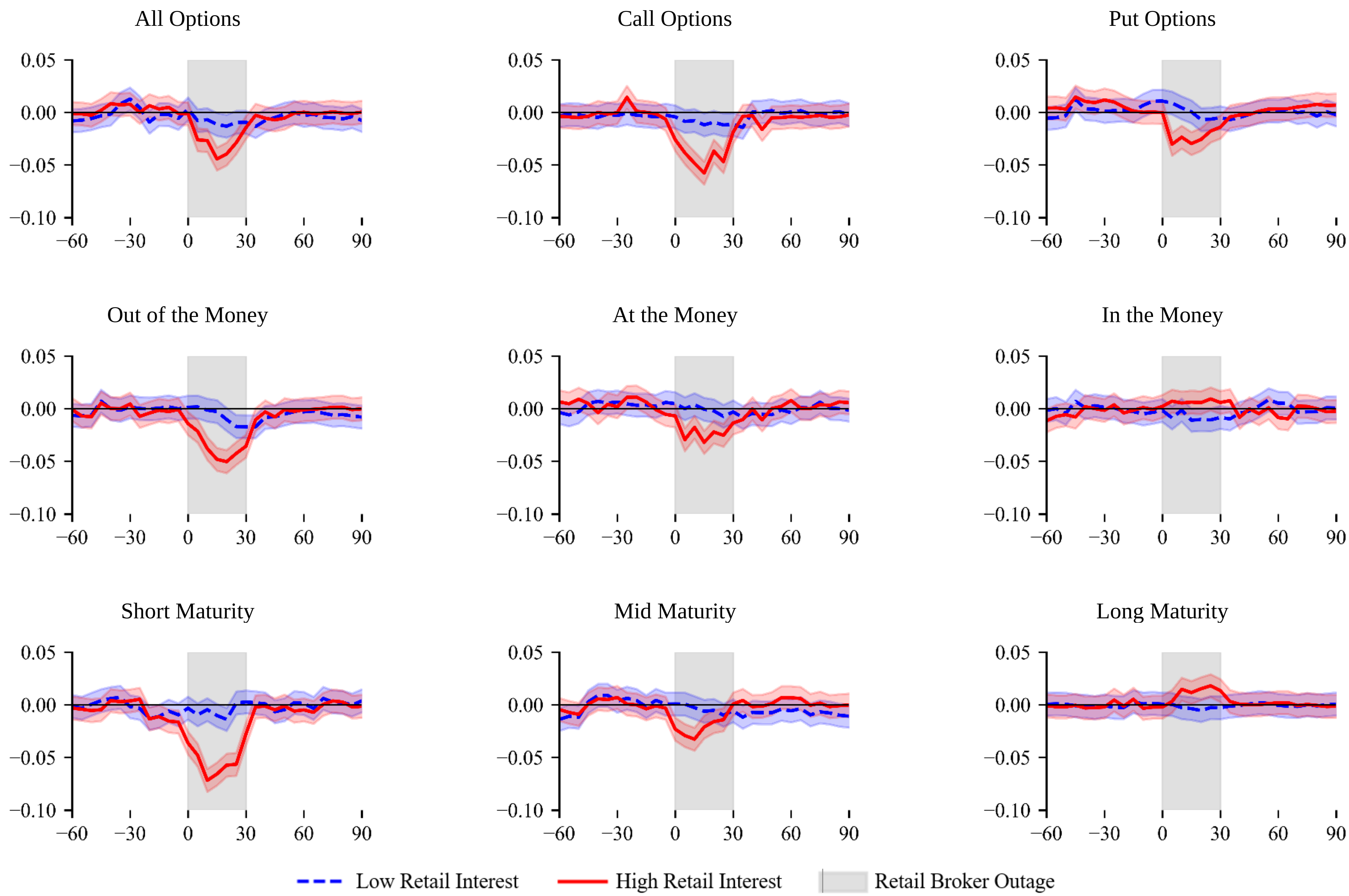

Figure 3. Implied Volatility around Retail Brokerage Outages
The figure plots abnormal option implied volatility around outages with 30-minute durations (represented in grey). IV is aggregated to the stock level separately for stocks in the top quintile of retail interest (red solid line) and the remaining quintiles (dotted blue line). For each 5-minute window, we calculate abnormal IV as the difference between stock IV on the outage day and the average during the same time window over the previous five trading days. Statistical significance is assessed by regressing abnormal IV on firm and date fixed effects, with 5% confidence intervals indicated by shaded bands. Appendix A defines the variables.

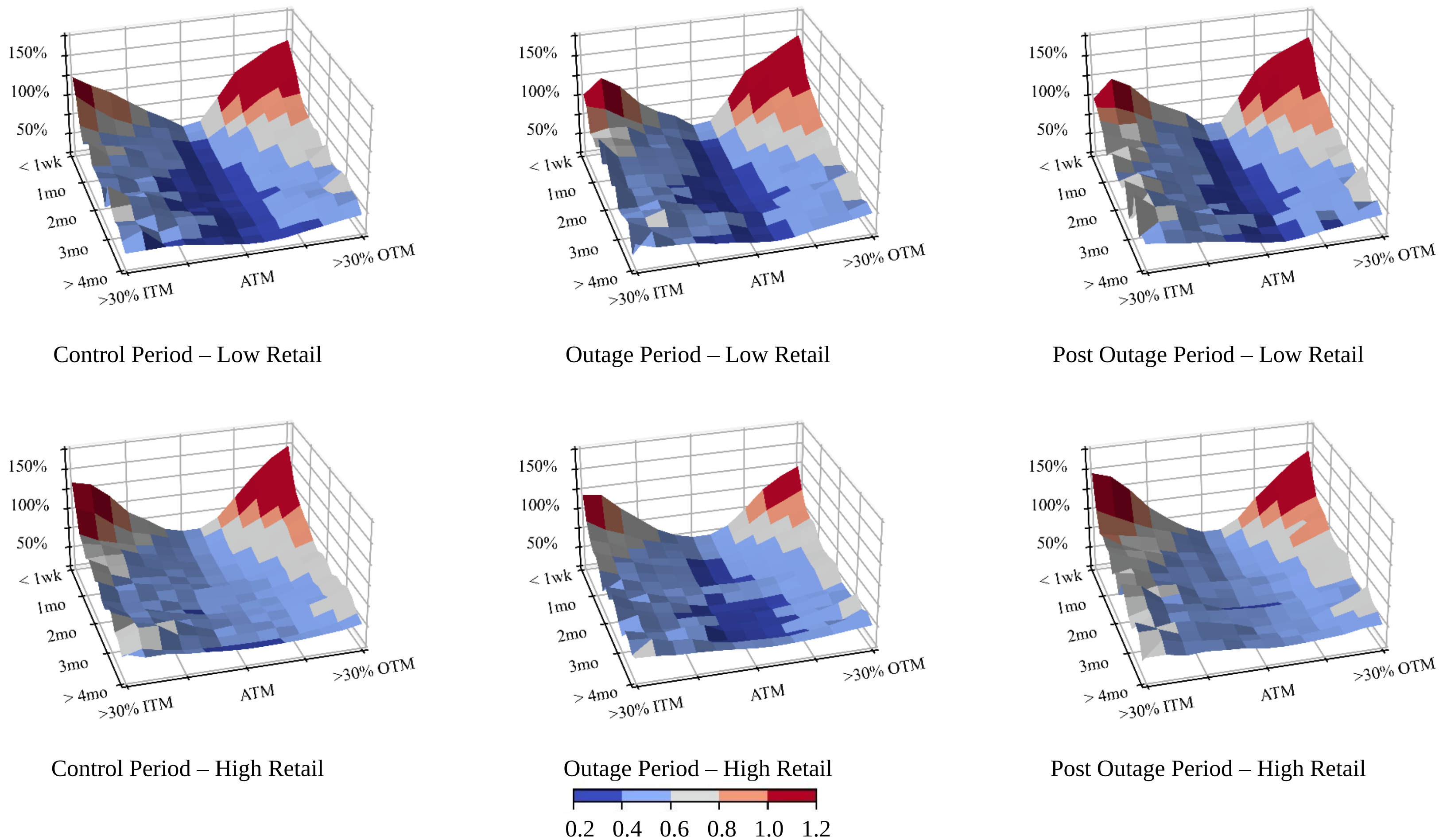

Figure 4. Implied Volatility Surface around Retail Brokerage Outages

This figure illustrates implied volatility levels in various maturity-moneyness bins before, during, and after brokerage outages for options favored the most by retail investors (High Retail) compared to those less favored by retail investors (Low Retail). Implied volatility for each maturity-moneyness bin is computed by volume-weighting across option chains for each stock-day and then averaging across stock-days.

Table 1. Summary Statistics

The table presents descriptive statistics of the characteristics and trading activity of options traded by retail traders. Retail option activity is identified as trades marked in OPRA as single leg auction trades and automatically executed trades of less than five contracts. Panel A presents stock-day level summary statistics. Calls is the fraction of retail dollar volume in call options. Option Price, Implied Volatility, Moneyness, and Days to Expiration are weighted to the stock-day level by retail option dollar volume. Panel B reports option trading activity at the stock-15-minute-level separately for stocks with high retail interest, defined as stocks with top quintile retail dollar volume over the last five trading days, and low retail interest is all remaining stocks. The sample spans November 2019 to June 2021.

Panel A: Option Characteristics

	Mean	Standard Deviation	25th Percentile	Median	75th Percentile
Option Dollar Volume	159,974	762,890	4,964	12,682	42,963
Retail Dollar Volume	73,808	377,568	759	3,197	13,736
Calls	0.78	0.32	0.65	1.00	1.00
Option Price	9.99	15.65	2.64	5.45	11.12
Implied Volatility	0.50	0.42	0.34	0.47	0.73
Moneyness	-0.01	0.07	-0.03	-0.01	0.02
Days to Expiration	21.29	37.42	2.00	8.00	22.00

Panel B: Proportion of Stock-level Retail Option Trading by 15-minute periods

High Retail Interest Stocks					
Option Trades	3,445.53	4,215.40	1,040.00	2,030.00	4,385.00
Option Dollar Volume	80,592.59	145,315.80	10,914.98	28,772.61	84,452.49
Retail Trades	1,583.94	2,698.30	300.00	715.00	1,733.00
Retail Dollar Volume	39,261.50	71,115.70	4,704.94	12,476.06	40,213.55
Low Retail Interest Stocks					
Option Trades	156.60	442.42	14.00	35.00	124.00
Option Dollar Volume	20,14.74	7,166.67	7.15	159.54	1219.48
Retail Trades	73.13	300.3	1.00	7.00	39.00
Retail Dollar Volume	731.45	3,089.37	0.69	58.86	385.09

Table 2. Retail Broker Outages and Option Dollar Volume

The table presents estimated slope coefficients from OLS regressions in which the dependent variable is a measure of option dollar volume and the dependent variables are a high retail interest indicator, an outage indicator, and an interaction between the two. Column labels denote different option volume measures. The sample consists of fifteen-minute intervals, t, for options aggregated up to each stock i during the window on day d when the broker experiences an outage, matched with fifteen-minute intervals for the same stock and time for each of the five trading days preceding the outage date. $Retail_{i,d-1}$ represents an indicator variable that is one if the security is in the top quintile of retail option trading, which is measured by trades flagged in OPRA as single-leg auctions or automatic executions. $Outage_t$ is an indicator variable equal to one during the outage period and zero otherwise. The *Total Option Volume* dependent variable aggregates across all option trading dollar volume. All of the volume measures are logged. Each specification includes firm and day fixed effects. ∗∗∗, ∗∗, and ∗ indicate statistical significance at the 1%, 5%, and 10% levels, respectively, with t-statistics reported in parentheses for standard errors clustered at the firm and day level. Appendix A provides further details on data definitions.

	Total Option Volume	Retail Option Volume	Retail Call Volume	Retail Put Volume
$Retail_{i,d-1} \times Outage_t$	-0.084**	-0.129***	-0.131***	-0.100***
	(-2.117)	(-3.506)	(-3.554)	(-3.534)
$Retail_{i,d-1}$	0.407**	0.522***	0.466***	0.275***
	(2.422)	(2.680)	(3.875)	(2.947)
$Outage_t$	0.050	0.083	0.077	0.111
	(1.196)	(1.171)	(1.019)	(1.041)
Observations	563,793	542,684	521,894	188,148
Number of Firms	898	894	845	617
R-squared	0.0779	0.0944	0.0929	0.1671

Table 3. Retail Broker Outages and Net Retail Trader Option Dollar Volume

The table presents estimated slope coefficients from OLS regressions in which the dependent variable is net retail option dollar volume and the dependent variables are a high retail interest indicator, an outage indicator, and an interaction between the two. The sample consists of fifteen-minute intervals, *t*, for options aggregated up to each stock *i* during the window on day *d* when the broker experiences an outage, matched with fifteen-minute intervals for the same stock and time for each of the five trading days preceding the outage date. $Retail_{i,d-1}$ represents an indicator variable that is one if the security is in the top quintile of retail option trading, which is measured by trades flagged in OPRA as single-leg auctions or automatic executions. $Outage_t$ is an indicator variable equal to one during the outage period and zero otherwise. The *Net Dollar Volume* dependent variable is the difference between buyer- and seller-initiated dollar volume, scaled by total dollar volume. Each specification includes firm and day fixed effects. The *t*-statistics are reported in parentheses for standard errors clustered at the firm and day level. Appendix A provides further data definitions.

	All Options	Calls	Puts	Short Maturity	Mid Maturity	Long Maturity	OTM	ATM	ITM
$Retail_{i,d-1}$ × $Outage_t$	-0.065***	-0.154***	-0.122***	-0.144**	-0.117***	0.147**	-0.133***	-0.145**	0.189*
	(-3.138)	(-3.269)	(-3.246)	(-2.027)	(-2.687)	(2.627)	(-2.664)	(-2.374)	(1.885)
$Retail_{i,d-1}$	0.080	0.107	-0.091	0.040	0.048	0.166	0.016	0.179	0.068
	(1.105)	(1.412)	(-1.568)	(0.665)	(0.954)	(1.105)	(0.199)	(1.052)	(0.875)
$Outage_t$	-0.000	0.023	-0.117	0.026	0.087	-0.025	0.031	-0.008	0.045
	(-0.014)	(0.449)	(-1.150)	(0.537)	(1.016)	(-0.558)	(0.673)	(-0.179)	(0.921)
Observations	542,175	521,389	187,995	288,746	272,514	443,024	373,725	385,158	237,870
Number of Firms	894	845	617	576	645	844	754	746	750
R-squared	0.0194	0.0136	0.0112	0.0251	0.0176	0.0118	0.0131	0.0245	0.0171

Table 4. Retail Broker Outages and Implied Volatility

The table presents estimated slope coefficients from OLS regressions of the effect of retail brokerage outages on call and put option implied volatility. The dependent variable is implied volatility, aggregated to the stock level by dollar volume per fifteen minutes, and the dependent variables are a high retail interest indicator, an outage indicator, and an interaction between the two. The column labels denote the different option contract samples. The sample consists of fifteen-minute intervals, *t*, for options aggregated up to each stock *i* during the window on day *d* when the broker experiences an outage, matched with fifteen-minute intervals for the same stock and time for each of the five trading days preceding the outage date. $Retail_{i,d-1}$ represents an indicator variable that is one if the security is in the top quintile of retail option trading, which is measured by trades flagged in OPRA as single-leg auctions or automatic executions. $Outage_t$ is an indicator variable equal to one during the outage period and zero otherwise. We also include firm and day fixed effects in the model. ∗∗∗, ∗∗, and ∗ indicate statistical significance at the 1%, 5%, and 10% levels, respectively for *t*-statistics with standard errors clustered at the firm and day level. Appendix A provides further details on data definitions.

	All Options	Calls	Puts	Call - Put
$Retail_{i,d-1} \times Outage_t$	-0.019***	-0.036***	-0.024***	-0.050**
	(-4.167)	(-3.950)	(-3.694)	(-1.989)
$Retail_{i,d-1}$	0.143*	0.145**	0.112	0.003
	(1.734)	(2.006)	(1.455)	(0.287)
$Outage_t$	0.034	0.017	0.028	-0.017
	(0.509)	(0.092)	(0.813)	(-1.250)
Observations	718,634	672,851	283,154	237,371
Number of Firms	820	819	643	480
R-squared	0.0466	0.0464	0.1053	0.0124

Table 5. Retail Broker Outages and the Implied Volatility Moneyness Curve

The table presents estimated slope coefficients from OLS regressions of the effect of retail brokerage outages on implied volatility by moneyness bins. The dependent variable is implied volatility, aggregated to the stock level by dollar volume per fifteen minutes, and the independent variables are a high retail interest indicator, an outage indicator, and an interaction between these two. The column labels denote the different option samples. The sample consists of fifteen-minute intervals, *t*, for options aggregated up to each stock *I* during the window on day *d* when the broker experiences an outage, matched with fifteen-minute intervals for the same stock and time for each of the five trading days preceding the outage date. $Retail_{i,d-1}$ represents an indicator variable that is one if the security is in the top quintile of retail option trading, which is measured by trades flagged in OPRA as single-leg auctions or automatic executions. $Outage_t$ is an indicator variable equal to one during the outage period and zero otherwise. We also include firm and day fixed effects in the model. ∗∗∗, ∗∗, and ∗ indicate statistical significance at the 1%, 5%, and 10% levels, respectively for *t*-statistics with standard errors clustered at the firm and day level. Appendix A provides further details on data definitions.

	Out of the Money	At the Money	In the Money	OTM-ITM
$Retail_{i,d-1} \times Outage_t$	-0.036***	-0.019***	0.040	-0.045***
	(-3.006)	(-2.995)	(1.484)	(-3.651)
$Retail_{i,d-1}$	0.181***	0.157***	0.212***	0.060
	(2.552)	(2.985)	(2.922)	(0.449)
$Outage_t$	0.015	0.011	0.030	-0.017
	(1.125)	(0.865)	(1.421)	(-0.003)
Observations	472,217	482,040	390,517	280,983
Number of Firms	779	769	787	529
R-squared	0.0564	0.0608	0.0938	0.0108

Table 6. Retail Broker Outages and Implied Volatility Term Structure

The table presents estimated slope coefficients from OLS regressions of the effect of retail brokerage outages on implied volatility by option maturity. The dependent variable is implied volatility, aggregated to the stock level by dollar volume per fifteen minutes, and the independent variables are a high retail interest indicator, an outage indicator, and an interaction between these two. The column labels denote the different option samples. The sample consists of fifteen-minute intervals, *t*, for options aggregated up to each stock *i* during the window on day *d* when the broker experiences an outage, matched with fifteen-minute intervals for the same stock and time for each of the 5 trading days preceding the outage date $Retail_{i,d-1}$ represents an indicator variable that is one if the security is in the top quintile of retail option trading, which is measured by trades flagged in OPRA as single-leg auctions or automatic executions. $Outage_t$ is an indicator variable equal to one during the outage period and zero otherwise. We also include firm and day fixed effects in the model. ∗∗∗, ∗∗, and ∗ indicate statistical significance at the 1%, 5%, and 10% levels, respectively, for *t*-statistics with standard errors clustered at the firm and day level. Appendix A provides further details on data definitions.

	Short Maturity	Mid Maturity	Long Maturity	Short – Long
$Retail_{i,d-1}$ × $Outage_t$	-0.061***	-0.044***	0.026**	-0.072***
	(-3.038)	(-2.979)	(2.379)	(-3.083)
$Retail_{i,d-1}$	0.191***	0.140***	0.110***	0.082
	(3.593)	(2.919)	(3.447)	(0.868)
$Outage_t$	-0.018	0.035	0.019	-0.030
	(-0.692)	(0.185)	(0.879)	(-1.330)
Observations	327,790	337,801	622,553	283,470
Number of Firms	492	562	669	425
R-squared	0.0569	0.0658	0.0461	0.0226

Table 7. Robustness Analysis

The table reports robustness checks. For brevity, each panel reports only estimates on the interaction term in Equations (1) and (2), which captures the effects of outages on net retail dollar volume or implied volatility for options with high expected retail trading. Panel A omits the top 30 stocks by option volume prior to each outage, Panel B omits morning outages (outages that begin before 9:45amET), Panel C identifies retail trades using only single leg auctions, Panel D identifies retail interest by retail volume as a share of overall option volume, Panel E aggregates implied volatility to the stock-level using equal-weighting instead of dollar value weighting, and Panel F measure retail trading using small customer data from Nasdaq. Each analysis consists of fifteen-minute intervals, *t*, for options aggregated up to each stock *i* during the window on day *d* when the broker experiences an outage, matched with fifteen-minute intervals for the same stock and time for each of the five trading days preceding the outage date. The $Retail_{i,d-1}$ variable represents and indicator variable that takes a value of one if the security is in the top quintile of expected retail trading and zero otherwise. The $Outage_t$ variable is an indicator variable equal to one during the outage period and zero otherwise. We also include firm and day fixed effects in the model. ∗∗∗, ∗∗, and ∗ indicate statistical significance at the 1%, 5%, and 10% levels, respectively for *t*-statistics with standard errors clustered at the firm and day levels. Appendix A provides further details on data definitions.

		Implied Volatility			
	Net Retail Option Volume	All Options	Call-Put	OTM-ITM	Short – Long
Panel A: Exclude top 30 stocks by option volume					
$Retail_{i,d-1} \times Outage_t$	-0.043***	-0.023***	-0.071*	-0.056**	-0.054***
	(-2.588)	(-2.673)	(1.712)	(-2.083)	(-3.724)
Panel B: Exclude morning outages					
$Retail_{i,d-1} \times Outage_t$	-0.037***	-0.010**	-0.036**	-0.064***	-0.072**
	(-3.131)	(-2.460)	(2.172)	(-2.783)	(-2.195)
Panel C: Identify retail trades only using single leg auctions					
$Retail_{i,d-1} \times Outage_t$	-0.023*	-0.028***	-0.053**	-0.052***	-0.092***
	(-1.779)	(-4.651)	(2.298)	(-2.954)	(-3.576)
Panel D: Identify retail interest using share of retail dollar volume					
$Retail_{i,d-1} \times Outage_t$	-0.067***	-0.021***	-0.047**	-0.048***	-0.071***
	(-3.251)	(-3.894)	(2.013)	(-3.542)	(-2.991)
Panel E: Equal-weight across contracts instead of dollar-volume-weight					
$Retail_{i,d-1} \times Outage_t$	-0.026*	-0.018***	-0.038*	-0.045**	-0.076***
	(-1.890)	(-2.633)	(-1.812)	(-2.175)	(-2.709)
Panel F: Identify retail trading using NASDAQ small customer identifier					
$Retail_{i,d-1} \times Outage_t$	-0.041**	-0.027***	-0.052*	-0.063***	-0.089***
	(-2.296)	(-3.604)	(-1.893)	(-3.349)	(-2.961)

Table 8. Realized Volatility, Implied Volatility, and Brokerage Outages

The table presents estimated slope coefficients from OLS regressions of the effect of retail brokerage outages on option implied volatility and realized volatility of the underlying stock. The dependent variable takes the value of either realized trade-based stock volatility, or option implied volatility, and both are aggregated to the stock level by dollar volume per fifteen minutes. The independent variables are a high retail interest indicator, an outage indicator, and an interaction between these two. The column labels denote the different option samples. The sample consists of fifteen-minute intervals, *t*, for options aggregated up to each stock *i* during the window on day *d* when the broker experiences an outage, matched with fifteen-minute intervals for the same stock and time for each of the 5 trading days preceding the outage date $Retail_{i,d-1}$ represents an indicator variable that is one if the security is in the top quintile of retail option trading, which is measured by trades flagged in OPRA as single-leg auctions or automatic executions. $Outage_t$ is an indicator variable equal to one during the outage period and zero otherwise. We also include firm and day fixed effects in the model. ∗∗∗, ∗∗, and ∗ indicate statistical significance at the 1%, 5%, and 10% levels, respectively, for *t*-statistics with standard errors clustered at the firm and day level. Appendix A provides further details on data definitions. Using subset of stocks where there are observations for both stock and options, and retail dummy is the same for both securities.

	All Outages		Non-Robinhood Outages		Robinhood Outages	
	Stock Volatility	Implied Volatility	Stock Volatility	Implied Volatility	Stock Volatility	Implied Volatility
$Retail_{i,d-1} \times Outage_t$	0.112	-0.019***	0.285**	-0.017***	-0.150*	-0.031**
	(1.402)	(-4.167)	(2.479)	(-3.841)	(-1.907)	(-2.133)
$Retail_{i,d-1}$	0.409**	0.143*	0.383*	0.147*	0.181**	0.163*
	(2.310)	(1.734)	(1.899)	(1.816)	(2.409)	(1.783)
$Outage_t$	0.046	0.034	-0.321	0.031	-0.112	0.015
	(0.642)	(0.509)	(-0.464)	(0.413)	(-0.900)	(0.042)
Observations	718,634	718,634	403,816	403,816	214,376	214,376
Number of Firms	820	820	544	544	483	483
R-squared	0.0832	0.0463	0.0565	0.0740	0.0269	0.0314

Internet Appendix for

Retail Option Traders and the Implied Volatility Surface

IA.1 Description of the Nasdaq Option Sample

The Nasdaq option sample covers the Nasdaq Options Market (NOM) and Nasdaq PHLX option exchanges. Each exchange provides two datasets. The Nasdaq ITCH-to-trade options (ITTO) and top-of-PHLX-options plus orders (TOPO Plus) databases are comprised of trade-by-trade level information and contain order and trade data, including option prices. We use these databases to compute implied volatility. The second type of dataset, namely the Nasdaq Options Trade Outline (NOTO) and the PHLX Options Trade Outline (PHOTO) intraday files, does not contain option prices but does provide information on open and close volume by trader type at ten-minute frequencies. The data sourced from the two exchanges represent two of the sixteen U.S. options exchanges and account for approximately 20-25% of the total option market volume during our sample period.[13]

NOTO and PHOTO data contain information on the number of open-to-buy, open-to-sell, close-to-buy, and close-to-sell trades for each option chain by different categories of traders: Market Makers, Broker-Dealers, Firms, Professional Customers, and (non-professional) Customers. Market Makers are financial institutions registered as market makers on an options exchange, Broker-Dealers trade on behalf of institutional investors and may also serve as de facto market makers, and Firm trades capture orders from proprietary accounts at Options Clearing

[13] CBOE tracks volume statistics for each option exchange and posts recent market share information at the following link: https://www.cboe.com/us/options/market_statistics/?mkt=exo.

Corporation (OCC) member firms. Professional Customers are traders who place more than 390 option orders per day (i.e., one per minute during the trading day) on average over the last month.[14]

Our measure of Nasdaq retail trading is based on small, non-professional customer trades from NOTO and PHOTO. Institutions that trade options infrequently will also be classified as non-professional. However, discussions with industry professionals suggest that, due to the less liquid nature of option markets, institutional trades are typically large (unlike in equity markets). We therefore measure retail trading using non-professional customers with average trade size less than 50 option contracts during a 10-minute interval.[15] The benefit of the Nasdaq data is that we are able to observe whether a transaction opened or closed a position or involved purchasing or writing contracts. The drawbacks are that it only accounts for a fraction of overall option trading, and the accuracy of the small customer trade retail proxy is unclear.

For the Nasdaq sample, we construct net retail trading volume by aggregating dollar volume across the eight position types by adding trades which exert upward pressure on option prices and subtracting trades that create downward pressure. Trades expected to create upward pressure on option prices and assigned a positive sign include: (1) new position call option purchases, (2) new position put option purchases, (3) closing previously written call positions (by buying calls), and (4) closing previously written put positions (by buying puts). Analogously, trades expected to create downward pressure on prices and assigned a negative sign include: (5) closing previously purchased call positions (by selling calls), (6) closing previously purchased put positions (by selling puts), (7) new position call writing, and (8) new position put writing.

[14] Each option leg of complex multi-leg orders counts as a separate order, and orders that cancel and replace an existing order are also counted as a separate order. https://cdn.cboe.com/resources/regulation/circulars/regulatory/RG16-064.pdf
[15] Discussions with the Head of US Options at Nasdaq suggest that focusing on customer trades below 50 contracts excludes virtually all institutional trades.

Table IA1. Summary statistics of outage versus non-outage periods

The table presents descriptive statistics of the characteristics and trading activity of options traded by retail traders. Retail option activity is identified as trades marked in OPRA as single leg auction trades and automatically executed trades of less than five contracts. Panel A reports option trading activity during non-outage periods, and Panel B reports option trading activity during retail brokerage outages. Stocks with high retail interest are defined as those with top quintile retail dollar volume over the last five trading days, and low retail interest is all remaining stocks. The sample spans November 2019 to June 2021.

Panel A: Proportion of Stock-level Retail Option Trading by 15-minute periods, during non-outage periods

High Retail Interest Stocks					
Option Trades	3,316.75	4,073.48	909.5	1,909	3,996.5
Option Dollar Volume	90,593.2	178,709.7	10,658.22	28,843.42	87,311.85
Retail Trades	1,628.84	2,551.33	300	750	1,851.5
Retail Dollar Volume	43,080.99	82,944.44	4,457.61	12,507.97	41,684.75
Low Retail Interest Stocks					
Option Trades	155.26	446.82	13	33	116
Option Dollar Volume	2,082.08	7,006.58	8.8	172.42	1,239.44
Retail Trades	78.47	306.15	1	7	41
Retail Dollar Volume	788.36	3,166.43	2.25	65.74	409.67

Panel B: Proportion of Stock-level Retail Option Trading by 15-minute periods, during outage periods

High Retail Interest Stocks					
Option Trades	3,410.37	4,188.94	1,037	2,002	4,351
Option Dollar Volume	77,373.5	136,673.1	10,588.54	28,054.54	81,635.65
Retail Trades	1,250.25	2,176.73	232	599	1,584
Retail Dollar Volume	37,950.47	68,354.94	3,963.44	10,209.31	38,561.75
Low Retail Interest Stocks					
Option Trades	153.02	424.92	14	35	123
Option Dollar Volume	1,924.56	6,610.53	6.05	150.48	1,180.77
Retail Trades	69.97	287.3	0	7	38
Retail Dollar Volume	689.59	2,805.41	0	55.22	371.39

Table IA2. Determinants of Retail Option Trading

The table presents the results of regressions of retail option volume on contract and firm characteristics in the Nasdaq sample, which allows trades to be classified as purchased or underwritten. In Specification (1), the dependent variable is stock-day aggregate dollar volume across the option chain. In Specifications (2) through (5), dollar volume is considered separately for open positions by option transaction type. The sample consists of common stocks with options traded on the Nasdaq Option markets and Nasdaq PHLX markets from January 2019 to June 2021. Short Maturity is an indicator variable that equals one if the maturity of the option is less than or equal to 7 days. Middle Maturity is an indicator variable that equals one if the maturity of the option is from 8 days to 20 days. Call is an indicator variable if the option is call and 0 otherwise. Out-of-the-money (OTM) is defined as a dummy variable equal to one if moneyness is lower than -0.025. At-the-money (ATM) is defined as a dummy variable if moneyness is between -0.025 and 0.025. Volatility is daily volatility calculated using the last 22 days' stock return from CRSP. Idiosyncratic Skewness is defined as the skewness of daily residuals from a regression of the stock return on excess market return and square of excess market return, following Harvey and Siddique (2000). Other controls include stock returns from the past week, stock returns from t-20 to t-6, stock level bid-ask spread, size, and book-to-market. We also include day fixed effects in the model. ∗∗∗, ∗∗, and ∗ indicate statistical significance at the 1%, 5%, and 10% levels, respectively for *t*-statistics with standard errors clustered at the firm and day levels.

	Aggregate Volume	Purchase Calls	Purchase Puts	Underwrite Calls	Underwrite Puts
	(1)	(2)	(3)	(4)	(5)
Short Maturity	0.342***	0.392***	0.377***	0.385***	0.242***
	(7.97)	(8.47)	(7.01)	(8.63)	(4.41)
Middle Maturity	0.050***	0.070***	0.005	0.073***	-0.049**
	(2.86)	(3.16)	(0.25)	(3.11)	(-2.08)
Call	0.135***				
	(12.87)				
Out of the Money	0.139***	0.160***	0.035	0.168***	0.078***
	(9.43)	(9.51)	(1.39)	(7.44)	(4.60)
At the Money	0.189***	0.205***	0.054	0.192***	0.174***
	(6.70)	(5.29)	(1.18)	(5.43)	(4.55)
Volatility	3.098***	2.778***	2.798***	2.881***	2.648***
	(6.04)	(5.70)	(4.68)	(6.39)	(4.81)
Idiosyncratic Skewness	0.017***	0.021***	0.013**	0.017***	0.013***
	(2.87)	(3.64)	(2.27)	(3.38)	(2.64)
$Return_{-1to-5}$	0.121***	0.060*	0.120***	0.387***	0.012
	(4.23)	(1.68)	(2.84)	(13.63)	(0.34)
$Return_{-20\ to-6}$	-0.103***	-0.085***	-0.063*	-0.046***	-0.079**
	(-4.03)	(-3.78)	(-1.65)	(-2.60)	(-2.58)
Bid Ask Spread	0.528***	0.801***	0.764***	0.591***	0.683***
	(2.88)	(4.91)	(4.50)	(3.88)	(4.14)
Size	0.075***	0.069***	0.059***	0.072***	0.053***
	(3.80)	(3.76)	(2.99)	(3.96)	(2.69)
Book to Market	0.054	0.020	-0.004	0.026	0.031
	(1.31)	(0.54)	(-0.10)	(0.78)	(1.05)
Day Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	3,778,666	2,139,142	1,217,554	2,150,249	1,243,862
R-Squared	0.063	0.012	0.011	0.034	0.025

Table IA3. Summary Statistics for the Nasdaq sample

The table presents descriptive statistics. Panel A presents stock-day level summary statistics. Option Price, Calls (an indicator that is one if the option is a call), Implied Volatility, Moneyness, and Days to Expiration are weighted to the stock-day level by retail option dollar volume. Retail volume is measured using small, non-professional customer trades. Panel B reports the proportion of retail dollar volume based on open and closing positions. The sample spans January 2019 to June 2021 and covers the NOM and PHLX option exchanges.

Panel A: Option Characteristics

	Mean	Standard Deviation	25th Percentile	Median	75th Percentile
Non-market Maker Dollar Volume	46,711	310,877	750	2,936	12,847
Retail Dollar Volume	24,688	163,979	316	1,032	4,977
Option Price	2.24	5.20	0.42	0.90	1.04
Calls	0.76	0.32	0.60	0.84	1.00
Implied Volatility	0.45	0.38	0.22	0.35	0.58
Moneyness	-0.03	0.06	-0.05	-0.02	-0.01
Days to Expiration	23	39	3	10	28

Panel B: Proportion of Retail Dollar Volume by Position Type

	Buying Options		Writing Options	
	Open Position	Close Position	Open Position	Close Position
All Retail Options	0.435	0.337	0.153	0.076
Call Options	0.444	0.355	0.133	0.068
Put Options	0.376	0.288	0.230	0.106

Table IA4. Retail Broker Outages and Non-Retail Option Dollar Volume.

This table reports the results from OLS regressions for total non-retail, non-market maker option dollar volume. Column labels denote different option samples. The sample consists of fifteen-minute intervals, *t*, for options aggregated up to each stock *i* during the window on day *d* when the broker experiences an outage, matched with fifteen-minute intervals for the same stock and time for each of the five trading days preceding the outage date. $Retail_{i,d-1}$ represents an indicator variable that is one if the security is in the top quintile of expected retail trading and zero otherwise. $Outage_t$ is an indicator variable equal to one during the outage period and zero otherwise. The *Dollar Volume* dependent variable aggregates across all non-retail option trading dollar volume. Each specification includes firm and day fixed effects. ∗∗∗, ∗∗, and ∗ indicate statistical significance at the 1%, 5%, and 10% levels, respectively, with *t*-statistics reported in parentheses for standard errors clustered at the firm and day level. Appendix A provides further details on data definitions.

	All Options	Calls	Puts
$Retail_{i,d-1} \times Outage_t$	-0.024	-0.017	-0.013
	(-1.048)	(-0.967)	(-1.274)
$Retail_{i,d-1}$	0.051*	0.022*	0.042
	(1.796)	(1.770)	(1.177)
$Outage_t$	0.075	0.076	0.005
	(0.402)	(0.879)	(0.862)
Observations	648,498	627,716	195,598
Number of Firms	709	680	371
R-squared	0.032	0.054	0.037

Table IA5. Retail Broker Outages and Option Prices.
The table repeats the analysis in Tables 4-6 using log option price as the dependent variable instead of option implied volatility.

	Option Type			Moneyness			Maturity		
	All Options	Calls	Puts	OTM	ATM	ITM	Short	Mid	Long
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Retail$_{i,d\text{-}1}$×Outage$_t$	-0.022***	-0.018***	-0.135**	-0.040***	-0.072**	0.034	-0.167***	-0.061***	0.067***
	(-3.757)	(-3.249)	(-2.430)	(-2.852)	(-2.465)	(0.748)	(-3.385)	(-2.701)	(2.764)
Retail$_{i,d\text{-}1}$	0.528**	0.540***	0.668***	0.578***	0.467***	0.315**	0.535***	0.640***	0.725***
	(2.486)	(2.778)	(4.576)	(5.297)	(4.707)	(2.454)	(3.146)	(6.169)	(5.578)
Outage$_t$	0.071	0.030	0.200	0.043	0.087	0.191	-0.022	0.053	0.117
	(1.448)	(0.587)	(0.384)	(0.918)	(0.244)	(0.622)	(-0.345)	(0.558)	(0.375)
Observations	718634	672851	283154	472,217	482,040	390,517	327,790	337,801	622,553
Number of Firms	820	819	643	779	769	787	492	562	669
R-Squared	0.0256	0.0316	0.0555	0.0417	0.0402	0.0724	0.0759	0.0703	0.0388

Table IA6. Alternate Methods to Measure Implied Volatility

The table presents estimates of the main results from Tables 3-6 using alternative methods to construct the sample and implied volatility measures. In Panel A, implied volatility is computed using option transaction prices instead of midquotes. To be included in the sample, we require option contracts to trade during a given event-day 15-minute window and also at least once during the same 15-minute time window during the pre-event period. In Panel B, implied volatility is computed using midquotes as in Tables 3-6, but we consider an expanded sample that relaxes the restriction that option contracts have quote changes during the outage window on the outage day.

		Implied Volatility			
	Net Option Volume	All Options	Call-Put	OTM-ITM	Short – Long
Panel A: Using Transaction Prices for Implied Volatility					
$Retail_{i,d-1}$ × $Outage_t$	-0.074**	-0.062**	-0.039*	-0.031**	-0.052*
	(-2.421)	(-2.078)	(-1.873)	(-2.153)	(-1.865)
$Retail_{i,d-1}$	0.230***	0.526***	0.260***	0.233***	0.124**
	(3.416)	(3.461)	(2.725)	(2.764)	(2.513)
$Outage_t$	0.097	0.023	0.192	0.020	-0.001
	(1.094)	(0.256)	(0.961)	(0.307)	(-0.011)
Observations	633,548	558,077	365,634	438,068	229,347
Number of Firms	522.0	461.0	369.0	470.0	183
R-squared	0.0665	0.0685	0.077	0.0607	0.173
Panel B: Constructing the Sample without Removing Static Quotes					
$Retail_{i,d-1}$ × $Outage_t$	-0.099***	-0.025*	-0.066**	-0.084*	-0.024***
	(-2.753)	(-1.742)	(-2.312)	(-1.884)	(-2.850)
$Retail_{i,d-1}$	0.290***	0.783***	0.132***	0.596***	0.040*
	(3.002)	(2.590)	(3.124)	(3.317)	(1.830)
$Outage_t$	0.062	0.251	0.259	0.002	-0.022
	(0.303)	(1.267)	(1.179)	(0.014)	(-1.360)
Observations	464,513	366,930	366,149	719,204	358,744
Number of Firms	619	375	435	675	441
R-squared	0.0759	0.0812	0.0802	0.0816	0.0558

Table IA7. Retail Brokerage Outages and Zero-day to Expiration Option Prices

The table presents estimated slope coefficients from OLS regressions of the effect of retail brokerage outages on prices of zero-day to expiration options. The dependent variable takes the value of the logged option price. The independent variables are a high retail interest indicator, an outage indicator, and an interaction between these two. The column labels denote the different option samples. The sample consists of fifteen-minute intervals, *t*, for options aggregated up to each stock *i* during the window on day *d* when the broker experiences an outage, matched with fifteen-minute intervals for the same stock and time for each of the 5 trading days preceding the outage date $Retail_{i,d-1}$ represents an indicator variable that is one if the security is in the top quintile of retail option trading, which is measured by trades flagged in OPRA as single-leg auctions or automatic executions. $Outage_t$ is an indicator variable equal to one during the outage period and zero otherwise. We also include firm and day fixed effects in the model. ∗∗∗, ∗∗, and ∗ indicate statistical significance at the 1%, 5%, and 10% levels, respectively, for *t*-statistics with standard errors clustered at the firm and day level. Appendix A provides further details on data definitions.

	All Options	Calls	Puts	OTM	ATM	ITM
$Retail_{i,d-1} \times Outage_t$	-0.052**	-0.093**	-0.034	-0.124**	-0.035*	-0.105***
	(-2.338)	(-2.340)	(-0.581)	(-2.150)	(-1.721)	(-2.946)
$Retail_{i,d-1}$	0.528***	0.544***	0.353***	0.427***	0.400***	0.402***
	(4.705)	(4.626)	(3.561)	(3.570)	(5.471)	(3.016)
$Outage_t$	-0.015	-0.010	0.049	0.034	0.047	0.045
	(-0.418)	(-0.280)	(0.962)	(0.857)	(1.417)	(1.433)
Observations	78,203	76,026	32,162	45,643	62,660	34,245
Number of Firms	260	243	138	153	187	221
R-Squared	0.1426	0.1483	0.1752	0.1689	0.1464	0.1322