Informed Trading in Options Markets Surrounding Data Breaches

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Abstract

We explore whether there is informed trading, which takes advantage of data breach events. By analyzing transactions in the options market, we conjecture that there are two distinct informed trading patterns that likely begin approximately four months prior and from twelve months to eight months prior to corporate data-breach announcements, which are supported by evidence of higher trading volume and open interest for put options, a higher put-to-call volume ratio, a higher put-to-call open interest ratio, and lower spreads prior to data-breach announcements. We further examine stock reactions following data-breach announcements and find significantly negative CARs of -0.35% within one day. Cross-sectional analysis provides evidence that put-call ratios have predictive power for stock returns. We provide additional evidences such as possible trading strategies in stock markets and options markets.

JEL classification: G13, G14, K24

Keywords: informed trading, cybersecurity, data breach, option market.

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1. Introduction

Data breaches have gained widespread attention as companies in different industries become increasingly reliant on digital data, cloud computing, and workforce mobility. A recently released 2018 report by the Council of Economic Advisers estimates that cyberattacks negatively impacted the U.S. economy by between $57 billion and $109 billion in 2016, which represents 0.31% to 0.58% of that year's GDP [1]. During 2018, the Securities and Exchange Commission (SEC) addressed cybersecurity on three fronts: issuing long-awaited guidance concerning cybersecurity disclosure issues for public companies; commencing enforcement actions against several companies for cyber-related mistakes; and finally, issuing an investigatory report about internal control failures relating to cyber or "business compromise" e-mail fraud, which resulted in $100 million in losses. The SEC also briefly stated the regulatory expectation for 2019 and that cybersecurity will become even more important in 2019. The 2017 Verizon report[2] on data breach finds that the majority of the data breaches involve outsiders, and criminal groups intent on profiting from the attack, and a majority of the cyberattacks involve hacking. Informed trading prior to data-breach announcements could be one channel of making profits from data breaches.

In a frictionless, dynamically complete market, options are redundant securities. However, the last two decades have witnessed a proliferation of options and other derivative securities, with option open interest in all major options exchanges increasing tenfold in 15 years. Options markets are an ideal venue for informed trading, given the high leverage achievable with options and the built-in downside protection. Options can also relax different types of short-sale constraints such as equity borrowing constraints because investors can short stocks synthetically in option markets (Diamond and Verrecchia (1987), Figlewski and Webb (1993), Liu and Piccotti (2019)).

We examine informed trading in the options market surrounding various cybersecurity events, such as hacking and other forms of data breaches. If there is informed trading in the options market, then we would expect at least some data-breach information to be reflected in options prices first. The question of whether options order flow is informative about data breaches is directly relevant to options market makers concerned with managing the data breach risk. If a significant amount of informed trading occurs in the options market, then there are also implications for traders watching for signals about future price movements, as well as for regulators surveying for illegal trading activities.

Our study examines two primary research questions. First, does informed trading prior to

[1] https://www.whitehouse.gov/articles/cea-report-cost-malicious-cyber-activity-u-seconomy/

[2] Data breach investigations report Verizon Media 2017 is retrieved from https://www.verizondigitalmedia.com/blog/2017/07/2017-verizon-databreach-investigations-report/

corporate data-breach announcements exist in options markets? Probit regressions show that options trading activity has predictive power for whether or not a data-breach announcement will occur, controlling for fundamental factors. This is consistent with informed trading prior to corporate announcement in options markets, although it does not establish whether the informed traders are "hackers" or "insiders".

We next analyze whether there are two groups of informed traders, hackers and insiders, taking advantage of data breaches. Difference-in-difference analysis results lead us to conjecture that there are two groups of informed traders: hackers, who initiate informed trading from approximately twelve months to eight months prior to data-breach announcements and insiders, who begin trading on their information of a breach from approximately four months prior to public data-breach announcements. Insiders' trading occurs after a firm has detected a breach, but before the firm discloses the data-breach information to the public. For example, a former Chief Information Officer (CIO) of Equifax has been issued a prison sentence for trading on knowledge of the firm's disastrous data breach before the incident became public knowledge[3].

The second question is whether the trading activity in options markets can predict ex-post stock returns. We provide empirical evidence suggesting that options trading activity (i.e. the put-to-call volume ratio and put-to-call open interest ratio) has predictive power for CARs immediately surrounding the event date within (0,+1d) and within (0+5d). We find that the mean 5-day cost to a breached frim is $66.573 million in lost market cap following their public announcement of the breach.

Our paper contributes to the literature in several ways. First, prior literature has provided both indirect evidence of informed trading in options markets (Mayhew, Sarin, and Shastri (1995), Easley, O'Hara, and Srinivas (1998), Pan and Poteshman (2006), Cao, Chen, and Griffin (2005), Piccotti and Schreiber (2015) etc.) and direct evidence of price discovery in option markets (Chakravarty, Gulen, and Mayhew (2004)). Our paper contributes to this strand of literature and provides evidence of price discovery in options markets in the setting of data breaches.

Second, our study contributes to a growing yet still limited literature in finance on data breaches or cyberattacks. It is worth to analyze data-breach events because of the fol-

[3]For example, WSJ reported that "it is a refrain that can often be heard from consumers who learn through a news report that their personal details such as credit-card and Social Security numbers have been exposed to identity thieves, often for months before they are alerted. Sadly, cyber incompetence isn't a crime and identity thieves rarely get caught. But now at least one senior executive, former chief information officer of Equifax's U.S. Information Solutions Jun Ying, will do some hard time. His crime, though, was insider trading. Made aware of a 2017 security breach affecting 143 million customers, he first exercised stock options and sold the shares, avoiding a loss of over $117,000 according to the U.S. Attorney's Office." – *Nobody Cares About Your FICO Score in Prison by Spencer Jakab, July 1, 2019 11:54 am ET*

lowing characteristics that are different from other corporate events: a) Data breaches are unpredictable or periodic, unlike earning announcements, dividend announcements, analyst forecast or repurchases that are reported quarterly or annually. b) Data breaches have relatively high frequency that is different from the events such as Merger&Acquisition (M&A) and corporate sandals. c) Data breaches have uncertain disclosure and uncertain effect. The data breach disclosure is voluntary, and SEC had not provided relatively detailed disclosure guidance of data breaches until 2018. d) Data breaches induce benefits and losses among complicated market participants such as the firms who experience data breaches, their cooperators, their competitors, customers, investors, or even "hackers", etc.

By using different cyber-breach datasets, we confirm Mitts and Talley (2018)'s findings that there is "informed cyber-trading" approximately sixteen months to eight months prior to disclosure of the data breach. Our study has additional contributions that are not explored in Mitts and Talley (2018). First, by considering the date that a data breach occurred and the date that a firm discovered the breach, we find two distinct two patterns, approximately four months prior till the announcement date, and fifteen months to eight months prior to the data-breach announcement. The empirical evidence of distinct two patterns of informed trading prior to data-breach announcements provide implications for traders, firms, and regulators with respect to data-breach informed trading. Some cybersecurity insurance has been designed to mitigate losses from a variety of cyber incidents, including data breaches, business interruption, and network damage. State-level data protection laws are becoming more common in the United States. States such as California, Massachusetts, Minnesota, Nevada, Oregon and Washington have laws that govern minimum cybersecurity requirements. Second, we divide our sample into three different groups of moneyness, near-the-money, out-of-the money, and deep out-of-the money. It gives implications that whether the data-breach informed traders have preference in option moneyness. We find that "hackers" tend to trade liquid near-the-money options, while insiders trade both near-the-money and out-of-the-money options. Third, we provide possible trading strategies in stock markets and options markets to test whether the informed tradings are feasible. We find significantly positive abnormal return in the long-short strategy and positive profits by holding put options of the firms with data breaches.

The paper proceeds as follows. Section 2 provides a review of the literature investigating data breaches and the hypotheses development. The empirical evidence of informed tradings around data breaches is presented in Section 3. The impact of data breaches on stock markets is discussed in Section 4. Section 5 presents the long-short stock trading strategy. Finally, we summarize and suggest directions for future research in Section 6.

2. Background and Hypotheses

Cybersecurity is an increasingly important topic in the research of computer science or information systems. One notable study in this area, Spanos and Angelis (2016), presents a meta-analysis of 37 papers containing 45 empirical studies of the effects of information-security breaches on public-company stock prices from 2003 to 2015. The authors find that 75.6% of the studies measure statistically significant stock-price reactions to the disclosure of cybersecurity breaches. 20 out of 25 studies find negative and significant stock-price reactions for victim firms, and none of these find significant positive reactions for victim firms. Several other studies have found positive and significant stock-price reactions for information security firms, plausibly reflecting the additional demand for their services in the wake of security breaches. Pirounias, Mermigas, and Patsakis (2014) state that organizations worldwide have spent every year on average more than $1 trillion on information technology investments. Any flaws that lead to cyberattacks result in large losses to various stakeholders such as taxpayers, shareholders, and consumers.

However, research related to cybersecurity in the finance field is limited. To our knowledge, Lending, Minnick, and Schorno (2018) is the first article published in a finance journal. They study whether corporate governance and social responsibility are related to data breaches and find that socially responsible companies with smaller boards and greater financial expertise are less likely to be breached. The financial impact of a breach is visible in the long-term CARs (-3.5% one-year buy-and-hold abnormal returns). Companies are also more likely to replace their CEO and Chief Technology Officer as well as improve their governance and social responsibility following a data breach.

Some articles start to explore the impact of data breach on different issues in capital markets, corporate governance and risk managements in very recent years. Kamiya, Kang, Kim, Milidonis, and Stulz (2021) focus on malicious external actions, such as hacking and malware, and analyze the impact of "successful cyber attacks". They not only find a significant CAR of -0.76% (approximately $439 million per attack) during the three-day window surrounding cyber attack announcements, but also show that firms are more likely to experience cyber attacks when they are larger, are more visible, and have lower leverage, worse past stock performance, higher growth opportunities, and more intangible assets. Akey, Lewellen, and Liskovich (2018) consider data breaches as negative reputation events and find that data breaches negatively affect firm value by 10-20% following an event and this effect lasts for years. Iyer, Simkins, and Wang (2020) examine the impact of cyber attacks on bond markets, and find that bondholders lose approximately 2% of their wealth within a one-month period surrounding the attack (a loss of $3.8 million on average). Ashraf and

Sunder (2018) test whether data breach disclosure laws protect consumers, while shifting cyber risk to shareholders, and show that the cost of equity decreases, on average, after the staggered passage of data breach disclosure laws by states in the United States. Nordlund (2018) analyzes director experience associated with cybersecurity events and they find that corporate directors that experience data breach events lose shareholder support at the hacked firms, but not at interlocking firms. Furthermore, interlocking firms exhibit better cybersecurity risk monitoring after the breach, and hack-experienced directors receive more appointments at larger, better-governed firms following the event.

Extant studies have provided evidence that there is informed trading in the options markets prior to dividend announcements (Zhang, 2018a), auditor change announcements (Zhang, 2018b), credit rating change announcements (Zhang, 2019), and takeover announcements (Augustin, Brenner, and Subrahmanyam, 2019). However, the studies of informed trading taking advantage of data breaches are limited. The most relevant article, Mitts and Talley (2018), considers the phenomenon of securities-market trading on the basis of advanced knowledge of a cybersecurity breach, called "informed cyber-trading" in their article. However, they only examine the trading volume and open interest rate of at-the-money put options with relatively limited number of events, and find only one pattern of informed trading prior to the date of announcement. Lin, Sapp, Ulmer, and Parsa (2019) find evidence of insider trading in stock markets ahead of cyber breaches. Our study not only extends their work and show additional evidence to verify the data-breach "insider" and "informed" trading in option markets, but also further shows the predictive power of option trading activities and provides possible trading strategies.

Put options reflect a downside bet on the firm's stock, since the value of a put option increases as the firm's stock price at maturity decreases. It is not surprising that breach announcements have a negative impact on stock prices (Lending et al., 2018; Kamiya et al., 2021; Spanos and Angelis, 2016). Therefore, we expect to see abnormal trading in the put options market prior to data-breach announcements, if there is informed trading. Supporting the SECs recently announced goal of tightening restrictions on insider trading ahead of cyber breach announcements, our first hypothesis is,

H1: Firms with relatively higher put-option trading activities do not increase the probability that the underlying firm is one that has experienced a data breach.

As shown in Figure 1, there are two important time points prior to data-breach announcements. A data breach occurs first, then the firm discovers the breach, and the firm makes an announcement in the end. The informed trading can be done in two different intervals although the lengths of intervals are uncertain. In fact, it is difficult to define an

exact date that the data breaches actually occurred, since some breaches occur continuously over a few days to even a few months. There are also cases where a firm has not discovered data breaches even after they have occurred for a few months [4]. It is also possible that insiders delay the data breach news and implement the insider trading before the news is made public, such as the CIO of Equifax. Therefore, we expect to see that there are two distinct groups of informed traders, insiders and other informed traders, taking advantage of corporate data breaches. Thus, we form the following hypothesis.

H2: There is no abnormal put-option trading on the attacked firms prior to data breach announcements.

[Insert Figure 1 near here]

Previous studies document that the options market contributes to price discovery both directly (Kumar, Sarin, and Shastri, 1992; Chakravarty et al., 2004) and indirectly (Mayhew et al., 1995; Easley et al., 1998; Cao et al., 2005; Pan and Poteshman, 2006). To further test whether options trading activity has predictive power for ex-post stock returns in the setting of data breaches, we propose our third and fourth hypothesis,

H3: Data-breach announcements have a no impact on stock returns.

H4: Trading activity in options markets does not have predictive power for future stock returns surrounding data-breach events.

In the next section, we describe the data, test these hypotheses, and provide empirical findings.

3. Empirical Evidence of Informed Data-Breach Trading

3.1. Data Sources and Data Descriptions

We obtain the data on announced corporate data breaches from Privacy Rights Clearinghouse [5](PRC) for the period 2005 to 2018. PRC data contains valuable data-breach

[4]For example, "a former Countrywide Financial Corp. employee and another man in an alleged scheme to steal and sell sensitive personal information, including Social Security numbers. The breach occurred over a two-year period though July. The insider was a senior financial analyst at Full Spectrum Lending, Countrywide's subprime lending division. The alleged data thief was said to have downloaded about 20,000 customer profiles each week and sold files with that many names for $500, according to the affidavit. "

[5]`https://www.privacyrights.org/data-breaches`. The types of data breaches include CARD (Payment Card Fraud), HACK (Hacking or Malware), INSD (Insider), PHYS (Physical Loss), PORT (Portable

information made public, and has been used for many financial studies such as Kamiya et al. (2021) and Lending et al. (2018). We also confirm the accuracy of PRC information with other sources including company websites and Factiva. PRC provides the data-breach announcement date, the name of the firm, the type of data breach, and the description of the event.

The number of annual data-breach announcements from 2005 to 2018 is shown in Figure 2. Interestingly, there is a periodicity of data-breach announcements, with a wave period of approximately 5 years. The number of data breaches reaches its highest level in 2018. By looking at the make up of different types of breaches, which are shown in Figure 3, PORT drops dramatically since 2008 and decreases to around 5% in 2018. HACK increases over the sample period and peaks at making up over 80% of data breaches in 2016. However, in the period from 2016 to 2018, HACK falls back to 20% in 2018, but UNKN jumps to 55% in the same year. An example of a data breach identified as UNKN is the breach of Discover Financial Services reported on August 17th, 2012[6]. STAT and PHYS have a stable performance over time, and INSD has decreased below 5% since 2016.

[Insert Figure 2-3 near here]

We obtain options data from Ivy OptionMetrics, stock data from CRSP, and accounting data from Compustat. PRC reported 8,804 data breaches, which have been made public since 2005. After removing private firms and matching with CRSP and Compustat, our final sample consists of 593 data-breach events and 322 unique firms. The trading activity measures in options markets that we use include the trading volume of put options (Put Volume), the open interest of put options (Put Open Interest), bid-ask spread of put options (Spread), put-to-call volume ratio (P-C Volume Ratio) calculated as the ratio of Put Volume to total trading volume, and put-to-call open interest ratio (P-C Open Interest Ratio) calculated as the ratio of Put Open Interest to total open interest.

Device), STAT (Stationary Device), DISC (Unintended Disclosure) and UNKN (Unknown). CARD involves debit and credit cards that is not accomplished via hacking, such as skimming devices at point-of-service terminals. HACK refers to being hacked by an outside party or infected by malware. INSD is caused by insiders with legitimate access who intentionally breach information, such as an employee, contractor or customer. PHYS includes paper documents that are lost, discarded or stolen (non-electronic). PORT include lost, discarded or stolen laptop, PDA, smartphone, memory stick, CDs, hard drive, data tape, etc. STAT refers to stationary computer loss (lost, inappropriately accessed, discarded or stolen computer or server not designed for mobility). DISC is unintended disclosure not involving hacking, intentional breach or physical loss, such as sensitive information posted publicly, mishandled or sent to the wrong party via publishing online, sending in an email, sending in a mailing, or sending via fax.

[6]An unspecified number of Discover customers had their account numbers changed and were issued a new card. It is unclear what type of security breach prompted the notification and when it may have occurred. Several customers in California received the notification letter; residents of other states may have been notified as well.

Table 1 presents the summary statistics of the treatment firms with data breaches (Panel A) and the control firms that had not (Panel B) after merging with options database. To ensure that similar firms are compared to each other, we employ propensity-score matching to select control firms by one-to-one matching not only on five firm-level characteristics (i.e. 4-digit SIC industry code, log market capitalization, log total assets, log net income, and log total liabilities) that are used in Mitts and Talley (2018), but also on the trading volume average of put options. Thus, these two groups of firms have very similar fundamental characteristics and put-option trading volume.

Table 1 shows that both groups have similar firm size. The market capitalization are 9.61 and 9.96, respectively. The SIZE mean (10.01 vs. 10.12) and median (10.03 vs. 10.14) of the firms with data breaches and the control firms are close to each other as well. The ROA means are both 0.05. The LEVER means are 1.79 and 1.61, respectively. The put-option activities on average are close to each other in put-call volume ratio (0.35 vs. 0.36), put-call open interest ratio (0.36 vs. 0.35), log put-option volume (7.18 vs. 7.72), and put-option open interest (9.81 vs. 10.33). Besides, we provide the density distribution of propensity scores in Figure 5 before and after matching DID sample. The DID sample shows a similar density distribution of propensity scores for the firms with data breach and the control firms. Overall, there is little difference in fundamental measures between the attacked firms and control firms, which suggests that we have matched firms well.

[Insert Table 1 near here]

[Insert Figure 5 near here]

3.2. Probit Regression Analysis

To test H1 with respect to the occurrence of a data breach event, we fit a Probit model with the dependent variable being equal to 1 if the firm is one that is attacked and equal to 0 for control firms. We include return on assets (ROA), log of total assets (SIZE), leverage (LEVER) and log of market capitalization (MKTCAP) as control variables. We test put-to-call ratio of trading volume and open interest, and the spread as dependent variables over the period from pre-48 week to the announcement date.

As Black (1975) and Easley et al. (1998) demonstrated that the leverage of an option is a key determinant of whether informed investors choose to also trade in the option market. Options with varying moneyness provide investors with differing levels of leverage. It is also possible that informed traders choose to trade in the most liquid part of the option market.

Motivated by these considerations, we divide the sample into three groups, near-the-money options (delta between -0.6 and -0.4), out-of-the-money options (deltas between -0.4 and -0.2), and deep out-of-the-money options (deltas between -0.2 and 0).

We examine the Probit model for those three subsamples, near-the-money option, out-of-the-money (OTM) options, and deep out-of-the-money (Deep OTM) options. Table 2 shows the Probit regressions of options in different moneyness. Panel A presents the results of near-the-money options. Columns (1)-(4) show that higher put option volume and put option open interest significantly increase the probability that the underlying firm is one that has experienced a cyberattack. However, Panel B and C show a mixed results before and after considering control variables in the samples of OTM and deep OTM. Interestingly, lower put option bid/ask spreads significantly increase the probability that the underlying firm has experienced a cyber attack in three panels of Table 2. This result is consistent with the possibility that options dealers are willing to 'pay' informed options traders (in terms of a lower spread) for their information, similar to as has been found in the foreign exchange market (Osler and Menkhoff, 2011; Piccotti and Schreiber, 2019). By comparison, the activities of near-the-money options have significant and consistent performance prior to data breach announcements, and suggest that the informed traders taking advantage of data breach information tend to trade in more liquid options.

[Insert Tables 2 near here]

3.3. Difference-in-Difference Analysis

In this section, we test H2, and analyze whether there are informed tradings prior to data breach announcements. Furthermore, we examine whether there are two possible distinct groups of informed traders taking advantage of corporate data breaches.

In fact, the time to detect data breach is longer than you may have expected. According to the Ponemon Institute's Cost of a Data Breach Study[7], based on interviews with 2,200 professionals from 477 companies, the average time to detect a data breach is 197 days in the 2018 study, 206 days in the 2017 study, and 201 days in the 2016 survey.

It is difficult to define an exact date that the data breaches actually occurred, since some breaches occur continuously over a few days to even a few months. Firms are more likely to disclose the date that the firm first discovered data breaches for the first time in the event description. Still, only 200 out of the 593 firms in our sample include discovered dates in the event description. Among these 200 firms, some firms have very obscure descriptions

[7]https://www.ibm.com/downloads/cas/861MNWN2

about the date that data breaches were discovered or the date that data breaches actually happened[4]. According to the event description, we compute the interval between the discovered date and the announcement date, which ranges from four days to three years and we plot the histogram of these interval lengths in Figure 4. The average value of the intervals between those two dates is eighty days and the majority are located within four months.

[Insert Figure 4 near here]

Therefore, we use every four weeks as a cutoff point to do the difference-in-difference (DID) regressions analysis until the 48th week prior to the data breach announcement. The testing periods include [-8w, -4w) vs. [-4w, 0), [-16w, -8w) vs. [-8w, 0), [-24w, -12w) vs. [-12w, 0), [-32w, -16w) vs. [-16w, 0), [72w,-36w) vs. [-36w, 0), [-80w, -40w) vs. [-40w, 0), [-88w,-44w) vs. [-44w, 0), [-96w, -48w) vs. [-48w, 0). All of the models contain fixed industry effects and fixed-year effects. The regression model, with control variables, is shown in Equation (1).

$$\begin{aligned} OptionTradingActivity_{i,t} = {} & \alpha_0 + \beta_1 * Attack + \beta_2 * Post + \beta_3 * Attack * Post \\ & + \beta_4 * ROA_{i,t-1} + \beta_5 * SIZE_{i,t-1} + \beta_6 * LEVER_{i,t} + \beta_7 * MKTCAP_{i,t} \\ & + IndustryFE + YearFE + \epsilon_t \end{aligned} \tag{1}$$

Our dependent variables include put-option trading volume, put-option open interest, put-to-call volume ratio, put-to-call option interest ratio, and bid-ask spread. *Attack* is a dummy variable that is equal to 1 for attacked firms and is equal to 0 for control firms. *Post* is a dummy variable that is equal to 1 after the cutoff point; and equal to 0 before the cutoff point.

The coefficients of the interaction term , $Attack * Post$, in Equation (1) with different cutoff points are presented in Figure 6 - 8. Panel A in each figure shows the coefficients in regressions of put-option volume and put-option open interest, while Panel B in each figure shows the coefficients in regressions of put-call volume ratio and put-call open interest ratio. Figure 6 presents the coefficients for near-the-money options, and shows that there are two peaks, 16 weeks and 48 weeks prior to data breach announcements. Figure 7 presents the coefficients for OTM options. We can still find similar trend in put-option volume and open interest in Panel A. However, the results of put-call volume ration in Panel B show only one pattern of informed trading approximately 16 weeks prior to the announcement, and the results of put-call open interest tend to be either insignificant or flat. Figure 8 presents the coefficients for Deep OTM options. Deep OTM options have mixed results that the peaks and dips are located in different periods in Panel A and Panel B.

The empirical results in Figure 6 suggest that there are two distinct patterns of informed tradings prior to data breach announcements in near-the-money options. Combined with the Ponemon Istitute's Data Breach Study and the intervals between the discovered date and the announcement date, we conjecture that there are two groups of informed traders, "insiders" who trade between the discovered date and the announcement date, and other informed traders such as "hackers" who trade after a data breach occurs but before the firm discovers it.[8] We further separately test those two distinct patterns of informed tradings below.

[Insert Figure 6 - 8 near here]

We report the regression results of sixteen-week and forty-eight-week cutoff points in Table 3. Table 3 presents two cutoff-point tests that have consistent empirical results in all measures of put-option activities in Equation (2). In Panel A, put-option volume, open interest, and put-call ratios are all significantly higher, while spread is lower in the period from around four months prior till the announcement. Although we also obtain significantly positive coefficients of $Attack * Post$ in Panel B with a cutoff of forty eight weeks, it is possible that the insider trading starting around four months prior to announcements is able to influence the DID results in Panel B. Therefore, we further test the DID analysis excluding the period [-16w,0) to separate the effects of two patterns of informed trading. The results are provided in Table 4.

[Insert Tables 3 near here]

In order to exclude the effect of data-breach insider tradings starting approximately sixteen weeks prior to data breach announcements, we test the DID analysis between [-48w, -32w) and [-32w, -16w). Table 4 presents DID analysis excluding window [-16w, 0). Panel A in Table 4 confirms the existence of a second pattern of informed trading prior to data breach announcements. Panel A shows that the option trading activities in window [-48w, -32w) are significantly higher than in window [-32w, -16w). Furthermore, we compare the window [-48w, -32w) with earlier period, window [-64w, -48w) in Panel B. The coefficients of $Attack * Post$ in Panel B are significantly positive in all option trading activities except for put-option volume. The insignificant coefficients of put-option volume in Panel B makes us to think about a possibility that the "hacker" informed trading might last longer than four months. Thus, we extend our testing period from [-48w, -32w) to [-52w, -32w), [-58w, -32w), and [-60w, -32w). We find significant and consistent results in the testing window

[8] To simplify, we will use "insiders" and "hackers" to refer to two distinct groups of informed traders thereafter.

[-60w, and -32w). The results are shown in Panel C of Table 4. Based on the findings in Table 4, we conjecture that the second pattern of informed trading is approximately from twelve months to eight months prior to the data breach announcement.

[Insert Tables 4 near here]

We examine OTM and deep OTM options by using the same method in Table 4. Without surprisingly, we do not find significant empirical results to support the "hacker" informed trading in OTM or deep OTM options, but the DID analysis still supports the data-breach "insider" trading that starts approximately four months prior in OTM and deep OTM markets. The results of (-32w, -16w) vs. (-16w, 0) are reported in Table 5. It is possible that insiders who have the priority to obtain inside information and the exact date of data breach announcements trade both liquid near-the-money options and less liquid OTM options.

[Insert Tables 5 near here]

Overall, our DID regression results reject H2, and provide suggestive evidence that informed trading surrounding data breach events leads the public announcement date in both a relatively short period, sixteen weeks prior to the announcement date, and in a relatively longer period, from sixty weeks to thirty two weeks prior to the announcement date. The results are consistent with the difference interval shown in Figure 4. From the combined evidence, we conjecture that there are two groups taking advantage of data breaches, which include hackers and insiders. Hackers try to take advantage of data breaches after they attack the firms, approximately from twelve months to eight months prior to data-breach announcements, while insiders try to take advantage of data breaches after they detect that the firm was attacked and before the data-breach news is publicly announced, approximately four months prior to data-breach announcements. Our evidence is also consistent with Collin-Dufresne and Fos (2015)'s findings that liquidity increases when there is active informed trading. Besides, we find that hackers trade liquid near-the-money options to take advantage data breaches, while insiders trade both near-the-money and OTM options probably because of the priority of inside information.

In the next section, we discuss the impact of data breaches on stock returns and whether the trading activities in the options market have predictive power for future stock returns.

4. Impact of Data Breaches on Stock Returns

4.1. Cumulative Abnormal Returns (CARs) following Data-Breach Announcements

In this section, we test H4 and examine the impact of data- breach announcements on stock returns.

We test H4 by computing post cumulative abnormal returns (CARs) over the window (0,+1d), (0,+5d) and (-1d,+1d) based on the CAPM Model. Table 6 shows that data breaches are significantly negative related to stock CARs overall. The CARs are -0.35% within (0,+1d), -0.46% within (0,+5d) and -0.31% within (-1d,+1d) respectively. Overall, this reveals that the average cost to an attacked firm in our sample is $66.573 million ($= e^{9.58} \times (-0.0046)$) in market cap for the 5 days following a breach announcement. CARs across different type of breaches are presented in Panel B. CARs within (0,+1d) are significantly negative in the categories of HACK, PHYS, PORT, and UNKN, which implies that stock returns are more sensitive to these 4 types of breaches. HACK has a significant impact on stocks returns both statistically and economically. the CARs in HACK are both significantly negative within (0,+1d) and within (-1d,+1d), and the proportion of HACK attacks increase from 35.3% in 2005 to 59.1% in 2019 according to PRC report[9]. In addition, IBM and Ponemon's Institute's Cost of a Data Breach Study found that not only are malicious or criminal attacks the major cause of data breaches, but they are also the most costly. According to the study, 48 percent of data breaches are as a result of malicious or criminal attacks (compared to 27 percent for human error and 25 percent for system glitch). Non-electronic lost or stolen documents, PHY, is significantly associated with a negative CAR on average, -0.75% within (0+1d), but it becomes insignificant within (0,+5d). Even the CAR related to UNKN breaches is significantly negative within (0,+1d). similar results are obtained for the window (-1d,+1d). To control for extreme values affecting the means, we further report the median and the ratio of the number of positive CARs to negative CARs in Table 6. For each category, the number of negative CARs is larger than the number of positive CARs except for INSD. Consistent results are obtained in the median value as well.

The overall CAR decreases to -0.46% within five days following a data-breach announcement. However, only the type of PORT obtains a significantly negative CAR, -0.84%. PORT announcements are incorporated into prices more slowly than the types of HACK and PHY, and it only makes up approximately 1% of total data breaches according to the PRC report. For robustness, we examine various alternative windows are examined and we present the

[9] `https://www.privacyrights.org/data-breaches/breach-type?taxonomy_vocabulary_11_tid=2439`

results in the Internet Appendix.

[Insert Table 6 near here]

Overall, the empirical results reject hypothesis H4 and find that data breaches have negative impacts on stock returns, which is consistent with previous literature (Lending et al. (2018), Kamiya et al. (2021), Spanos and Angelis (2016), etc.).

4.2. Predictive Power of Option Trading Activities

We test H5 that whether options trading activities prior to the data-breach announcement date can predict future stock returns by using the following cross-sectional regression:

$$\begin{aligned} CAR_{i,t} = \alpha_0 + \beta_1 * OptionTradingActivity + \beta_2 * ROA_{i,t-1} + \beta_3 * SIZE_{i,t-1} + \beta_4 * LEVER_{i,t-1} \\ + \beta_5 * BM_{i,t-1} + \beta_6 * S\_volume_{i,t-1} + \beta_7 * Ownership_{i,t-1} + \beta_8 * VIX \\ + IndustryFE + YearFE + \epsilon_t \end{aligned} \tag{2}$$

The options trading activities are estimated by using the previous four-week period. The dependent variables include CARs within (0,+1d) in Panel A and CARs within (0,+5d) in Panel B. The explanatory variables of interest include the trading volume of put options (P_volume), the open interest of put options (P_interest), the put-to-call volume ratio (PC_Vratio), the put-to-call open interest ratio (PC_Iratio) and the bid-ask spread (Spread). The control variables include: return on assets (ROA), log of total assets (SIZE), leverage (LEVER), and book-to-market ratio (BM) at year $t-1$, in addition to the VIX, stock trading volume (S_volume) during the period of four weeks prior to data-breach announcements, and the stock's institutional ownership (Ownership) one quarter prior to the announcement date.

Table 7 provides the empirical results of near-the-money options.[10] For both CARs within (0,+1d) and CARs within (0,+5d), only put-call ratios in terms of trading volume and option interest are significantly negatively associated with future stock returns, both before and after controlling for other fundamental variables. The magnitude is larger within (0,+1d) than within (0,+5d), which indicates that data-breach price discovery is reflected in the stock market relatively quickly. An attacked firm's one unit increase in PC_Vratio in around 1.17% decrease in CARs within (0,+1d), and around 1.47% decrease in CARs within (0,+5d). An attacked firm's one unit increase in PC_Iratio in around 0.35% decrease in

[10]Out-of-money options are also examined. The results are reported in the Appendix.

CARs within (0,+1d), and around 0.15% decrease in CARs within (0,+5d).[11] Our findings are consistent with Pan and Poteshman (2006)'s findings that the put-call volume ratio parsimoniously combines the information of the put and call volumes and has predictive power for future stock returns. The significant coefficients of put-call option interest ratio are consistent with Buraschi and Jiltsov (2006)'s argument that put-call option interest ratio contains private information or investors' heterogeneous beliefs and has predictive power for future stock returns. Overall, the results in Table 7 reject H5 and find that put-call ratios have predictive power for future stock returns.

To determine whether the predictability of our data-breach option trading activity measures exist only in the information event, we conduct Placebo tests to compare it with the results in the nonevent period and non-attacked firms. First, for each attacked firm, we randomly choose a non-data breach announcement date and assume that it is the actual data breach announcement date. Second, on each actual data breach announcement date, we examine the corresponding control firms. We regress the same model as Equation (3). Table 8 reports the results for attacked firms on non-data breach announcement date and non-attacked firms on data breach announcement date. For convenience, we also provide the coefficient in Table 7 for comparison in row 1. The small p-values indicate that the option trading activities are less likely to have stronger predictability on normal days than on the day immediately before data breach announcements or for non-attacked firms. These results provide further evidence suggesting that if a firm experiences a cyberattack, then that information and the negative future CAR is revealed in the options market.

[Insert Table 7-8 near here]

[11]Both the actual date of data breaches and the date that firms discover data breaches are uncertain. Therefore, unlike regular corporate announcements, data-breach announcements are not periodic and are less likely to be coincident with other corporate events. To eliminate the concern of confounding events, we also compare our sample of data breaches with the date of quarterly earnings announcements (QEA). Only 5 (or 0.8%) events are coincident with QEA on the same day. These events are Toyota Motor on 08/04/2006; Xerox on 01/23/2007; Under Armour Inc. on 04/20/2012; Choice Hotels on 04/26/2012; and Sabre on 05/02/2017. In addition, we examine the number of confounding event happened on the same month. We find 7 events happened on the same month with the credit rating change, and 152 events happened on the same month with QEA. Furthermore, we also construct a dummy variable that is equal to 1 if the event has confounding event on the same month; and equal to 0 if not. We add the dummy variable into the testing models above and find very robust results. Thus, it will not lead to a conclusion against our empirical results by taking the confounding events into consideration.

5. Additional Evidence: Trading Opportunities

To explore whether trading opportunities exist surrounding data-breach announcements, we construct possible long-short stock trading strategies and put-option trading strategies. Since the performance of spread is statistically significant and consistent across different testing models, we employ the probit model, Model (10) in Table 2, to predict the probability that a firm would experience a data breach. We only keep the events with high data-breach probabilities (i.e. the predicted data-breach probability is greater than 50%). The number of events with over a data-breach probability of 50% is 434.

5.1. Long-short Stock Trading Strategy

We construct long-short stock trading strategies over different windows prior to data-breach announcements. The short portfolio is consist of the firms with high data-breach probabilities, while the long portfolio is consist of the corresponding control firms.

We assume that informed traders start to trade prior to data breach announcements, and hold the portfolio until the announcement date. Table 9 provides the excess returns based on three different risk models, market model, Fama French 3-factor model and Fama French/Carhart 4-factor model. The trading windows are 1 day, 3 days, 5 days, 10 days, 60 days, 90 days, 100 days and 120 days, shown from Panel A to Panel H. When conducting the long-short strategy over long periods, we find a 90-day excess return of 2.54%, 100-day excess return of 2.71%, a 120-day excess return of 3.74% based on the market model. The magnitude of long-short excess returns in these three windows are slightly smaller by using the other two risk models, but all of them are still significantly positive. When conducting the long-short strategy over short period (Panel A - Panel D), we find about 0.6% excess returns of 3-day, 5-day and 10-day windows, and an excess return of 3.74% within 1 day. The short excess returns are significantly negative from Panel A to Panel C; while most long excess returns are significantly positive.

[Insert Table 9]

5.2. Profits of Put Options

To further examine whether the put options trading prior to data-breach announcements is feasible or not, we compute the profits of put options by holding different periods. We create the put-option trading strategies that put options of attacked firms are purchased prior to the announcements and are exercised on the announcement date if they are in the

money. For each strategy, we require that the expiration date of those put options is after the data-breach announcement date. We examine the periods of 1 day, 5 days, 15 days, 30 days, 60 days, 100 days, 150 days, 180 days, 200 days, 250 days, 270 days, and 300 days prior to the announcements. The profits of put option is:

$$Profit = Max(StrikePrice - SpotPrice, 0) - OptionPrice \tag{3}$$

We scale the profit as a percentage by dividing by the option price. The profits of put options in percentage are reported in Table 10. Table 10 shows that both equal-weighted and value-weighted profits are significantly positive for different strategies. The average profit of put options is 133.2% for 300 days, 351% for 60 days, and 365.8% for 5 days. Overall, we find enough positive profits by trading put options prior to data-breach announcements. The feasible trading strategies in options markets further support our conjecture that the informed trading in options markets exists prior to data-breach announcements.

[Insert Table 10]

6. Conclusion

Financial markets, products and services offered, and innovations in advanced technology continue to grow at a rapid pace. The SEC encourages companies to consider and disclose cybersecurity risk factors in its 2018 Guidance, which include the description of cybersecurity incidents, associated costs and potentical costs, litigation and regulatory investigation of cybersecurity incidents, and so on. Many researchers have examined potential losses to a public corporation such as stock returns, bond returns and firm's reputation. The corporate governance and the insurance related to data breaches have been analyzed as well. However, the literature on informed trading surrounding data-breach announcements is still very limited.

To our knowledge, we are one of the first to examine informed trading in options markets by using a large sample of data-breach events and to provide empirical results that option market trading activities have predictive power for ex-post stock returns. First, we find significantly different option trading activities between attacked firms and control firms in the Probit regressions. Second, we employ the DID method to test for the existence of informed trading taking advantage of data breaches and we find two possible distinct abnormal tradings, the informed trading from around twelve months to eight months prior to a data-breach announcement and the insider trading that starts from around four months

prior. The attacked firms tend to have larger put-option trading volume, open interest, put-to-call volume ratio and put-to-call option interest ratio, but lower bid-ask spread prior to data-breach announcements. Furthermore, we find that the informed traders who trade during the period from around twelve months to eight months prior tend to trade liquid near-the-money options, while insiders trade both near-the-money and OTM options. Finally, we provide empirical evidence that put-call ratios are able to predict ex-post stock returns. These empirical results also provide implications for traders watching for signals about future price movements, and for regulators engaged in surveillance for illegal insider trading.

Although we conjecture that insiders trade in option markets during the period between the time when data-breach nonpublic information is discovered and when it is revealed to the public, more detailed evidence needs to be provided. Future research can explore the corporate insiders' trading after the firm detects data breaches and before it discloses the data-breach information to the public. How do insiders, especially opportunistic insiders (Ali and Hirshleifer (2017)), take advantage of corporate data-breach announcements? Who is involved in the insider trading of data breaches? Other markets, such as short-selling markets, can also be explored.

Fig. 1. The process of a data breach.

Fig. 2. The number of data breaches from 2005 to 2018. This figure shows the number of data-breach announcements from 2005 to 2018. The total number of data-breach announcements is 596.

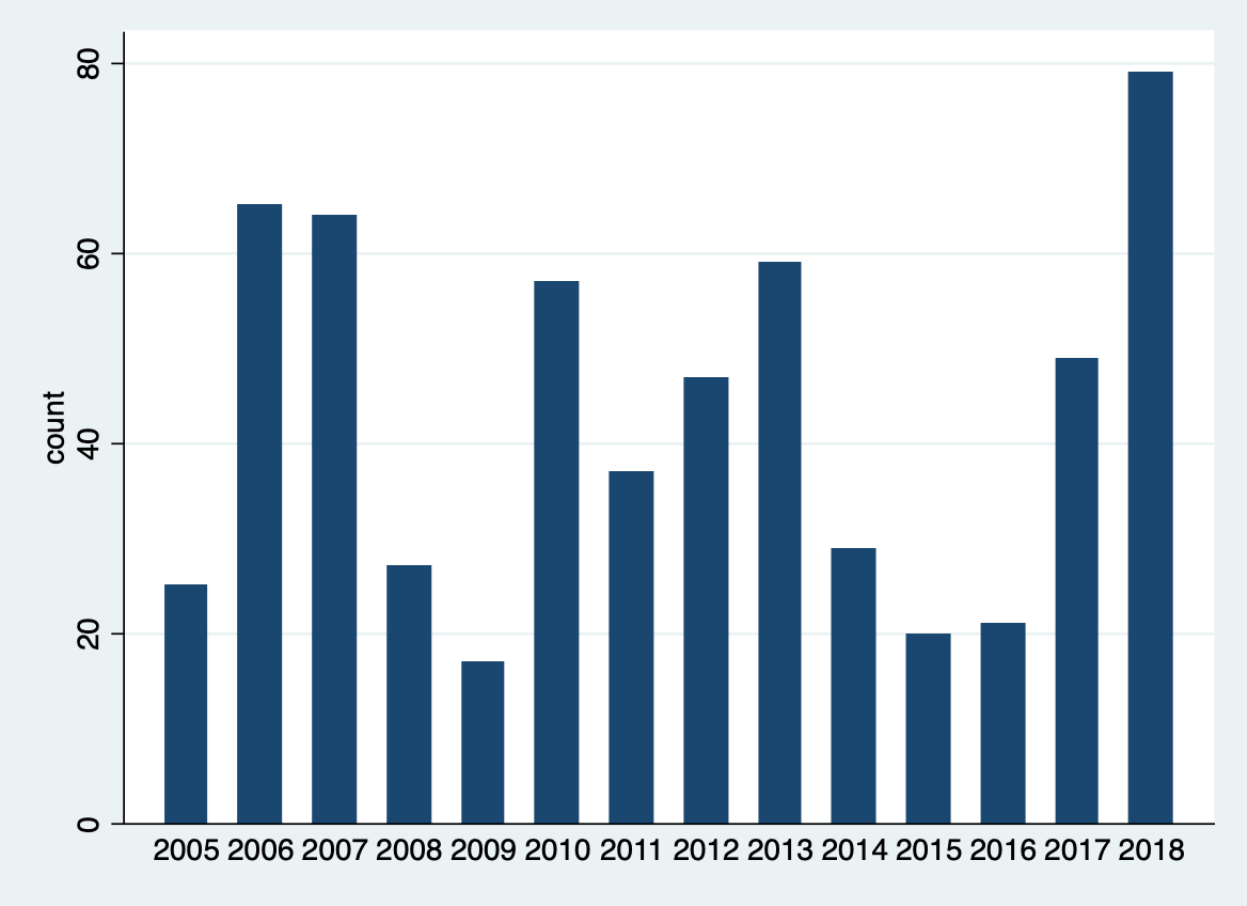

Fig. 3. Fraction of different data-breach types from 2005 to 2018.The categories of data breaches include CARD (Payment Card Fraud), HACK (Hacking or Malware), INSD (Insider), PHYS (Physical Loss), PORT (Portable Device), STAT (Stationary Device), DISC (Unintended Disclosure) and UNKN (Unknown).

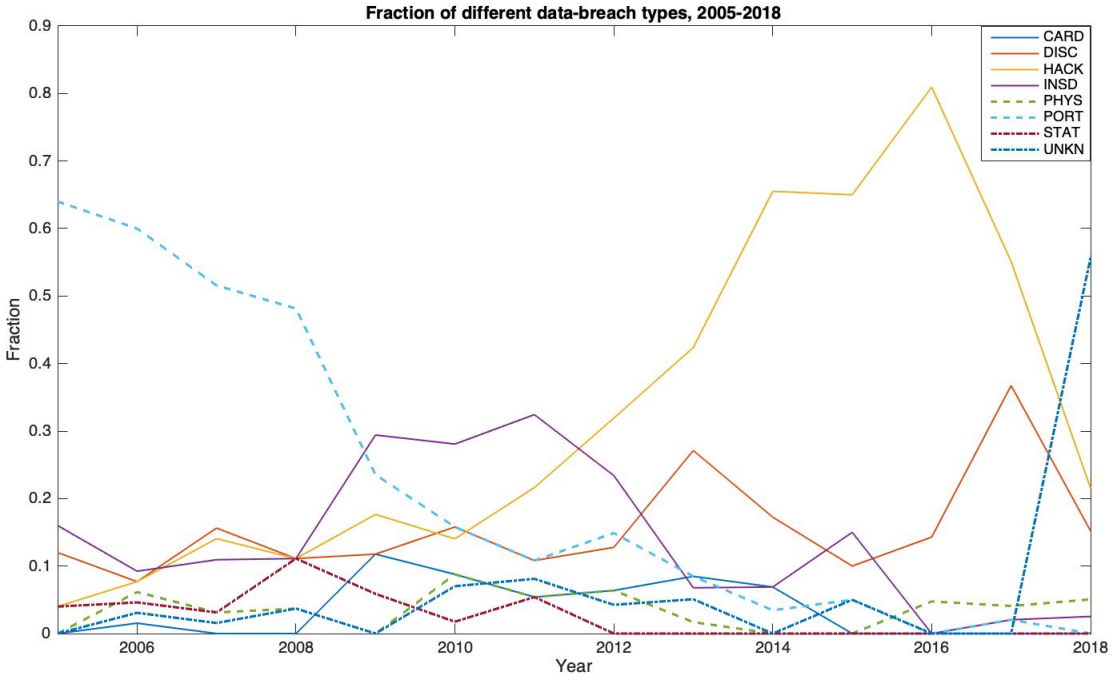

Fig. 4. Histogram of the distribution of intervals between discovered date and announcement date. This figure presents the difference between discovered date and announcement date of data beach. The dates discovered by companies are obtained from the description of the data-breach event in PRC.

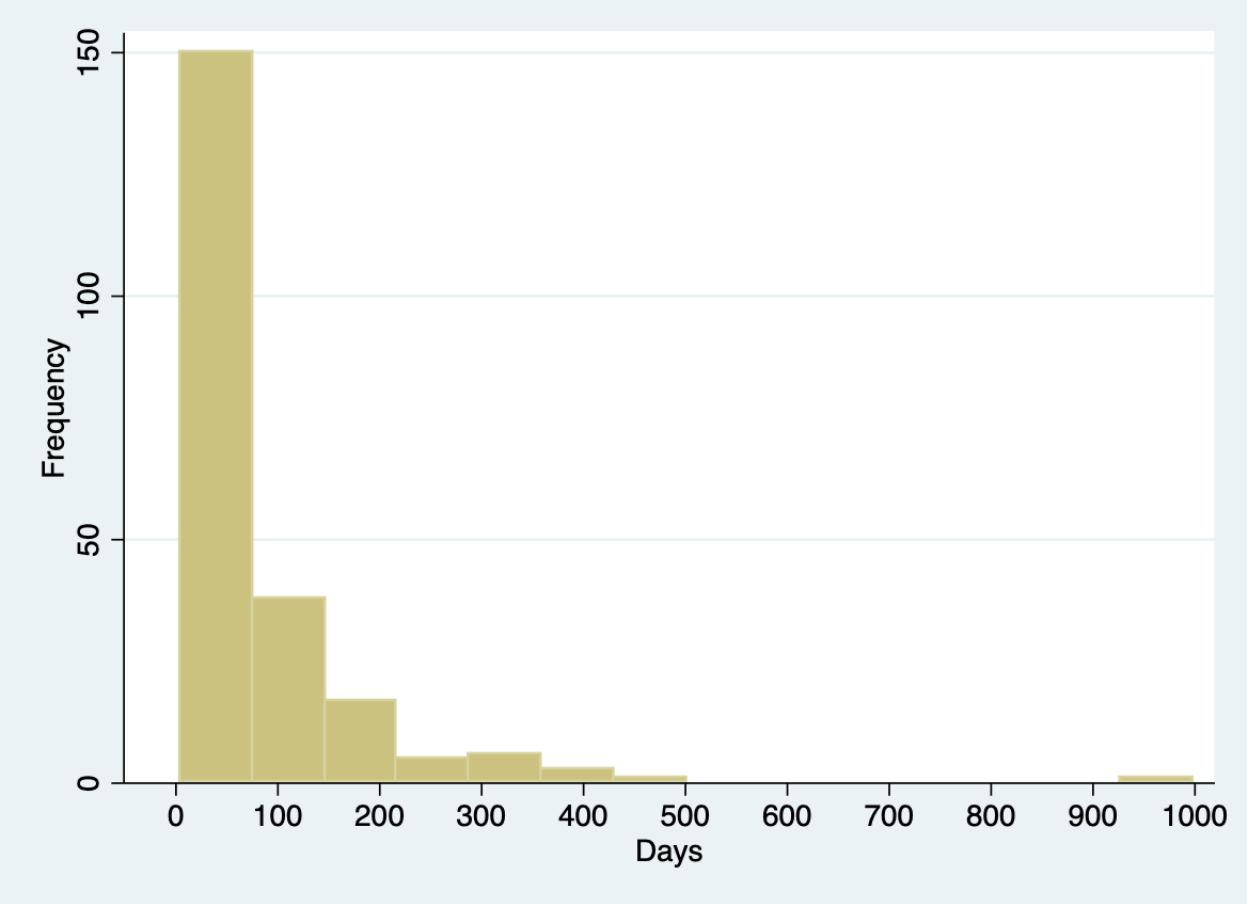

Fig. 5. Propensity Score Balance Test. This figure presents the density distribution of propensity scores before and after matching DID sample. The density of propensity scores is plotted for the treatment group (red solid line) and the control group (blue dashed lines), comparing the raw controls with the propensity-score matched observations.

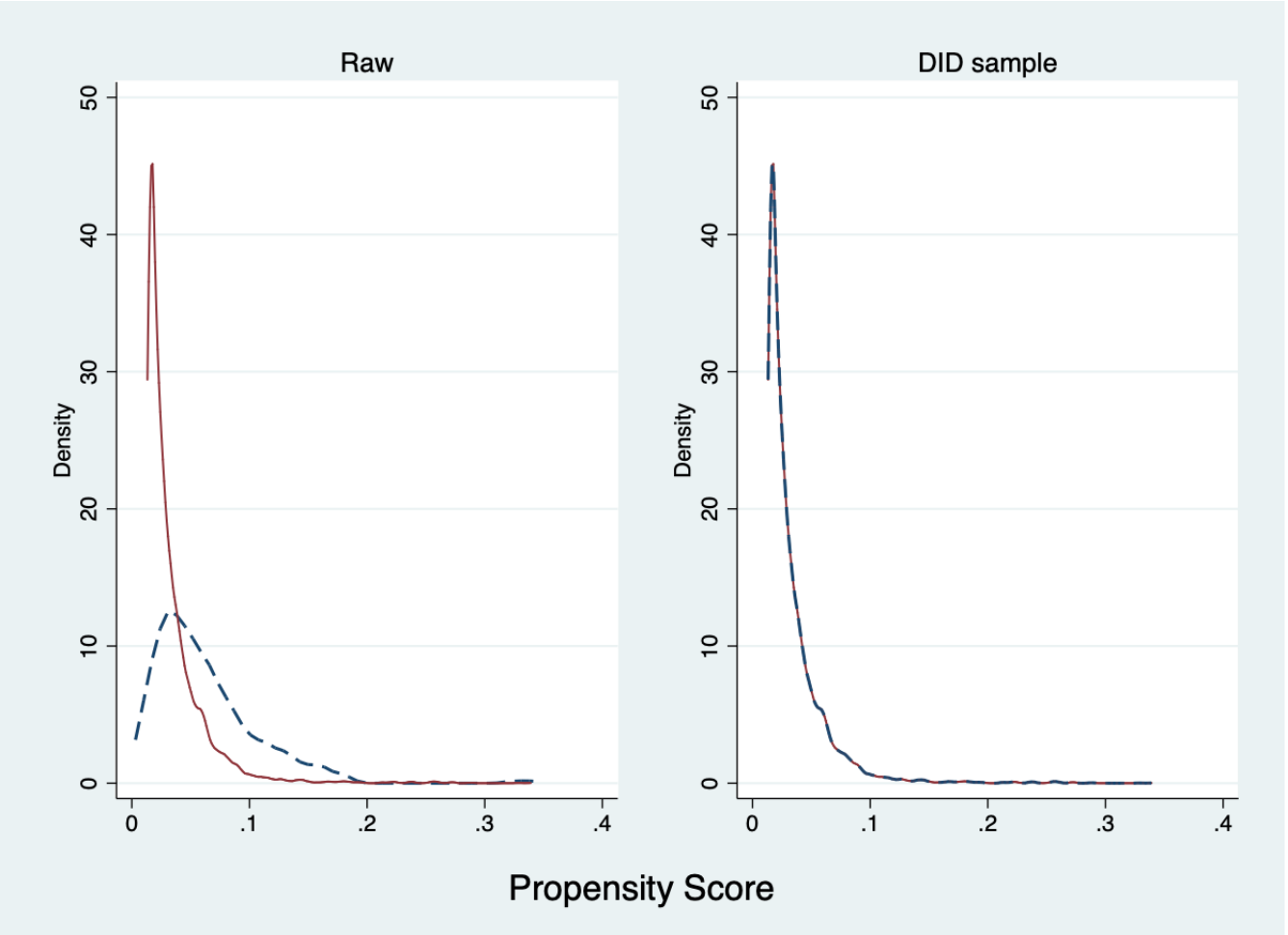

Fig. 6. Coefficients of $Attack * Post$ in Equation (1) for near-the-money options. This figure presents the coefficients of $Attack * Post$ in different testing periods under the DID regressions analysis for near-the-money options. The testing periods include [-8w, -4w) vs. [-4w, 0), [-16w, -8w) vs. [-8w, 0), [-24w, -12w) vs. [-12w, 0), [-32w, -16w) vs. [-16w, 0), [72w,-36w) vs. [-36w, 0), [-80w, -40w) vs. [-40w, 0), [-88w,-44w) vs. [-44w, 0), [-96w, -48w) vs. [-48w, 0). All of the models contain fixed industry effects and fixed-year effects. Panel A provides the results in regressions of put-option volume (log value) and open interest (log value). Panel B provides the results in regressions of put-call volume ratio and put-call open interest ratio.

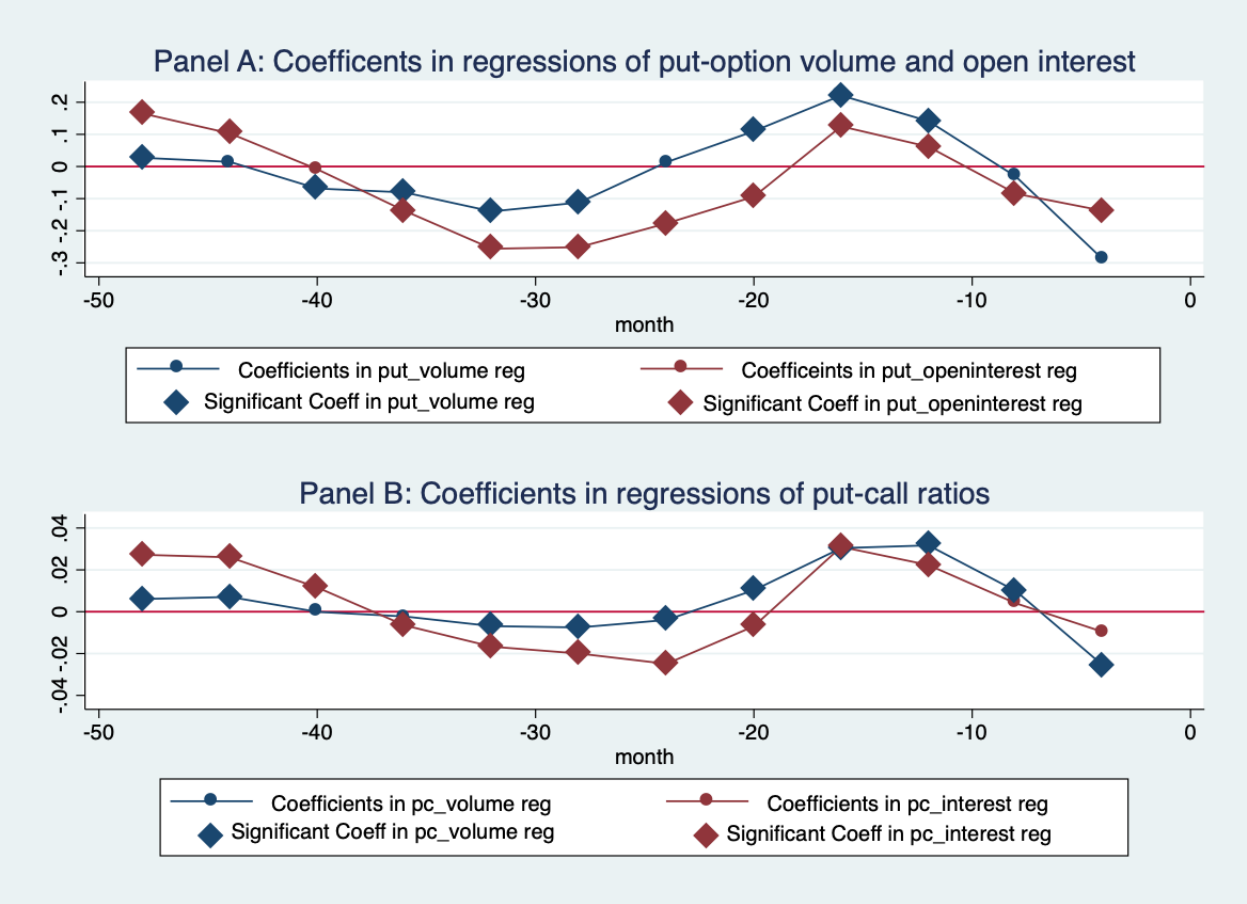

Fig. 7. Coefficients of Attack*Post in Equation (1) for OTM options. This figure presents the coefficients of $Attack*Post$ in different testing periods under the DID regressions analysis for OTM options. The testing periods include [-8w, -4w) vs. [-4w, 0), [-16w, -8w) vs. [-8w, 0), [-24w, -12w) vs. [-12w, 0), [-32w, -16w) vs. [-16w, 0), [72w,-36w) vs. [-36w, 0), [-80w, -40w) vs. [-40w, 0), [-88w,-44w) vs. [-44w, 0), [-96w, -48w) vs. [-48w, 0). All of the models contain fixed industry effects and fixed-year effects. Panel A provides the results in regressions of put-option volume (log value) and open interest (log value). Panel B provides the results in regressions of put-call volume ratio and put-call open interest ratio.

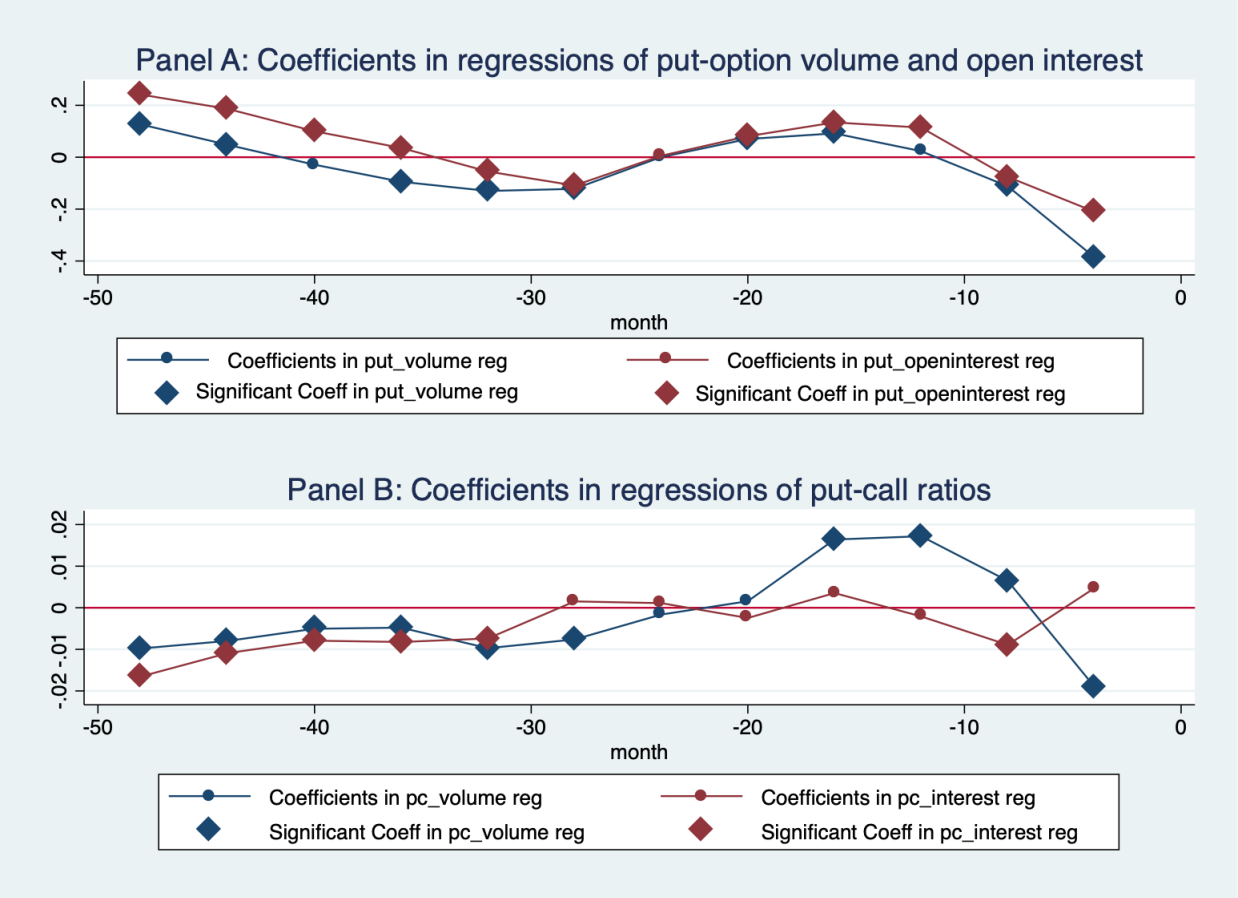

Fig. 8. Coefficients of Attack*Post in Equation (1) for Deep OTM options. This figure presents the coefficients of $Attack*Post$ in different testing periods under the DID regressions analysis for deep OTM options. The testing periods include [-8w, -4w) vs. [-4w, 0), [-16w, -8w) vs. [-8w, 0), [-24w, -12w) vs. [-12w, 0), [-32w, -16w) vs. [-16w, 0), [72w,-36w) vs. [-36w, 0), [-80w, -40w) vs. [-40w, 0), [-88w,-44w) vs. [-44w, 0), [-96w, -48w) vs. [-48w, 0). All of the models contain fixed industry effects and fixed-year effects. Panel A provides the results in regressions of put-option volume (log value) and open interest (log value). Panel B provides the results in regressions of put-call volume ratio and put-call open interest ratio.

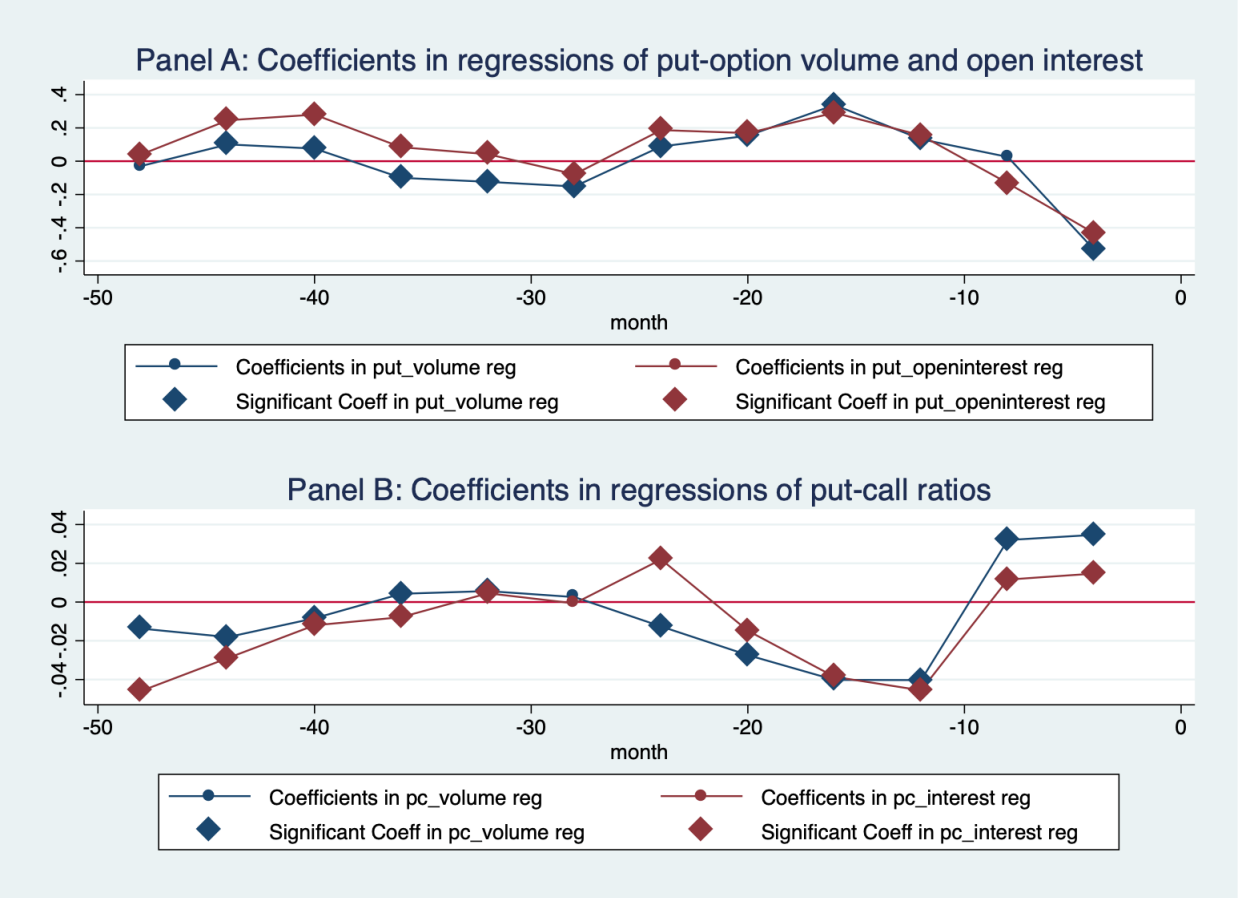

Table 1: Summary Statistics. Panel A provides descriptive statistics of firms with data-breach announcements, and Panel B provides descriptive statistics for control firms without data-breach announcements. N is the number of data-breach announcements. The measures of option trading activity are the log value of put-option trading volume(P_volume), the log value of put-option open interest(P_interest), put-call trading volume ratio(PC_Vratio), put-call open interest ratio(PC_Iratio) and bid-ask spread(Spread) within (-36w,0). The firm characteristic measures are return on asset(ROA), log of total assets(SIZE), the ratio of total liabilities to total assets (LEVER) and log of market capitalization(MKTCAP).

Panel A: Firms with data-breach announcements

Variable	N	Mean	Mdn	S.D.	Min	Max
PC_Vratio	456	0.35	0.35	0.19	0.00	1.00
PC_Iratio	456	0.36	0.34	0.20	0.00	1.00
P_volume	456	7.18	7.48	2.59	0.00	14.52
P_interest	456	9.81	10.12	2.62	0.00	16.50
Spread	456	0.45	0.25	0.57	0.01	5.00
ROA	456	0.05	0.04	0.09	-1.24	0.37
SIZE	456	10.01	10.03	2.30	4.56	14.75
LEVER	456	1.79	1.52	1.26	0.25	16.13
MKTCAP	456	9.61	9.68	1.85	3.49	13.50

Panel B: Control firms without data-breach announcements

Variable	N	Mean	Mdn	S.D.	Min	Max
PC_Vratio	456	0.36	0.35	0.13	0.00	1.00
PC_Iratio	456	0.35	0.35	0.10	0.00	1.00
P_volume	456	7.72	7.41	2.34	0.00	15.28
P_interest	456	10.33	10.84	2.18	0.00	17.26
Spread	456	0.51	0.37	0.41	0.04	4.82
ROA	456	0.05	0.04	0.07	-1.09	0.90
SIZE	456	10.12	10.14	1.41	4.55	14.70
LEVER	456	1.61	1.31	0.70	0.22	4.72
MKTCAP	456	9.96	10.03	1.10	3.38	12.39

Table 2: Probit Regressions of Options in different moneyness. This table presents the probit regression results for the options with delta from -0.6 to -0.4 in Panel A, for the options with delta from -0.4 to -0.2 in Panel B, and for the options with delta from -0.2 to 0. The dependent variable is 1 for attacked firm and is 0 for control firms. PC_Vratio is Put-Call volume ratio; PC_Iratio is Put-Call open interest ratio; Spread is the bid-ask spread of put options. The control variables are ROA (return on asset), SIZE(log of total assets), LEVER(total liabilities to total assets), MKTCAP (log of market capitalization). Industry is classified by the Fama-French 12 industries.

Panel A: Delta from -0.4 to -0.6						
	(1)	(2)	(3)	(4)	(5)	(6)
PC_Vratio	0.347***	0.332***				
	(9.637)	(8.864)				
PC_Iratio			0.364***	0.555***		
			(11.33)	(16.55)		
Spread					-0.191***	-0.184***
					(-17.57)	(-14.84)
Controls	No	Yes	No	Yes	No	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
N	119,423	112,767	120,442	113,755	120,725	114,024
R2-adj	0.326	0.355	0.323	0.353	0.324	0.351
Prob Wald:	0	0	0	0	0	0
Panel B: Delta from -0.2 to -0.4						
	(1)	(2)	(3)	(4)	(5)	(6)
PC_Vratio	0.0854**	-0.0678*				
	(2.487)	(-1.913)				
PC_Iratio			0.452***	0.408***		
			(13.06)	(11.46)		
Spread					-0.346***	-0.276***
					(-24.28)	(-16.43)
Controls	No	Yes	No	Yes	No	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
N	113,363	103,857	114,254	104,733	114,427	104,889
R2-adj	0.329	0.352	0.329	0.349	0.332	0.350
Prob Wald:	0	0	0	0	0	0
Panel C: Delta from 0 to -0.2						
	(1)	(2)	(3)	(4)	(5)	(6)
PC_Vratio	0.0972***	-0.143***				
	(3.696)	(-5.161)				
PC_Iratio			-0.0846***	-0.329***		
			(-3.735)	(-13.51)		
Spread					-0.258***	-0.343***
					(-10.56)	(-11.58)
Controls	No	Yes	No	Yes	No	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
N	122,763	118,341	124,529	120,039	124,696	120,204
R2-adj	0.320	0.358	0.319	0.356	0.320	0.355
Prob Wald:	0	0	0	0	0	0

Table 3: DID Regression of near-the-money options. The sample include put options with delta from -0.6 to -0.4. Dependent variables include the trading volume (log value) of put options, the open interest (log value) of put options, put-call volume ratio, put-call open interest ratio, the bid-ask spread of put options. Attack is equal to 1 if data breach happened; equal to 0 for control firms. Post is equal to 1 when t is in the window [-16w,0) and [-48w, 0); is equal to 0 when t is in the window [-32w, -16w) and [-96w,-48w). The interaction term is Attack × Post. The control variables are ROA (return on assets), SIZE(firm size), LEVER(total liabilities to total assets), MKTCAP (log of market capitalization). Industry is classified by the Fama-French 12 industries.

Panel A: [-32w, -16w) vs. [-16w, 0)

	Volume		Open Interest		PC Volume Ratio		P-C Open Interest Ratio		Spead	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Attack	-3.168***	-3.126***	-3.360***	-3.139***	-0.00443***	-0.00837***	-0.00841***	-0.00337*	-0.0939***	-0.0736***
	(-105.2)	(-120.3)	(-118.6)	(-130.5)	(-2.718)	(-4.958)	(-4.485)	(-1.733)	(-18.63)	(-15.72)
Post	-0.180***	-0.186***	-0.134***	-0.121***	-0.0230***	-0.0242***	-0.0226***	-0.0229***	0.0430***	0.0380***
	(-10.66)	(-12.91)	(-8.188)	(-8.740)	(-24.57)	(-25.19)	(-20.74)	(-20.39)	(14.58)	(13.99)
Attack*Post	0.300***	0.221***	0.210***	0.125***	0.0295***	0.0304***	0.0318***	0.0310***	-0.0414***	-0.0428***
	(7.834)	(6.783)	(5.822)	(4.137)	(14.15)	(14.31)	(13.30)	(12.69)	(-6.422)	(-7.258)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	77,409	73,726	78,952	75,217	78,575	74,859	79,242	75,507	79,436	75,690
R2-adj	37.40%	53.60%	38.20%	56.70%	1.65%	2.73%	3.01%	3.66%	6.41%	13.50%

Panel B: [-96w, -48w) vs. [-48w,0)

	Volume		Open Interest		PC Volume Ratio		P-C Open Interest Ratio		Spead	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Attack	-3.246***	-3.048***	-3.489***	-3.137***	0.00689***	0.00957***	-0.00781***	0.00652***	-0.0758***	-0.0221***
	(-184.0)	(-202.5)	(-212.3)	(-227.1)	(6.984)	(9.436)	(-6.785)	(5.537)	(-23.30)	(-7.798)
Post	0.0883***	0.118***	-0.0574***	-0.0474***	-0.00684***	-0.00543***	-0.0294***	-0.0300***	0.0244***	0.0522***
	(9.059)	(14.08)	(-6.130)	(-5.959)	(-12.27)	(-9.382)	(-44.52)	(-44.10)	(13.06)	(31.74)
Attack*Post	0.126***	0.0270**	0.245***	0.165***	0.00822***	0.00605***	0.0270***	0.0272***	-0.0425***	-0.0733***
	(5.691)	(2.434)	(11.83)	(9.551)	(6.611)	(4.772)	(18.65)	(18.48)	(-10.37)	(-20.72)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	232,570	217,554	237,425	222,276	236,083	220,980	238,110	222,951	238,721	223,539
R2-adj	37.60%	54.30%	38.80%	57.80%	1.18%	1.98%	3.79%	5.08%	4.86%	13.60%

Table 4: DID Regression of near-the-money options. The sample include put options with delta from -0.6 to -0.4. Dependent variables include the trading volume (log value) of put options, the open interest (log value) of put options, put-call volume ratio, put-call open interest ratio, the bid-ask spread of put options. Attack is equal to 1 if data breach happened; equal to 0 for control firms. Post is equal to 1 when t is in the window [-32w,-16w) in Panel A, [-48w, -32w) in Panel B, and [-60w,-32w) in Panel C; is equal to 0 when t is in the window [-48w, -32w) in Panel A, [-64w,-48w) in Panel B, and [-88w,-60w) in Panel C. The interaction term is Attack × Post. The control variables are ROA (return on assets), SIZE(firm size), LEVER(total liabilities to total assets), MKTCAP (log of market capitalization). Industry is classified by the Fama-French 12 industries.

Panel A: [-48w, -32w) vs. [-32w, -16w)

	Volume		Open Interest		PC Volume Ratio		P-C Open Interest Ratio		Spead	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Attack	-3.145***	-2.908***	-3.194***	-2.757***	0.0242***	0.0289***	0.0454***	0.0666***	-0.0778***	-0.0348***
	(-106.8)	(-115.3)	(-115.9)	(-119.8)	(14.98)	(17.44)	(24.63)	(36.24)	(-15.57)	(-7.629)
Post	0.0839***	0.215***	0.271***	0.393***	0.0221***	0.0265***	0.0367***	0.0398***	0.0297***	0.0445***
	(5.034)	(15.03)	(16.86)	(29.21)	(23.75)	(27.62)	(33.96)	(36.84)	(10.11)	(16.53)
Attack*Post	-0.0325	-0.217***	-0.219***	-0.406***	-0.0243***	-0.0304***	-0.0528***	-0.0576***	-0.0194***	-0.0383***
	(-0.871)	(-6.865)	(-6.256)	(-14.05)	(-11.87)	(-14.67)	(-22.60)	(-25.03)	(-3.057)	(-6.709)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	80,555	75,997	82,171	77,568	81,773	77,188	82,466	77,862	82,656	78,045
R2-adj	37.70%	53.90%	38.00%	57.50%	1.84%	2.75%	3.70%	9.26%	6.23%	13.30%

Panel B: [-64w, -48w) vs. [-48w,-32w)

	Volume		Open Interest		PC Volume Ratio		P-C Open Interest Ratio		Spead	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Attack	-3.161***	-3.008***	-3.370***	-3.046***	0.00921***	0.0119***	-0.00414**	0.0104***	-0.0611***	-0.0255***
	(-107.4)	(-121.2)	(-123.3)	(-135.7)	(5.601)	(7.021)	(-2.211)	(5.519)	(-11.78)	(-5.449)
Post	0.0980***	0.102***	-0.125***	-0.147***	-0.0112***	-0.0142***	-0.0410***	-0.0477***	0.0151***	0.0145***
	(6.003)	(7.290)	(-8.023)	(-11.26)	(-12.01)	(-14.62)	(-38.12)	(-43.21)	(5.028)	(5.258)
Attack*Post	-0.0146	-0.0317	0.196***	0.209***	0.0127***	0.0160***	0.0493***	0.0568***	-0.0301***	-0.0259***
	(-0.395)	(-1.022)	(5.716)	(7.473)	(6.156)	(7.589)	(20.97)	(24.14)	(-4.616)	(-4.433)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	79,099	73,179	80,812	74,854	80,324	74,384	81,055	75,089	81,261	75,288
R2-adj	36.50%	54.30%	36.90%	57.90%	1.48%	2.59%	4.46%	8.27%	5.22%	14.40%

Panel C: [-88w, -60w) vs. [-60w,-32w)

	Volume		Open Interest		PC Volume Ratio		P-C Open Interest Ratio		Spead	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Attack	-3.270***	-3.154***	-3.491***	-3.218***	0.0109***	0.0143***	-0.00576***	0.0103***	-0.0831***	-0.0216***
	(-145.7)	(-166.5)	(-168.2)	(-187.7)	(8.549)	(10.94)	(-3.860)	(6.776)	(-19.45)	(-5.915)
Post	0.0158	-0.118***	-0.167***	-0.305***	-0.00147**	-0.00159**	-0.0250***	-0.0278***	-0.0134***	0.0136***
	(1.288)	(-11.18)	(-14.25)	(-30.93)	(-2.070)	(-2.139)	(-29.60)	(-31.78)	(-5.509)	(6.426)
Attack*Post	0.0870***	0.210***	0.253***	0.391***	0.00235	0.00286*	0.0246***	0.0277***	-0.00494	-0.0343***
	(3.095)	(8.943)	(9.758)	(18.38)	(1.475)	(1.756)	(13.20)	(14.70)	(-0.924)	(-7.561)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	139,581	129,342	142,536	132,233	141,684	131,405	142,900	132,590	143,277	132,955
R2-adj	37.50%	55.50%	39.00%	59.50%	1.25%	2.30%	4.48%	5.99%	4.75%	14.50%

Table 5: DID Regression of OTM options and Deep OTM options. The sample include put options with delta from -0.4 to -0.2 (OTM) and with delta from -0.2 to 0 (Deep OTM). Dependent variables include the trading volume (log value) of put options, the open interest (log value) of put options, put-call volume ratio, put-call open interest ratio, the bid-ask spread of put options. Attack is equal to 1 if data breach happened; equal to 0 for control firms. Post is equal to 1 when t is in the window [-16w,0); is equal to 0 when t is in the window [-32w, -16w). The interaction term is Attack × Post. The control variables are ROA (return on assets), SIZE(firm size), LEVER(total liabilities to total assets), MKTCAP (log of market capitalization). Industry is classified by the Fama-French 12 industries.

Panel A: OTM Options [-32w, -16w) vs. [-16w, 0)

	Volume		Open Interest		PC Volume Ratio		P-C Open Interest Ratio		Spead	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Attack	-3.198***	-3.043***	-3.192***	-2.964***	-0.00425**	-0.0107***	0.00950***	0.00894***	-0.125***	-0.0554***
	(-102.0)	(-111.8)	(-111.0)	(-122.6)	(-2.409)	(-5.677)	(5.591)	(4.953)	(-30.48)	(-15.33)
Post	-0.225***	-0.0787***	-0.201***	-0.0892***	-0.0132***	-0.0117***	0.000875	0.00708***	-0.0210***	0.0254***
	(-12.27)	(-4.898)	(-11.69)	(-6.093)	(-12.66)	(-10.38)	(0.860)	(6.462)	(-8.508)	(11.54)
Attack*Post	0.310***	0.0918***	0.318***	0.134***	0.0173***	0.0164***	0.00863***	0.00354	0.0114**	-0.0317***
	(7.806)	(2.709)	(8.730)	(4.457)	(7.757)	(7.010)	(4.014)	(1.571)	(2.193)	(-7.013)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	73,553	67,063	74,759	68,240	74,249	67,742	74,813	68,296	74,931	68,408
R2-adj	0.370	0.514	0.370	0.561	0.0187	0.0306	0.0617	0.0733	0.156	0.164

Panel B: Deep OTM Options [-32w, -16w) vs. [-16w, 0)

	Volume		Open Interest		PC Volume Ratio		P-C Open Interest Ratio		Spead	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Attack	-3.581***	-3.534***	-3.836***	-3.572***	0.0323***	0.0191***	0.00978***	-0.0115***	-0.0381***	-0.0263***
	(-107.9)	(-125.2)	(-124.9)	(-143.9)	(13.88)	(7.943)	(3.780)	(-4.349)	(-17.45)	(-13.98)
Post	-0.455***	-0.317***	-0.469***	-0.327***	0.0359***	0.0362***	0.0331***	0.0286***	0.0133***	0.0164***
	(-22.90)	(-19.04)	(-24.70)	(-21.55)	(25.40)	(25.09)	(20.60)	(17.69)	(9.788)	(14.25)
Attack*Post	0.557***	0.338***	0.517***	0.291***	-0.0406***	-0.0402***	-0.0415***	-0.0386***	-0.0160***	-0.0215***
	(12.91)	(9.371)	(12.96)	(9.150)	(-13.42)	(-13.09)	(-12.33)	(-11.41)	(-5.643)	(-8.951)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	79,275	76,326	81,241	78,231	80,160	77,189	81,339	78,321	81,442	78,421
R2-adj	0.390	0.565	0.417	0.631	0.0399	0.0588	0.0455	0.0850	0.0677	0.173

Table 6: Cumulative Abnormal Returns (CAR) following a data breach during the windows, (0,+1d), (0,+5d) and (-1,+1d). This table reports the CARs based on the CAPM Model. N-P Ratio is the number of negative CARs versus the number of positive CARs. The categories of data breaches include CARD (Payment Card Fraud), HACK (Hacking or Malware), INSD (Insider), PHYS (Physical Loss), PORT (Portable Device), STAT (Stationary Device), DISC (Unintended Disclosure) and UNKN (Unknown).

Panel A: CARs	(0,+1)				(0,+5)				(-1,+1)			
	Mean	Median	N	N-P Ratio	Mean	Median	N	N-P Ratio	Mean	Median	N	N-P Ratio
Overall	-0.35%***	-0.18%	573	1.22	-0.46%**	-0.21%	573	1.15	-0.31%**	-0.30%	574	1.32
	(-2.59)				(-2.15)				(-2.06)			
Panel B: Type of Breach												
CARD	-1.34%	-0.44%	18	1.25	0.06%	0.53%	18	0.50	-0.95%	-0.17%	18	1.57
	(-1.60)				(0.05)				(-0.97)			
DISC	0.12%	-0.08%	96	1.18	0.09%	-0.49%	96	1.18	-0.24%	-0.41%	96	1.53
	(0.21)				(0.15)				(-0.40)			
HACK	-0.43%**	-0.11%	161	1.12	-0.67%	-0.03%	161	1.06	-0.46%*	-0.34%	161	1.27
	(-1.96)				(-1.33)				(-1.72)			
INSD	0.25%	0.15%	70	0.94	0.06%	0.18%	70	0.79	0.29%	0.12%	70	0.94
	(1.19)				(0.13)				(0.93)			
PHYS	-0.75%*	-0.31%	26	1.60	-0.29%	-0.20%	26	1.36	-1.02%**	-0.86%	26	2.25
	(-1.86)				(-0.44)				(-2.37)			
PORT	-0.39%**	-0.16%	129	1.26	-0.84%**	-0.50%	129	1.58	-0.15%	-0.16%	129	1.24
	(-2.11)				(-2.22)				(-0.75)			
STAT	-1.32%	-0.86%	13	1.60	-1.75%	-1.34%	13	1.60	-0.70%	-0.68%	14	1.80
	(-1.51)				(-1.41)				(-0.55)			
UNKN	-0.80%**	-0.66%	60	1.73	-0.55%	-0.38%	60	1.14	-0.50%	-0.34%	60	1.40
	(-2.09)				(-1.08)				(-1.21)			

Table 7: Cross-sectional Regression (put options with delta from -0.6 to -0.4). The dependent variable is the CAR of (0,+1d) in Panel A and (0,+5d) in Panel B. Explainable variables are the option trading activities within (-1m,0) (i.e. (-4w,0)). P_volume is the log value of put option trading volume; P_interest is the log value of put option open interest; PC_Vratio is Put-Call volume ratio; PC_Iratio is Put-Call open interest ratio; Spread is the bid-ask spread of put options. Control variables include return on assets (ROA), log of total assets (SIZE), leverage (LEVER), book-to-market ratio (BM), the log value of stock trading volume (S_volume), the log value of institutional ownership (Ownership) and VIX. Industry is classified by the Fama-French 12 industries.

Panel A: CAR(0,+1)										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
P_Volume	-1.82e-05	0.00142								
	(-0.127)	(1.019)								
P_interest			0.000535	0.00138						
			(1.174)	(0.036)						
PC_Vratio					-0.00428*	-0.0117***				
					(-1.785)	(-5.245)				
PC_Iratio							-0.0063***	-0.00348*		
							(-3.317)	(-1.952)		
Spread									-0.000294	-0.00137
									(-0.446)	(-1.264)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Year&Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	423	313	441	328	439	327	442	330	445	332
R2-adj	4.38%	4.33%	4.78%	4.71%	4.33%	4.54%	4.48%	4.29%	4.65%	4.31%
Panel B: CAR (0,+5)										
P_Volume	0.00142	0.00319								
	(1.477)	(1.555)								
P_interest			0.00196	-0.000958						
			(1.186)	(-0.479)						
PC_Vratio					-0.0352***	-0.0147***				
					(-9.234)	(-3.575)				
PC_Iratio							-0.0161***	-0.0015***		
							(-5.278)	(-3.463)		
Spread									-0.000817	-0.00651
									(-0.778)	(-0.904)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Year&Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	418	310	439	327	434	324	439	329	443	330
R2-adj	2.44%	4.81%	4.30%	4.45%	3.52%	4.66%	2.98%	4.36%	3.45%	4.75%

t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8: Placebo Tests. This table reports the results of Placebo tests to compare with the results in the nonevent period and non-attacked firms. First, for each attacked firm, we randomly choose a non-data breach announcement date and assume that it is the actual data breach announcement date. Second, on each actual data breach announcement date, we examine the corresponding control firms. We regress the same model as Equation (3). For convenience, we add the coefficient in Table 7 for comparison in row 1. The results of CAR(0,+1d) are reported in Panel A, and the results of CAR(1,+5d) are reported in Panel B.

Panel A: CAR(0,+1)		
	PV_Vratio	PC_Iratio
Original sample for attacked firms on data breach announcement dates	-0.0117***	-0.00348*
Attacked firms on non-data breach announcement date	0.00856	0.00105
	(0.497)	(0.0664)
Non-attacked firms on data breach announcement date	0.00471	-0.00187
	(0.566)	(-0.113)
Panel B: CAR(0,+5)		
	PV_Vratio	PC_Iratio
Original sample for attacked firms on data breach announcement dates	-0.0147***	-0.0015***
Attacked firms on non-data breach announcement date	0.0272	0.0175
	(0.885)	(0.618)
Non-attacked firms on data breach announcement date	-0.00454	-0.0223
	(-0.142)	(-0.755)

Table 9: Excess Returns of Long-Short Strategies. This Table provides the excess returns computed from, market model, Fama French 3-factor model, and Fama French/Carhart 4-factor model. Eight windows are computed, respectively from pre-1 day, pre-3 day, pre-5 day, pre-10 day, pre-60 day, pre-90 day, pre-100 day, pre-120 day to the data-breach announcement date.

Panel A: 1-Day Excess Return			
	Market	Factor-3	Factor-4
Short Excess-Return	-0.31%***	-0.32%***	-0.30%***
	(-3.04)	(-3.11)	(-3.01)
Long Excess-Return	0.11%	0.05%	0.05%
	(1.14)	(0.58)	(0.56)
Long-Short Excess-Return	0.42%**	0.37%**	0.35%**
	(2.54)	(2.14)	(2.16)

Panel B: 3-Day Excess Return			
	Market	Factor-3	Factor-4
Short Excess-Return	-0.39%***	-0.39%***	-0.38%***
	(-2.92)	(-2.93)	(-2.85)
Long Excess-Return	0.30%***	0.28%***	0.28%**
	(2.66)	(2.58)	(2.50)
Long-Short Excess-Return	0.69%***	0.67%***	0.66%***
	(3.85)	(3.80)	(3.73)

Panel C: 5-Day Excess Return			
	Market	Factor-3	Factor-4
Short Excess-Return	-0.38%**	-0.39%***	-0.37%**
	(-2.49)	(-2.61)	(-2.52)
Long Excess-Return	0.27%**	0.27%**	0.25%*
	(2.05)	(2.07)	(1.90)
Long-Short Excess-Return	0.66%***	0.66%***	0.62%***
	(3.14)	(3.23)	(3.06)

Panel D: 10-Day Excess Return			
	Market	Factor-3	Factor-4
Short Excess-Return	-0.19%	-0.19%	-0.15%
	(-0.81)	(-0.83)	(-0.65)
Long Excess-Return	0.44%**	0.38%**	0.39%**
	(2.44)	(2.18)	(2.26)
Long-Short Excess-Return	0.63%**	0.57%**	0.54%*
	(2.19)	(2.01)	(1.91)

Panel E: 60-Day Excess Return			
	Market	Factor-3	Factor-4
Short Excess-Return	-0.64%	-0.30%	-0.20%
	(-1.22)	(-0.61)	(-0.41)
Long Excess-Return	0.63%	0.51%	0.50%
	(1.23)	(0.99)	(0.97)
Long-Short Excess-Return	1.27%*	0.82%	0.71%
	(1.80)	(1.15)	(0.95)

Panel F: 90-Day Excess Return			
	Market	Factor-3	Factor-4
Short Excess-Return	-0.98%	-0.34%	-0.33%
	(-1.55)	(-0.55)	(-0.53)
Long Excess-Return	1.56%**	1.58%**	1.51%**
	(2.43)	(2.41)	(2.30)
Long-Short Excess-Return	2.54%***	1.92%**	1.83%*
	(2.82)	(2.04)	(1.92)

Panel G: 100-Day Excess Return			
	Market	Factor-3	Factor-4
Short Excess-Return	-0.74%	-0.19%	-0.17%
	(-1.12)	(-0.29)	(-0.27)
Long Excess-Return	1.96%***	1.83%***	1.72%**
	(2.96)	(2.71)	(2.56)
Long-Short Excess-Return	2.71%***	2.02%**	1.89%*
	(2.86)	(2.06)	(1.91)

Panel H: 120-Day Excess Return			
	Market	Factor-3	Factor-4
Short Excess-Return	-1.29%*	-0.54%	-0.52%
	(-1.72)	(-0.74)	(-0.71)
Long Excess-Return	2.45%***	2.41%***	2.26%***
	(3.31)	(3.28)	(3.07)
Long-Short Excess-Return	3.74%***	2.96%***	2.78%**
	(3.40)	(2.61)	(2.44)

t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 10: Profits of Put Options. This table reports the profits by holding put options prior to data-breach announcements. We compute the put-option profit as $Profit = Max(StrikePrice - SpotPrice, 0) - OptionPrice$. We then scale the profit as a percentage by dividing by the option price. Both equal-weighted and value-weighted (weighted by the option price) profits reported. N is the number of put options. We compute the profits of put option within different windows including 1 day, 5 days, ..., 300 days.

	300 days	270 days	250 days	200 days
EW-Profits	1.332***	1.927***	1.566***	1.842***
	(8.16)	(10.82)	(9.34)	(10.62)
VW-Profits	2.725***	2.560***	2.054***	2.391***
	(15.91)	(14.82)	(12.82)	(14.02)
N	308	359	332	390
	180 days	150 days	100 days	60 days
EW-Profits	1.924***	2.221***	2.722***	3.510***
	(11.60)	(12.09)	(13.88)	(19.72)
VW-Profits	2.399***	3.302***	3.424***	4.242***
	(15.25)	(18.23)	(17.96)	(25.41)
N	460	593	673	1119
	30 days	15 days	5 days	1 day
EW-Profits	3.690***	3.710***	3.658***	3.894***
	(15.35)	(18.96)	(18.32)	(19.50)
VW-Profits	3.835***	3.818***	3.999***	3.854***
	(18.65)	(22.76)	(23.67)	(23.11)
N	1068	1540	1177	1509

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Supplemental Appendix: Informed Trading Surrounding Data Breaches in Options Markets

Table IA.1: Cumulative Abnormal Returns (CAR) following a data breach under the windows, (-2d,+1d), (-1d,+2d), (-1d,+3d) and (+6d,+10d). This table reports the CARs based on the CRSP value-weighted average. N-P Ratio is the number of negative CARs versus the number of positive CARs.

Panel A: CARs	(-2,+1)				(-1,+2)			
	Mean	Median	N	N-P Ratio	Mean	Median	N	N-P Ratio
Overall	-0.40%**	-0.32%	574	1.30	-0.26%	-0.22%	574	1.17
	(-2.31)				(-1.38)			
Panel B: Type of Breach								
CARD	-1.45%	-0.63%	18	1.57	-0.06%	-0.60%	18	1.25
	(-1.49)				(-0.07)			
DISC	-0.12%	-0.30%	96	1.23	-0.10%	-0.32%	96	1.23
	(-0.2)				(-0.17)			
HACK	-0.46%	-0.51%	161	1.48	-0.37%	-0.04%	161	1.04
	(-1.48)				(-0.83)			
INSD	-0.04%	-0.05%	70	1.06	0.35%	0.85%	70	0.75
	(-0.09)				(0.82)			
PHYS	-0.64%	-0.47%	26	1.17	-0.98%*	-0.45%	26	1.89
	(-0.98)				(-1.74)			
PORT	-0.21%	-0.26%	129	1.30	-0.14%	-0.21%	129	1.19
	(-0.83)				(-0.58)			
STAT	-0.79%	-0.12%	14	1.00	-1.41%	-0.54%	14	2.50
	(-0.64)				(-0.92)			
UNKN	-0.96%**	-0.36%	60	1.31	-0.67%	-0.68%	60	1.73
	(-2.03)				(-1.54)			
Panel C: CARs	(-1,+3)				(+6,+10)			
	Mean	Median	N	N-P Ratio	Mean	Median	N	N-P Ratio
Overall	-0.31%	-0.23%	574	1.13	0.04%	0.01%	571	0.99
	(-1.48)				(0.20)			
Panel D: Type of Breach								
CARD	0.41%	-0.37%	18	1.57	1.29%	1.38%	18	0.64
	(0.29)				(1.55)			
DISC	-0.09%	-0.21%	96	1.09	-0.04%	0.46%	96	0.66
	(-0.14)				(-0.08)			
HACK	-0.52%	-0.11%	161	1.09	0.47%	-0.03%	161	1.01
	(-1.10)				(1.30)			
INSD	0.29%	0.72%	70	0.75	-0.18%	-0.32%	70	1.69
	(0.63)				-0.48			
PHYS	-1.00%	-0.83%	26	1.60	0.05%	0.32%	26	0.73
	(-1.51)				0.06			
PORT	-0.21%	-0.29%	129	1.15	-0.30%	-0.01%	129	1.02
	(-0.74)				-0.81			
STAT	-0.99%	-0.38%	14	1.80	0.16%	0.48%	12	0.50
	(-0.56)				0.15			
UNKN	-0.75%	-0.93%	60	1.40	-0.43%	-0.37%	59	1.36
	(-1.39)				-0.59			

Table IA.2: Cross-sectional Regression (put options with delta from -0.4 to -0.2). The dependent variable is the CAR of (0,+1d) in Panel A and (0,+5d) in Panel B. Explainable variables are the option trading activities within (-1m,0) (i.e. (-4w,0)). P_volume is the log value of put option trading volume; P_interest is the log value of put option open interest; PC_Vratio is Put-Call volume ratio; PC_Iratio is Put-Call open interest ratio; Spread is the bid-ask spread of put options. Control variables include return on assets (ROA), log of total assets (SIZE), leverage (LEVER), book-to-market ratio (BM), the log value of stock trading volume (S_volume), the log value of institutional ownership (Ownership) and VIX. Industry is classified by the Fama-French 12 industries.

Panel A: CAR(0,+1)										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
P_Volume	-0.000179	0.000221								
	(-0.272)	(0.200)								
P_interest			-0.000101	0.00107						
			(-0.151)	(0.876)						
PC_Vratio					-0.0193*	-0.0202**				
					(-1.925)	(-2.195)				
PC_Iratio							-0.00421	8.45e-05		
							(-0.431)	(0.00887)		
Spread									0.00163	0.00316
									(0.398)	(0.803)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Year&Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	432	322	442	331	439	328	442	331	442	331
R2-adj	3.02%	4.38%	2.76%	3.52%	3.90%	5.27%	2.86%	3.15%	2.80%	3.31%
Panel B: CAR (0,+5)										
P_Volume	0.00155	-0.000192								
	(1.478)	(-0.0946)								
P_interest			0.00133	-0.000192						
			(1.253)	(-0.0869)						
PC_Vratio					-0.0285*	-0.0137*				
					(-1.784)	(-1.813)				
PC_Iratio							-0.0106	-0.00608		
							(-0.684)	(-0.353)		
Spread									0.00153	0.0108
									(0.234)	(1.519)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Year&Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	432	322	442	331	439	328	442	331	442	331
R2-adj	3.84%	5.35%	3.28%	4.72%	3.16%	5.41%	2.28%	4.77%	2.19%	5.23%

t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1