

# THE EFFECT OF CYBER-ATTACKS ON STOCK RETURNS

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## Abstract

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A widely debated issue in recent years is cybercrime. Breaches in the security of accessibility, integrity and confidentiality of information involve potentially high explicit and implicit costs for firms. This paper investigates the impact of information security breaches on stock returns. Using event-study methodology, the study provides empirical evidence on the effect of announcements of cyber-attacks on the market value of firms from 1995 to 2015. Results show that substantial negative market returns occur following announcements of cyber-attacks. Financial entities often suffer greater negative effects than other companies and non-confidential cyber-attacks are the most dangerous, especially for the financial sector. Overall findings seem to show a link between cybercrime and insider trading.

**Keywords:** Cyber Risk, Cyber-Attack, Information Security, Stock Market

## 1. INTRODUCTION

The proliferation of information technology has affected all economic sectors, and although the internet has often improved the way business is carried out, it has increased the vulnerability of critical infrastructures to information security breaches.

Cybercrime costs more than is often thought. It costs the global economy up to \$450 billion every year (direct damage plus post-attack disruption to the normal course of targeted business), a figure higher than the market capitalization of Microsoft Inc. Furthermore, cyber-attacks are becoming more frequent, more complex and bigger. Hamilton Place Strategies<sup>3</sup> reveals that in the last five years, the global median cost of a cyber-attack has increased by nearly 200 percent. From 2013 to 2015, cybercrime global costs quadrupled and it appears that there will be another quadrupling from 2015 to 2019. Juniper research<sup>4</sup> recently predicted that the rapid digitization of consumers' lives and enterprise records will increase the cost of data breaches to \$2.1 trillion globally by 2019. Nevertheless, a

significant portion of cybercrime goes undetected, e.g. industrial espionage gaining access to confidential information is difficult to spot.

Ginni Rometty, IBM Corp Chairman and CEO noted recently that cybercrime may be the greatest threat to every company in the world. Cyber risk represents, in fact, an enormous potential threat to public and private institutions because of its effects on organizational information systems, reputation, loss of stakeholders' confidence and financial losses. In other words, when a firm suffers from an information breach, there is an immediate direct cost as a result but also many residual costs. Kaspersky Lab<sup>5</sup> estimates that attacked enterprises suffer an average of 23 hours of downtime, resulting in an average loss of \$1.4 million and that damage to the brand of the company results in costs that are 7.5 times higher than the direct costs associated with recovering from the attack. Moreover, the average total of financial losses from security incidents at enterprises is \$3.4 million. These numbers make it clear that a cyber-attack can have a disastrous impact on business. Furthermore, it is estimated that security incidents are growing at a compound annual growth rate of 66%.

<sup>3</sup> Source: Hamilton Place Strategies (2015), *Cybercrime costs more than you think*.

<sup>4</sup> Source: Juniper research (2016), *Cybercrime will cost businesses over \$2 trillion by 2019*.

<sup>5</sup> Source: Kaspersky lab (2016), *The true costs of a cyberattack for enterprises*.

To this point, Sir Michael Rake, Chairman of BT Group, notes: *“Cyber Security matters to me because it fundamentally impacts the day to day activities of almost every individual and organisation. With technology positively influencing the flexibility, agility and global reach of our day to day business, it is vital that we seek to protect ourselves, our customers and our supply chain from the loss of personal or sensitive information. We also need to guard against the theft of intellectual property, damage to our reputation or brand and of course financial and commercial losses”*.

Understanding the true impact of cyber-attacks on stock market returns is crucial in deciding investment levels in information security activities. Cyber risk is thus a very important topic for all firms, including financial institutions. Indeed, Ponemon Institute<sup>6</sup> finds that in 2015 the companies in financial services industry experienced the highest annualized cost for cybercrime. With reference to banks, Danièle Nouy, Chair of the Single Supervisory Mechanism (SSM) Supervisory Board, considers cyber risk as a risk related to data integrity, and notes that *“previously, banks dealt with the risk that IT system failures could hamper their daily operations, trigger operational losses and cause damage to their reputations. But in today’s world, cyber risk also includes cyber-attacks, the digital version of a classic bank robbery”*. In light of this, in 2015, the SSM Supervisory Board performed a cyber-security review and set up a process to closely monitor significant IT incidents at banks. The purpose was to gain an overview of trends and developments in cyber risk.

Several studies have examined the impact of announcements of cyber-attack on the stock market returns of publicly traded companies. However, findings are mixed: the announcements have often, but not always, had a significant negative impact. Despite its importance, to our knowledge, there is currently little literature (Gordon & Loeb, 2002; and Anderson, 2001) on the economics of information security. Moreover, very little literature addresses the issue with reference to the financial sector. How large are negative market returns following cyber-attacks? And do hackers use insider information for personal gain?

The purpose of this paper is to empirically address these questions by analysing a large sample of firms between 1995 and 2015. We assume that negative market returns vary in size according to the sector (financial vs. non-financial firms) and the nature of cyber-attack.

The remainder of the paper proceeds as follows. In Section 2, we present a literature review. In Section 3, we describe the data and methodology. In Section 4, we discuss the results and in Section 5, we provide concluding comments.

## 2. LITERATURE REVIEW

A large number of studies deal with information security breaches, but there is still a limited amount of literature related to the financial sector. Some authors (Garg et al., 2003; Ko & Dorantes, 2006; Andoh-Baidoo & Osei-Bryson, 2007; Ishiguro et al.,

2007; Oates, 2001; Kannan et al., 2007; Odulaja & Wada, 2012; Ettredge & Richardson, 2003; Hovav & D’Arcy, 2003; Kundur et al., 2011; Eisenstein, 2008; Winn & Govern, 2009) evaluate the impact of cyber-attacks on the breached firms. Geers (2010) and Lilienthal & Ahmad (2015) examine the cyber risk at the national level. Gordon et al. (2003a) consider the issue of sharing information on computer systems security. Dos Santos et al. (1993) and Gordon and Loeb (2002) highlight the importance of IT investment. Brockett et al. (2012) and Shackelford (2009) focus on enterprise cyber risk management, risk mitigation and cyber risk insurance.

The economic impact of cyber-attacks is hard to measure. An information security breach can have a negative economic impact, including lower sales revenues, higher expenses, decrease in future profits and dividends, worsening of reputation and reduction in the market value (Gordon et al., 2003b). However, the economic consequences can also be slight in the long run because firms can protect their main information assets, e.g. customer data or secret formulas. It is, therefore, possible that many information security breaches have an insignificant economic impact. Uma and Padmavathi (2013) outline that there is a lack of understanding of the different types of cyber-attacks, characteristics and possible results. Some types of cyber-attack are considered as a normal business cost for firms that use information technologies (Power, 2002). Moreover, there is a reason to believe that breached firms respond to cyber-attacks by making a new investment in information security (Campbell et al., 2003).

The allocate efficiency of capital markets depends on the extent to which capital asset prices fully reflect information that affects their value (Pettit, 1972). With this in mind, the market value represents the confidence that investors have in a firm, and measuring it is a way of calculating the impact of a cyber-attack. Moreover, Bener (2000) states that investor behaviour depends on what they have observed in the past. Several studies (Campbell et al., 2003; Cavusoglu et al., 2004; Hovav & D’Arcy, 2004) use event study methodology to estimate the consequences of cyber-attacks on the market value of breached firms. These studies also consider the type of breach. Campbell et al. (2003) state that the nature of the breach influences Cumulative Abnormal Return (CAR), while Cavusoglu et al. (2004) and Hovav and D’Arcy (2004) find that the nature of the attack is not a determinant of CAR.

In general, there is a consensus that the announcement of a security breach leads to negative CAR. Campbell et al. (2003) focus on public firms and find a highly significant negative market reaction when breaches are related to unauthorized access to confidential data. Cavusoglu et al. (2004) find that breached firms lose an average of 2.1% market value within 2 days of the announcement. Acquisti et al. (2006) show that data breaches have a negative and statistically significant impact on a company’s market value on the announcement day. Ishiguro et al. (2007) find statistically significant reactions in around 10 days after the news reports and observe that the reaction to news reports of the

<sup>6</sup> Source: Ponemon Institute, 2015 Cost of Cyber Crime Study.

cyber-attacks is slower on the Japanese stock market than on the US market. Gordon et al. (2011) conduct the analysis over two distinct sub-periods and find that the impact of information security breaches on stock market returns of firms is significant. In particular, attacks associated with breaches of availability are seen to have the greatest negative effect on stock market returns. Some studies (Cohen, 1997a; Cohen, 1997b; Cohen et al., 1998) present a list of sets of attacks, defences and effects.

Gandhi et al. (2011) state that sometimes cyber-attacks are *politically motivated*, for example, they are carried out by members of extremist groups who use cyberspace to spread propaganda or attack websites. But information breaches can also be *non-politically motivated* and in this case, generally, the reason of the attack is financial. Sometimes, cyber-attacks are motivated by socio-cultural issues. The attacker's motivations are important because can determine the level of attack intensity (Gupta et al., 2000).

Anyway, firms must take a proactive attitude toward managing cyber-attacks, to enhance overall cybersecurity and help secure critical national infrastructure (Shackelford, 2012). Young et al. (2016) highlight the importance of strategies to minimize cyber risk and suggest some techniques to optimize the level of investment in cyber security and insurance for critical infrastructure owners and operators. Eling and Schnell (2016) consider the difficulties to insure cyber risk, especially due to a lack of data and modelling approaches, the risk of change and incalculable accumulation risks. The authors illustrate various ways to overcome these mentioned limitations, such as mandatory reporting requirements or pooling of data.

To our knowledge, there is little literature on the economics of information security. Gordon and Loeb (2002) present an economic model that determines the optimal amount to invest to protect a given set of information. They suggest that to maximize the expected benefit from investment in protecting information, a firm should spend only a small fraction of the expected loss caused by a security breach. Anderson (2001) puts forward a new concept of information insecurity, based on factors including network externalities, asymmetric information, moral hazard and adverse selection. Kahn and Roberds (2008) focus on identity theft in credit transactions, which they call "the quintessential crime of the information age", and model a trade-off between a desire to avoid costly/invasive monitoring of individuals and the need to control economic transactions. Cashell et al. (2004) point out the importance of information security in both public and private sectors. They focus on the resources used for information security and find that economic analysis can supply important information. Taplin (2016) highlights the importance of cyber risk for financial sector: cyber risk takes many forms including fraud for monetary gain, hacking, theft by criminals or malicious individuals of customer information held by companies, loss of key intellectual property, and the theft of medical data which can have a profound effect on the insurance sector.

The main contribution of our paper is that it focuses on a longer period, 1995-2015, and presents a comparison between the financial and other sectors. Information security is a very important issue in the financial sector, especially in the light of its potential impact on reputation. For financial intermediaries reputation is, in fact, crucial, considering that the supply of payment, risk management services and asymmetric information all create systemic risk (Bhattacharya & Thakor, 1993; Allen & Santomero, 1997, 2001; Cummins et al., 2006; Gillet et al., 2010). And given that today the banking industry has a significant online presence (Pennathur, 2001), cyber risk is an important category of banking risk. The second contribution to the literature is that our study considers the 'nature' of information security breaches in terms of whether they are confidential or non-confidential. This difference appears to be a determinant of whether and why a cyber-attack is likely to be a costly burden for a firm and its shareholders.

### 3. DATA AND METHODOLOGY

#### 3.1. Data

We selected our sample from the Factiva database, searching for newspaper reports of global cyber-attacks 1995-2015<sup>7</sup>. We used the following keywords: "information security breach", "cyber-attack", "computer break-in", "computer attack", "computer virus", "computer system security", "bank computer attack", "internet security incident", "denial of service attack", "hacker".

We initially identified 252 information security breaches (i.e., events). We obtained daily stock market prices from the Thomson Reuters Datastream database, which were adjusted for dividends and splits. To be included in our sample, information on the daily stock prices of the firms had to be available in this database. So our final sample includes 226 cyber-attacks affecting 110 firms. Of these 226 security breaches, 67 affected 34 financial entities.

Table 1 reports the industry distribution of the sample of cyber-attacks. Companies belonging to following sectors, Software Publishers, Electronic Shopping and All Other Telecommunications, announced the highest number of cyber-attacks; 37, 15 and 12 respectively; the Finance and Insurance sector announced 67 cyber-attacks (see Appendix, Table A.1 and Figures A.1 and A.2).

Table 2 shows event distribution over the period 1995-2015 (also see Appendix, Figure A.3). In the three years (2013-2015), the sample companies suffered from almost 30% of total cyber-attacks. In particular, financial companies registered over 41% and non-financial companies registered about 25% of cyber-attacks. Cybersecurity is thus becoming an increasingly important issue.

<sup>7</sup> In line with previous literature, we chose 1995 as the beginning date because it coincides with the emergence of the Internet globally.

**Table 1.** Sample industry distribution of the final sample

<b>NAICS</b>	<b>Industry description</b>	<b>No. of firms</b>
221118	Other Electric Power Generation	1
312111	Soft Drink Manufacturing	1
316211	Rubber and Plastics Footwear Manufacturing	1
324110	Petroleum Refineries	1
325412	Pharmaceutical Preparation Manufacturing	2
325620	Toilet Preparation Manufacturing	1
332312	Fabricated Structural Metal Manufacturing	1
333315	Photographic and Photocopying Equipment Manufacturing	1
334111	Electronic Computer Manufacturing	3
334112	Computer Storage Device Manufacturing	1
334119	Other Computer Peripheral Equipment Manufacturing	1
334210	Telephone Apparatus Manufacturing	2
336411	Aircraft Manufacturing	2
336414	Guided Missile and Space Vehicle Manufacturing	1
441228	Motorcycle, ATV, and All Other Motor Vehicle Dealers	3
441229	All Other Motor Vehicle Dealers	2
443120	Computer & Software Stores	1
443142	Electronics Stores	2
445110	Supermarket and Other Grocery (Except Convenience) Stores	1
446110	Pharmacies & Drug Stores	1
448140	Family Clothing Stores	2
451120	Hobby, Toy, & Game Stores	1
451211	Book Stores	1
452990	All Other General Merchandise Stores	1
453210	Office Supplies and Stationery Stores	1
454111	Electronic Shopping	5
481111	Scheduled Passenger Air Transportation	3
482111	Line-Haul Railroads	1
492110	Couriers	2
511110	Newspaper Publishers	3
511210	Software Publishers	5
513322	Cellular and Other Wireless Telecommunications	2
515210	Cable and Other Subscription Programming	1
517110	Wired Telecommunications Carriers	2
517210	Wireless Telecommunications Carriers	1
517919	All Other Telecommunications	4
518210	Data Processing & Related Services	3
519130	Internet Publishing and Broadcasting and Web Search Portals	1
520000	Finance and Insurance	34
541410	Interior Design Services	2
541511	Custom Computer Programming Services	2
541519	Other computer related services	1
561311	Employment Placement Agencies	1
561621	Security Systems Services (except Locksmiths)	1
811213	Communication Equipment Repair and Maintenance	1
<i>Total</i>		<i>110</i>

Notes: The table shows the sample industry distribution of the final sample following the North American Industry Classification System (NAICS).

**Table 2.** Event distribution of the final sample 1995-2015

<b>Year</b>	<b>Total sample</b>		<b>Financial entities</b>		<b>Non-Financial companies</b>	
	<b>No of events</b>	<b>% of the sample</b>	<b>No of events</b>	<b>% of the sample</b>	<b>No of events</b>	<b>% of the sample</b>
1995	2	0.88%	1	1.49%	1	0.63%
1996	1	0.44%	0	0.00%	1	0.63%
1997	4	1.77%	0	0.00%	4	2.52%
1998	2	0.88%	0	0.00%	2	1.26%
1999	17	7.52%	3	4.48%	14	8.81%
2000	22	9.73%	2	2.99%	20	12.58%
2001	11	4.87%	3	4.48%	8	5.03%
2002	4	1.77%	0	0.00%	4	2.52%
2003	10	4.42%	3	4.48%	7	4.40%
2004	10	4.42%	2	2.99%	8	5.03%
2005	11	4.87%	5	7.46%	6	3.77%
2006	3	1.33%	2	2.99%	1	0.63%
2007	10	4.42%	3	4.48%	7	4.40%
2008	3	1.33%	0	0.00%	3	1.89%
2009	10	4.42%	3	4.48%	7	4.40%
2010	11	4.87%	2	2.99%	9	5.66%
2011	13	5.75%	1	1.49%	12	7.55%
2012	15	6.64%	9	13.43%	6	3.77%
2013	31	13.72%	15	22.39%	16	10.06%
2014	17	7.52%	3	4.48%	14	8.81%
2015	19	8.41%	10	14.93%	9	5.66%
<i>Total</i>	<i>226</i>		<i>67</i>		<i>159</i>	

Notes: The table shows the cyber-attack distribution of the final sample from 1995 to 2015.

### 3.2. Methodology

Following previous studies (Campbell et al., 2003; Gordon et al., 2011), we run an event study to measure the impact of information security breaches on stock returns. An event study is a method used to measure the effects of an economic event on the value of firms. The null hypothesis is that the event has no impact on the distribution of returns.

The event study methodology makes it possible to verify whether cybercriminals are involved in insider trading. This is important because of the price impact of such a trade (Meulbroek, 1992) and the link between the size of an illegal insider's trade and the value of his private information, the probability of detection and the expected penalty if detected (Frino et al., 2013).

Event study methodology has been widely used in banking and finance literature (see, e.g., Brown & Warner, 1980). The assumption that the financial markets respond to news affecting the value of a security means that stock market returns are able to capture the implicit and explicit costs of cyber-attacks (Acquisti et al., 2006; Iheagwara et al., 2004; Kerschbaum et al., 2002; McConnell & Muscarella, 1985). In particular, if a firm suffers from an information security breach then it may incur financial losses, which should reflect in its stock price. Stock prices on the days surrounding the event can capture the impact of that event and measure the economic cost of the cyber-attack. Event study methodology is in fact based on a semi-strong version of the efficient market hypothesis (Fama et al., 1969).

Appraisal of the event's impact requires a measure of the abnormal return (AR) that is the forecast error of a specific normal return-generating mode. Specifically, the AR is the actual ex-post return of the security over the event window<sup>8</sup> minus the normal return of the firm over the event window. The normal return is defined as the expected return without conditioning on the event taking place. In other words, estimated ARs are defined as the company stock return obtained on a given day  $t$ , i.e. when the cyber-attack is announced, minus the predicted "normal" stock return. We estimate daily AR using the Sharpe (1963) market model<sup>9</sup>, which relates the return of any given security to the return of the market portfolio, as follows:

$$R_{i,t} = \alpha_i + \beta_i R_{m,t} + \varepsilon_{i,t} \quad (1)$$

where,  $R_{i,t}$  is the stock rate of return of the affected company  $i$  on day  $t$ ;  $R_{m,t}$  is the rate of return on market index on day  $t$ ;  $\alpha_i$  is the idiosyncratic risk component of share  $i$ ;  $\beta_i$  is the beta coefficient of share  $i$  and  $\varepsilon_{i,t}$  is the random error<sup>10</sup>. The  $\alpha_i$  and  $\beta_i$  coefficients were estimated for each company using an ordinary least square (OLS) regression of  $R_{i,t}$  on  $R_{m,t}$  for a 121-working-day estimation period (from the 21<sup>st</sup> to the 141<sup>st</sup> day before the cyber-attack announcement)<sup>11</sup>. The event window is defined as the time window that takes into account  $-\tau_1$  days before and  $+\tau_2$  day after the date of the announcement. The date of the announcement is defined as day zero. Following a standard approach, we consider various event windows with different lengths, with the widest lasting from 20 days before the announcement day to 20 days after it. Because our sample includes a large set of firms, we select the following market indexes: the S&P500 Composite<sup>12</sup>, NASDAQ and the S&P600 Small Cap. We use the market index total return as our proxy of  $R_{m,t}$ <sup>13</sup>. Using the firm-specific parameters estimated for the market model over the estimated period (MacKinlay, 1997), the  $AR_{i,t}$  is measured as follows:

$$AR_{i,t} = R_{i,t} - (\alpha_i + \beta_i R_{m,t}) \quad (2)$$

The average AR for  $n$  firm shares on day  $t$  ( $\overline{AR}_t$ ) of the event window is measured as follows:

$$\overline{AR}_t = \frac{1}{n} \sum_{i=1}^n AR_{i,t} \quad (3)$$

The concept of cumulative abnormal return (CAR) is necessary to accommodate a multiple period event window. The CAR from  $\tau_1$  to  $\tau_2$  is the sum of the included abnormal returns:

$$CAR_i(\tau_1, \tau_2) = \sum_{t=\tau_1}^{\tau_2} AR_{i,t} \quad (4)$$

where, the  $(\tau_1, \tau_2)$  is the event window. The average CAR for the event period [ $CAR(\tau_1, \tau_2)$ ] is measured as follows:

$$\overline{CAR}(\tau_1, \tau_2) = \frac{1}{n} \sum_{i=1}^n CAR_i(\tau_1, \tau_2) \quad (5)$$

where,  $n$  is the number of events.

We test the statistical significance of CARs using the Boehmer et al. (1991) test statistic  $Z$  to

<sup>10</sup> Specifically,  $\varepsilon_{i,t}$  describes the random component of the linear relationship between  $R_{m,t}$  and  $R_{i,t}$ .

<sup>11</sup> The most common choice is using the period prior to the event window for the estimation window (MacKinlay, 1997).

<sup>12</sup> Subramani and Walden (2001) use the S&P 500 Composite index.

<sup>13</sup> Some studies use a set of control firms in the same industry to assess AR, e.g., Cooper et al. (2001).

<sup>8</sup> The event window is the period over which the security prices of the firms involved in the event are examined.

<sup>9</sup> The market model is used as the normal performance return model.

capture the event-induced increase in return volatility as follows:

$$Z = \sqrt{n} \frac{\overline{SCAR}(\tau_1, \tau_2)}{\sqrt{((1/(n-1)) \sum (SCAR(\tau_1, \tau_2) - \overline{SCAR}(\tau_1, \tau_2))^2)}} \approx T(0, g / g - 2) \tag{6}$$

where,  $n$  is the number of the stocks in the sample and  $SCAR(\tau_1, \tau_2)$  is the standardized abnormal return on stocks  $i$  at day  $t$ , obtained

following the Mikkelsen and Partch (1988) approach as follows:

$$SCAR_{i,t} = \frac{CAR_i(\tau_1, \tau_2)}{\sigma_i \sqrt{T_s + T_s^2 / T} + \sum_{i=\tau_1}^{\tau_2} (R_{m,t} - T_s \bar{R}_m) / \sum_{i=1}^T (R_{m,t} - \bar{R}_m)} \tag{7}$$

where,  $R_m$  is the average return on market index in the estimation period,  $\sigma_i$  is the estimated standard deviation of AR on stock  $i$ ,  $T$  is the number of days in the estimation period,  $T_s$  is the number of days in the event window and all other terms as previously defined. The  $Z$  test in Equation (6) has a  $t$ -distribution with  $T-2$  degrees of freedom and converges to a unit normal.

We also carried out the following two tests. The first, described by Campbell et al. (1997), verifies whereby the event has no influence on CARs (null hypothesis) as follows:

$$T_1 = \frac{\overline{CAR}(\tau_1, \tau_2)}{\sqrt{\sigma^2(\tau_1, \tau_2)}} \approx N(0,1) \tag{8}$$

The second, called the Sign test (Peterson, 1989; Campbell et al., 1997; MacKinlay, 1997), is a non-parametric test used to validate the results of the test  $Z$  and  $T_1$ , as follows:

$$T_2 = \left[ \frac{N^{(c)}}{N} - 0,5 \right] \frac{N^{1/2}}{0,5} \approx N(0,1) \tag{9}$$

where,  $N$  is the number of events and  $N^{(c)}$  is the number of event with negative CAR. The null hypothesis is represented by the absence of significant CARs in the presence of announcements of cyber-attacks. The key parameter of the  $T_2$  is the median sample and the null hypothesis is rejected when a significant number of negative CARs are recorded.

## 4. RESULTS

### 4.1. Stock market reaction to cyber-attacks

Focusing on the whole sample of cyber-attacks (Table 3), we found that the average CARs are negative in all event windows, showing that cyber-attack announcements always lead to negative market returns for a company (the market reacts

negatively to the announcement of cyber-attack (it is a negative information). The extent of negative market returns and the statistical significance of mean CARs vary according to the event windows. In particular, results in the symmetric event windows after the announcement show a high statistical significance, at the 90% confidence level or above. The event windows (-5; 5) and (-3; 3) show mean CARs of -1.26% and -1.19% respectively. This means that significant negative market returns occur on the days prior to and after the announcement of information security breaches. Moreover, the official announcement of a cyber-attack is often partly anticipated by a few days: the asymmetric event windows (-10; -1), (-5; -1) and (-3; -1) display a statistical significance at the 90% confidence level or above. Specifically, they show mean CARs of -1.08%, -0.87% and -0.90% respectively. These results imply that cybercriminals could be implicated in insider trading. Insider threats (i.e. fraud, theft of confidential information and intellectual property, sabotage of computer systems), coming from people within the organization, such as employees, are, in fact, one of the most prevalent types of cyber threats. Furthermore, it must be said that, in the age of globalization, sometimes, it is hard to pinpoint the first release date of an information security breach. Finally, negative market returns also occur on the days after the announcement: the event window (0; 20) shows a mean CAR of -1.19%, but at low statistical significance.

In summary, the stock market seems to recognize the negative business impacts of a cyber-attack. Effects of cyber-attacks on businesses can be financial, reputational and legal. Some costs are well-known, such as customer breach notifications, post-breach customer protection, regulatory compliance, attorney fees and litigation, cybersecurity improvements, technical investigations. Other costs are less visible, e.g., operational disruption, loss of intellectual property, lost value of customer relationships, devaluation of trade name increased cost to raise debt, insurance premium increases.

**Table 3.** Test statistics on CARs for the whole sample

Event window	No. of observations	Mean CAR (%)	Z	$T_1$	$T_2$	% of negative CARs
(-20; 20)	226	-3.326	-1.361*	-1.634*	-0.399	48.67
(-10; 10)	226	-3.334	-2.360***	-2.190***	0.399	51.33
(-5; 5)	226	-1.257	-2.389***	-2.818***	2.794***	59.29
(-3; 3)	226	-1.190	-2.313***	-2.987***	2.129***	57.08
(-20; -1)	226	-0.991	-1.667*	-1.341*	0.532	51.77
(-10; -1)	226	-1.083	-2.681***	-2.479***	2.395***	57.96
(-5; -1)	226	-0.874	-3.820***	-2.971***	4.257***	64.16
(-3; -1)	226	-0.900	-3.429***	-3.718***	3.991***	63.27
(0; 20)	226	-1.194	-1.841**	-1.599*	0.931	53.10
(0; 10)	226	-2.251	-0.970	-1.754**	-0.266	49.12
(0; 5)	226	-0.382	0.183	-1.041	-0.133	49.56
(0; 3)	226	-0.290	-0.143	-0.885	-0.798	47.35
(0; 1)	226	-0.238	0.357	-0.855	-2.661	41.15

Notes: The table reports the results of the event study carried out on the data for 226 cases of cyber-attacks announced by 110 listed companies between 1995 and 2015. We measured the companies' normal return as reported in Equation (1). The abnormal return ( $AR_{i,t}$ ) was calculated as reported in Equation (2). The CAR statistical significance was assessed using the parametric tests Z and  $T_1$  reported in Equations (6) and (8) and the non-parametric test  $T_2$  reported in Equation (9).

\* Statistically significant at 10% (one-tailed test)

\*\* Statistically significant at 5% (one-tailed test)

\*\*\* Statistically significant at 1% (one-tailed test)

We classify the sample according to the economic sector of the firms. In particular, we analyse the potential differences between the financial and other sectors. Of course, the financial sector is one of the industries that are most at risk, given the nature of the data that it holds. Moreover, the risk has evolved from financial theft and fraud to more complex consequences like theft of intellectual property, business disruption and reputation damage.

Tables 4 and 5 report the results. We found that the average CARs are negative in all event windows, showing that cyber-attack announcements lead to negative market returns for both financial and non-financial companies. Moreover, the official announcement of information security breach is

partly anticipated by a few days. With reference to the financial sector, the event windows (-10; -1), (-5; -1) and (-3; -1) display a high statistical significance and show mean CARs of -2.04%, -0.91% and -0.80% respectively. For the other sectors, the event windows (-10; -1), (-5; -1) and (-3; -1) display a high statistical significance and show mean CARs of -0.68%, -0.86% and -0.94% respectively. Again, it could be possible that a link exists between cybercrime and insider trading.

The other sectors also register statistical significant mean CARs in the event windows (-5; 5) and (-3; 3), -1.18% and -1.22% respectively.

In general, financial entities show a greater negative effect in the event windows before the cyber-attack announcements.

**Table 4.** Test statistics on CARs for financial entities

Event window	No. of observations	Mean CAR (%)	Z	$T_1$	$T_2$	% of negative CARs
(-20; 20)	67	-3.423	-1.389*	-2.544***	0.122	50.75
(-10; 10)	67	-3.107	-2.323***	-3.373***	1.100	56.72
(-5; 5)	67	-1.446	-1.640*	-2.700***	1.100	56.72
(-3; 3)	67	-1.121	-1.730**	-2.648***	1.100	56.72
(-20; -1)	67	-2.111	-0.841	-2.418***	0.367	52.24
(-10; -1)	67	-2.041	-2.582***	-3.435***	2.321***	64.18
(-5; -1)	67	-0.910	-1.477*	-2.743***	2.321***	64.18
(-3; -1)	67	-0.797	-1.726**	-3.310***	2.077***	62.69
(0; 20)	67	-2.154	-0.764	-2.276***	0.855	55.22
(0; 10)	67	-1.067	-0.925	-1.752**	0.611	53.73
(0; 5)	67	-0.536	-0.248	-1.291*	0.122	50.75
(0; 3)	67	-0.324	0.014	-0.790	-0.122	49.25
(0; 1)	67	-0.165	0.737	-0.441	-0.367	47.76

Notes: The table reports the results of the event study carried out on the data for 67 cases of cyber-attacks announced by 34 listed financial companies between 1995 and 2015. We measured the companies' normal return as reported in Equation (1). The abnormal return ( $AR_{i,t}$ ) was calculated as reported in Equation (2). The CAR statistical significance was assessed using the parametric tests Z and  $T_1$  reported in Equations (6) and (8) and the non-parametric test  $T_2$  reported in Equation (9).

\* Statistically significant at 10% (one-tailed test)

\*\* Statistically significant at 5% (one-tailed test)

\*\*\* Statistically significant at 1% (one-tailed test)

#### 4.2. Confidential and non-confidential cyber-attacks: the whole sample

Next, we present our results by grouping information security breaches according to whether the attack is confidential (75 events) or non-

confidential (151 events). We consider a cyber-attack as confidential where unauthorized access to confidential information occurs, and non-confidential when it is a computer virus or worm, a DOS attack or system breakdown.

**Table 5.** Test statistics on CARs for non-financial entities

Event window	No. of observations	Mean CAR (%)	Z	T <sub>1</sub>	T <sub>2</sub>	% of negative CARs
(-20; 20)	159	-3.284	-0.687	-1.158	-0.872	46.54
(-10; 10)	159	-3.430	-1.326*	-1.611*	0.079	50.31
(-5; 5)	159	-1.177	-1.826**	-1.987**	2.776***	61.01
(-3; 3)	159	-1.219	-1.723**	-2.268***	1.824**	57.23
(-20; -1)	159	-0.520	-1.442*	-0.529	0.555	52.20
(-10; -1)	159	-0.679	-2.058***	-1.202*	1.348*	55.35
(-5; -1)	159	-0.859	-3.537***	-2.179***	3.410***	63.52
(-3; -1)	159	-0.943	-3.051***	-2.869***	3.727***	64.78
(0; 20)	159	-0.790	-1.705**	-0.804	0.714	52.83
(0; 10)	159	-2.750	-0.565	-1.524*	-0.714	47.17
(0; 5)	159	-0.317	0.315	-0.646	0.079	50.31
(0; 3)	159	-0.276	-0.183	-0.637	-0.714	47.17
(0; 1)	159	-0.268	-1.624	-0.741	-0.714	47.17

Notes: The table reports the results of the event study carried out on the data for 159 cases of cyber-attacks announced by 76 listed financial companies between 1995 and 2015. We measured the companies' normal return as reported in Equation (1). The abnormal return (AR<sub>it</sub>) was calculated as reported in Equation (2). The CAR statistical significance was assessed using the parametric tests Z and T<sub>1</sub> reported in Equations (6) and (8) and the non-parametric test T<sub>2</sub> reported in Equation (9).

\* Statistically significant at 10% (one-tailed test)

\*\* Statistically significant at 5% (one-tailed test)

\*\*\* Statistically significant at 1% (one-tailed test)

First, we analyse the whole sample. Regarding confidential attacks (Table 6), we found that all mean CARs are negative [except for the event windows (-5; 5), (0; 5) and (0; 3)] but their size is generally small and they are not statistically significant (i.e. they are below the 90% confidence level), except for the event windows (-10; -1) and (-5; -1). The event window (-10; -1) shows mean CARs of -0.17% but it is not completely reliable because the result passes only the parametric Z test. The event

window (-5; -1) shows mean CARs of -0.18%. Regarding non-confidential attacks (Table 7), we found that all mean CARs are negative and higher in symmetric event windows, ranging from -1.68% to -4.71%, and with a confidence level of 90% or more. The event windows (-10; -1), (-5; -1) and (-3; -1) also display a high statistical significance and show mean CARs of -1.53%, -1.22% and -1.18% respectively. This means that investors are able to forecast non-confidential cyber-attacks.

**Table 6.** Test statistics on CARs for sub-sample of confidential attacks for the whole sample

Event window	No. of observations	Mean CAR (%)	Z	T <sub>1</sub>	T <sub>2</sub>	% of negative CARs
(-20; 20)	75	-0.153	0.330	-0.084	-1.270	42.67
(-10; 10)	75	-0.565	-0.010	-0.396	-1.039	44.00
(-5; 5)	75	0.040	-0.241	0.065	0.577	53.33
(-3; 3)	75	-0.210	0.039	-0.398	0.115	50.67
(-20; -1)	75	-0.552	-1.015	-0.729	-0.346	48.00
(-10; -1)	75	-0.173	-1.364*	-0.262	1.039	56.00
(-5; -1)	75	-0.183	-1.348*	-0.479	1.963**	61.33
(-3; -1)	75	-0.327	-0.922	-1.195	1.501**	58.67
(0; 20)	75	-0.743	-1.027	-0.924	0.115	50.67
(0; 10)	75	-0.391	0.872	-0.315	-1.039	50.67
(0; 5)	75	0.223	0.693	0.413	-1.039	44.00
(0; 3)	75	0.116	0.864	0.240	-1.501	44.00
(0; 1)	75	-0.058	0.751	-0.137	-2.194***	37.33

Notes: The table reports the results of the event study carried out on the data for 75 cases of confidential cyber-attacks announced by 51 listed companies between 1995 and 2015. We measured the companies' normal return as reported in Equation (1). The abnormal return (AR<sub>it</sub>) was calculated as reported in Equation (2). The CAR statistical significance was assessed using the parametric tests Z and T<sub>1</sub> reported in Equations (6) and (8) and the non-parametric test T<sub>2</sub> reported in Equation (9).

\* Statistically significant at 10% (one-tailed test)

\*\* Statistically significant at 5% (one-tailed test)

\*\*\* Statistically significant at 1% (one-tailed test)

**Table 7.** Test statistics on CARs for sub-sample of non-confidential attacks for the whole sample

Event window	No. of observations	Mean CAR (%)	Z	T <sub>1</sub>	T <sub>2</sub>	% of negative CARs
(-20; 20)	151	-4.901	-1.809**	-1.691*	0.407	51.66
(-10; 10)	151	-4.710	-2.839***	-2.183***	1.546*	56.29
(-5; 5)	151	-1.901	-2.699***	-3.248***	3.174***	62.91
(-3; 3)	151	-1.676	-2.928***	-3.158***	2.523***	60.26
(-20; -1)	151	-1.210	-1.328*	-1.163	0.895	53.64
(-10; -1)	151	-1.535	-2.384***	-2.735***	2.360***	59.60
(-5; -1)	151	-1.218	-3.619***	-3.087***	3.988***	66.23
(-3; -1)	151	-1.184	-3.355***	-3.552***	4.313***	67.55
(0; 20)	151	-1.419	-1.528*	-1.359*	1.383*	55.63
(0; 10)	151	-3.175	-1.747**	-1.750**	0.407	51.66
(0; 5)	151	-0.683	-0.227	-1.430*	0.895	53.64
(0; 3)	151	-0.492	-0.641	-1.153	0.244	50.99
(0; 1)	151	-0.327	-1.033	-0.911	0.570	52.32

Notes: The table reports the results of the event study carried out on the data for 151 cases of non-confidential cyber-attacks announced by 86 listed companies between 1995 and 2015. We measured the companies' normal return as reported in Equation (1). The abnormal return (AR<sub>it</sub>) was calculated as reported in Equation (2). The CAR statistical significance was assessed using the parametric tests Z and T<sub>1</sub> reported in Equations (6) and (8) and the non-parametric test T<sub>2</sub> reported in Equation (9).

\* Statistically significant at 10% (one-tailed test)

\*\* Statistically significant at 5% (one-tailed test)

\*\*\* Statistically significant at 1% (one-tailed test)

### 4.3. Confidential and non-confidential cyber-attacks: financial vs non-financial sector

We also measured the effects on market returns of confidential and non-confidential attacks distinguishing between financial entities and non-financial companies. In the case of confidential attacks announced by financial entities (Table 8), we found no statistically significant results. In the financial industry, confidential attack announcements are likely to be predicted by investors because unauthorized access to confidential information is a big concern, and word of mouth is likely to spread fast.

Non-confidential attacks announced by financial entities (Table 9) appear to generate greater negative market returns than confidential attacks. The most significant results were found in the symmetric event windows (-10; 10), (-5; 5) and (-3; 3), showing statistically significant CARs of -4.03%,

-1.92% and -1.46%, respectively. Statistically significant negative market returns are also associated with the event windows (-10; -1), (-5; -1) and (-3; -1), with values of -2.63%, -1.34% and -1%, respectively.

Interestingly, non-confidential attacks in the financial system are more dangerous than confidential attacks. This may signal that the stock markets are more efficient when cyber-attacks do not concern access to confidential information. In general, non-confidential attacks determine larger negative returns than the confidential ones, so it may be the case that investors perceive financial entities damaged by non-confidential attacks as being more vulnerable. In fact, as well as protecting data, such as customer records, trading information, and confidential documents, banks and other financial service organizations have to safeguard their systems and networks as well as their financial assets. This means the financial sector faces a larger number of threats than many other industries.

**Table 8.** Test statistics on CARs for sub-sample of confidential attacks for financial entities

Event window	No. of observations	Mean CAR (%)	Z	T <sub>1</sub>	T <sub>2</sub>	% of negative CARs
(-20; 20)	23	-1.232	-0.067	-0.652	-0.209	47.83
(-10; 10)	23	-1.338	-0.752	-0.974	-0.209	47.83
(-5; 5)	23	-0.540	0.129	-0.718	-0.209	47.83
(-3; 3)	23	-0.465	0.332	-0.554	-0.626	43.48
(-20; -1)	23	-1.116	0.050	-0.773	-0.209	47.83
(-10; -1)	23	-0.922	-0.079	-0.984	0.626	56.52
(-5; -1)	23	-0.090	0.529	-0.199	0.209	52.17
(-3; -1)	23	-0.407	-0.010	-0.876	-0.209	47.83
(0; 20)	23	-1.309	0.117	-0.801	0.209	52.17
(0; 10)	23	-0.416	-0.361	-0.528	-0.209	47.83
(0; 5)	23	-0.450	0.009	-0.082	-0.209	47.83
(0; 3)	23	-0.058	0.958	-0.082	-0.626	43.48
(0; 1)	23	-0.326	1.026	-0.483	-1.043	39.13

Notes: The table reports the results of the event study carried out on the data for 23 cases of confidential cyber-attacks announced by 15 listed financial companies between 1995 and 2015. We measured the companies' normal return as reported in Equation (1). The abnormal return (AR<sub>*t*</sub>) was calculated as reported in Equation (2). The CAR statistical significance was assessed using the parametric tests Z and T<sub>1</sub> reported in Equations (6) and (8) and the non-parametric test T<sub>2</sub> reported in Equation (9).

\* Statistically significant at 10% (one-tailed test)

\*\* Statistically significant at 5% (one-tailed test)

\*\*\* Statistically significant at 1% (one-tailed test)

**Table 9.** Test statistics on CARs for sub-sample of non-confidential attacks for financial entities

Event window	No. of observations	Mean CAR (%)	Z	T <sub>1</sub>	T <sub>2</sub>	% of negative CARs
(-20; 20)	44	-4.569	-1.539*	-2.579***	0.905	56.82
(-10; 10)	44	-4.032	-2.250***	-3.412***	1.508*	61.36
(-5; 5)	44	-1.920	-1.978**	-2.727***	1.508*	61.36
(-3; 3)	44	-1.464	-2.392***	-3.153***	1.809**	63.64
(-20; -1)	44	-2.631	-1.042	-2.422***	0.603	54.55
(-10; -1)	44	-2.626	-3.114***	-3.522***	2.714***	70.45
(-5; -1)	44	-1.339	-2.583***	-3.091***	2.714***	70.45
(-3; -1)	44	-1.001	-1.847**	-3.710***	2.714***	70.45
(0; 20)	44	-2.596	-0.968	-2.248***	0.905	56.82
(0; 10)	44	-1.407	-0.856	-1.703**	0.905	56.82
(0; 5)	44	-0.581	-0.285	-1.102	0.302	52.27
(0; 3)	44	-0.462	-0.418	-0.922	0.302	52.27
(0; 1)	44	-0.081	-0.625	-0.180	0.302	52.27

Notes: The table reports the results of the event study carried out on the data for 44 cases of non-confidential cyber-attacks announced by 26 listed financial companies between 1995 and 2015. We measured the companies' normal return as reported in Equation (1). The abnormal return (AR<sub>*t*</sub>) was calculated as reported in Equation (2). The CAR statistical significance was assessed using the parametric tests Z and T<sub>1</sub> reported in Equations (6) and (8) and the non-parametric test T<sub>2</sub> reported in Equation (9).

\* Statistically significant at 10% (one-tailed test)

\*\* Statistically significant at 5% (one-tailed test)

\*\*\* Statistically significant at 1% (one-tailed test)

Focusing on confidential attacks announced by non-financial companies (Table 10), we found no statistically significant results except for the event window (-5; -1). Again, we found that confidential attack announcements are likely to be forecast by investors. Regarding non-confidential attacks announced by non-financial companies (Table 11), CARs are negative and statistically significant at

-1.89% and -1.76% for the event windows (-5; 5) and (-3; 3), respectively. Statistically significant negative market returns are also associated with the event windows (-5; -1) and (-3; -1), with values of -1.17%, and -1.26%, respectively.

Finally, we found that non-confidential attacks are more dangerous than confidential attacks for both financial and non-financial sectors but, in

general, the negative effects on the financial sector are greater than on other sectors. Most mean CARs values are statistically significant and higher than values in other sectors.

**Table 10.** Test statistics on CARs for sub-sample of confidential attacks for other sectors

Event window	No. of observations	Mean CAR (%)	Z	T <sub>1</sub>	T <sub>2</sub>	% of negative CARs
(-20; 20)	52	0.324	0.422	0.130	-1.387*	40.38
(-10; 10)	52	-0.223	0.377	-0.113	-1.109	42.31
(-5; 5)	52	0.297	-0.329	0.360	0.832	55.77
(-3; 3)	52	-0.098	-0.112	-0.147	0.555	53.85
(-20; -1)	52	-0.302	-1.254*	-0.342	-0.277	48.08
(-10; -1)	52	0.158	-1.518*	0.184	0.832	55.77
(-5; -1)	52	-0.224	-2.102***	-0.436	2.219***	65.38
(-3; -1)	52	-0.291	-1.111	-0.866	0.832	63.46
(0; 20)	52	-0.493	-1.297*	-0.545	0.000	50.00
(0; 10)	52	-0.380	1.174	-0.217	-1.109	42.31
(0; 5)	52	0.521	0.740	0.727	-1.109	42.31
(0; 3)	52	0.193	0.462	0.309	-1.387*	40.38
(0; 1)	52	0.061	-1.041	0.115	-1.941**	36.54

Notes: The table reports the results of the event study carried out on the data for 52 cases of confidential cyber-attacks announced by 36 listed companies between 1995 and 2015. We measured the companies' normal return as reported in Equation (1). The abnormal return (AR<sub>it</sub>) was calculated as reported in Equation (2). The CAR statistical significance was assessed using the parametric tests Z and T<sub>1</sub> reported in Equations (6) and (8) and the non-parametric test T<sub>2</sub> reported in Equation (9).

\* Statistically significant at 10% (one-tailed test)

\*\* Statistically significant at 5% (one-tailed test)

\*\*\* Statistically significant at 1% (one-tailed test)

**Table 11.** Test statistics on CARs for sub-sample of non-confidential attacks for other sectors

Event window	No. of observations	Mean CAR (%)	Z	T <sub>1</sub>	T <sub>2</sub>	% of negative CARs
(-20; 20)	107	-5.038	-1.111	-1.252*	-0.097	49.53
(-10; 10)	107	-4.988	-1.907**	-1.660**	0.870	54.21
(-5; 5)	107	-1.893	-1.982**	-2.447***	2.804***	63.55
(-3; 3)	107	-1.764	-2.080***	-2.435***	1.837***	58.88
(-20; -1)	107	-0.626	-0.908	-0.449	0.870	54.21
(-10; -1)	107	-1.086	-1.706**	-1.497*	0.870	54.21
(-5; -1)	107	-1.168	-2.958***	-2.214***	2.997***	64.49
(-3; -1)	107	-1.260	-2.862***	-2.756***	3.384***	66.36
(0; 20)	107	-0.935	-1.189	-0.672	1.063	55.14
(0; 10)	107	-3.902	-1.532**	-1.539**	-0.097	49.53
(0; 5)	107	-0.725	-0.113	-1.136	0.870	54.21
(0; 3)	107	-0.504	-0.489	-0.891	-0.097	49.53
(0; 1)	107	-0.428	-1.942**	-0.908	0.483	52.34

Notes: The table reports the results of the event study carried out on the data for 107 cases of non-confidential cyber-attacks announced by 58 listed companies between 1995 and 2015. We measured the companies' normal return as reported in Equation (1). The abnormal return (AR<sub>it</sub>) was calculated as reported in Equation (2). The CAR statistical significance was assessed using the parametric tests Z and T<sub>1</sub> reported in Equations (6) and (8) and the non-parametric test T<sub>2</sub> reported in Equation (9).

\* Statistically significant at 10% (one-tailed test)

\*\* Statistically significant at 5% (one-tailed test)

\*\*\* Statistically significant at 1% (one-tailed test)

In conclusion, it is important to manage the cyber risk and try to minimise the impact of information security breaches on business. After an attack happens, an effective cybersecurity incident response is necessary.

## 5. CONCLUSION

The Internet is an important driver of economic development, but dependence on cyberspace has increased the vulnerability of critical infrastructures to information security breaches.

In this paper, we study the effects on market returns of the announcement of information security breaches for listed companies. Our sample includes 226 cases of information security breach suffered by 110 companies in the period 1995-2015. Of these 226 cyber-attacks, 67 affected 34 financial entities.

We find evidence of an overall negative stock market reaction to public announcements of information security breaches. In the financial sector, we find more negative market returns than other sectors in the event windows before the cyber risk announcements, especially in asymmetric event windows (-10; -1) and (-5; -1). This may imply that

cybercriminals are involved in insider trading. Non-financial companies also show statistical mean CARs in two event windows, (-5; 5) and (-3; 3), after the announcement. Considering the confidential or non-confidential nature of cyber-attacks, we find that in general, non-confidential attacks (computer viruses and worms, DOS attacks and system breakdowns) are more dangerous in both financial and non-financial sectors. Moreover, financial entities show greater negative effects on market returns than companies belonging to other economic sectors. Most mean CARs in the financial sector are statistically significant and higher than in other sectors. This is not surprising given that beyond protecting data, banks and other financial entities also have the challenge of safeguarding their systems and networks as well as the financial assets they hold.

Our results have the following implications. Given that cyber-attacks determine negative, often very big, falls in market returns, it is extremely important that boards, especially of financial institutions (Brogi, 2011), consider this kind of risk.

Cybercrime also damages the company's reputation. Customers lose faith in businesses if their personal information and transactions are not

secure. Cybercrime damages trade, competitiveness, and innovation. Furthermore, some attributes of cyber risk exacerbate negative consequences. Cyber risk is an intangible peril: victims often only become aware that they have been targeted a long time after the attack. Cyber risk has a dynamic nature: information security breaches are often treated as an information technology problem, but they originate with human actors who anticipate defenders' actions. Finally, cyber risk can determine a systemic exposure: digital technologies form connections that can be exploited by attackers to generate widespread impacts. Consequently, all companies, especially financial ones, need to equip themselves with efficient control systems (Brogi, 2009), and to do this at an optimal level of investment, they need to understand the true negative impact of information insecurity. Second, we found that cybercrime may be linked to insider trading. It follows that financial authorities need to strengthen cybersecurity measures. Information

systems should be monitored, background checks should be periodically conducted and warnings should not be ignored. We show that the negative effect on market returns differ according to the nature of the event (confidential/non-confidential) and the sector of the company (financial/non-financial). After an attack occurs, an effective cybersecurity incident response is necessary. It can help to invest in training, education and awareness in the organisation on an on-going basis. Companies should create an action plan to manage cybercrime. But all companies, especially financial ones, need to prevent cyber-attacks and define levels of priority of different types of threat. Companies should budget money for repairs, reimbursement, and for future protection (Source: FBI (2016), <https://www.fbi.gov/investigate/cyber>) and insurance. Finally, they have to implement an effective risk management policy to ensure that investments in cybersecurity reflect the considerable and progressively increasing underlying risk.

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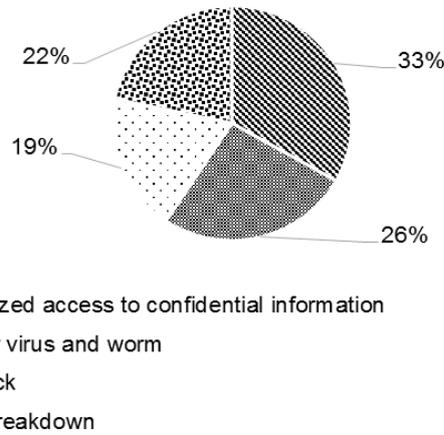
## Appendix

**Table A.1.** The types of cyber-attack announced by the sampled companies from 1995 to 2015

NAICS	Industry description	Type of attack				Total
		Unauthorized access to confidential information	Computer virus and worm	DOS attack	System breakdown	
221118	Other Electric Power Generation		1			1
312111	Soft Drink Manufacturing				1	1
316211	Rubber and Plastics Footwear Manufacturing	1				1
324110	Petroleum Refineries		1			1
325412	Pharmaceutical Preparation Manufacturing		1		1	2
325620	Toilet Preparation Manufacturing		1			1
332312	Fabricated Structural Metal Manufacturing	1				1
333315	Photographic and Photocopying Equipment Manufacturing			1		1
334111	Electronic Computer Manufacturing		1		3	4
334112	Computer Storage Device Manufacturing	1				1
334119	Other Computer Peripheral Equipment Manufacturing		1			1
334210	Telephone Apparatus Manufacturing	3				3
336411	Aircraft Manufacturing	2	3			5
336414	Guided Missile and Space Vehicle Manufacturing	1	2		1	4
441228	Motorcycle, ATV, and All Other Motor Vehicle Dealers	2	1			3
441229	All Other Motor Vehicle Dealers		2			2
443120	Computer & Software Stores		2		1	3
443142	Electronic Stores			2		2
445110	Supermarkets and Other Grocery (Except Convenience) Stores			1		1
446110	Pharmacies & Drug Stores	1				1
448140	Family Clothing Stores	3				3
451120	Hobby, Toy, & Game Stores	1				1
451211	Book Stores		1			1
452990	All Other General Merchandise Stores	1				1
453210	Office Supplies and Stationery Stores	1				1
454111	Electronic Shopping	7	1	3	4	15
481111	Scheduled Passenger Air Transportation	2	1			3
482111	Line-Haul Railroads		1			1
492110	Couriers		2			2
511110	Newspaper Publishers	1	2	1	2	6
511210	Software Publishers	7	9	6	15	37
513322	Cellular and Other Wireless Telecommunications	3	4	1		8
515210	Cable and Other Subscription Programming	1				1
517110	Wired Telecommunications Carriers		1	1	1	3
517210	Wireless Telecommunications Carriers	1	1			2
517919	All Other Telecommunications	5	4	1	2	12
518210	Data Processing & Related Svcs	2	1	2	5	10
519130	Internet Publishing and Broadcasting and Web Search Portals			1		1
520000	Finance and Insurance	23	10	22	12	67
541410	Interior Design Services	2	2			4
541511	Custom Computer Programming Services	1	2	1		4
541519	Other Computer Related Services		1			1
561311	Employment Placement Agencies	1				1
561621	Security Systems Services (except Locksmiths)	1				1
811213	Communication Equipment Repair and Maintenance				1	1
	<b>Total</b>	<b>75</b>	<b>59</b>	<b>43</b>	<b>49</b>	<b>226</b>

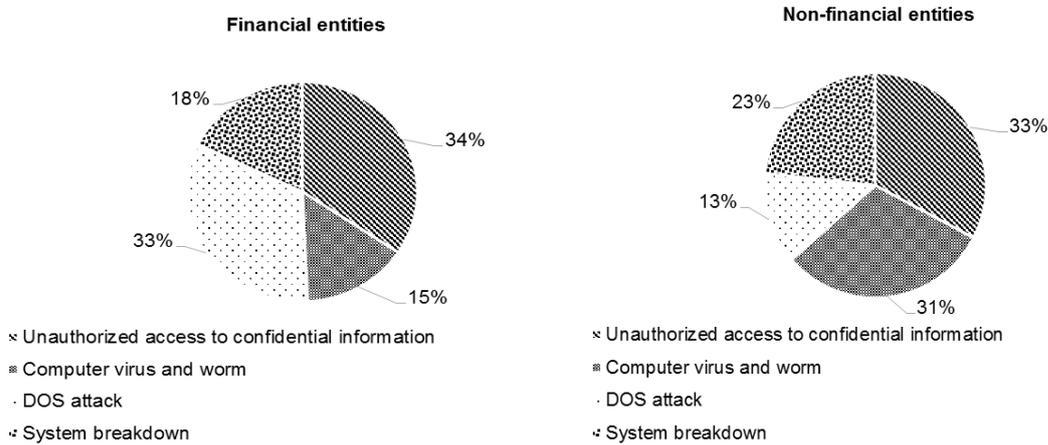
Notes: The table shows the composition of the cyber-attacks in our sample (i.e. types of cyber-attack announced by the sampled companies from 1995 to 2015). Unauthorized accesses to confidential information are confidential attacks and computer viruses and worms, DOS attacks and system breakdowns are non-confidential attacks.

**Figure A.1.** Composition of the cyber-attacks announced by the sampled companies from 1995 to 2015



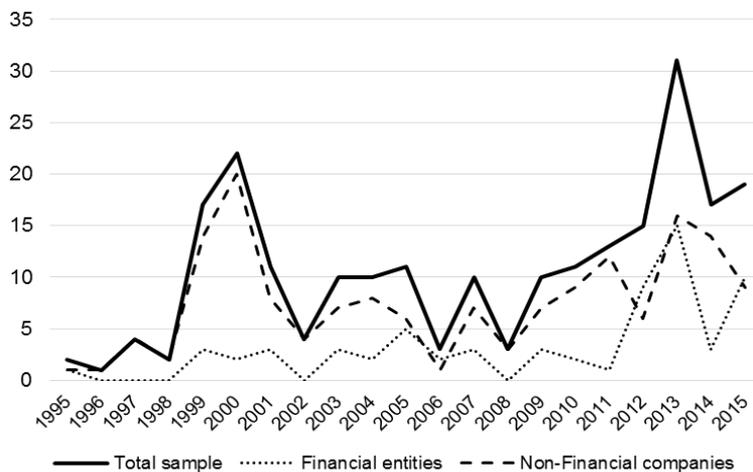
Notes: The figure shows the composition of the cyber-attacks in our sample from 1995 to 2015. 33% of attacks are unauthorized accesses to confidential information, 26% are computer viruses and worms, 22% are system breakdowns and 19% are DOS attacks.

**Figure A.2.** Composition of cyber-attacks announced by the financial and non-financial companies from 1995 to 2015



Notes: The figure shows the composition of the cyber-attacks in our sample from 1995 to 2015. For the financial entities, 34% of attacks are unauthorized accesses to confidential information, 33% are system breakdowns, 18% are DOS attacks and 15% are computer viruses and worms. For the non-financial entities, 33% of attacks are unauthorized accesses to confidential information, 31% are computer viruses and worms, 23% are DOS attacks and 13% are system breakdowns.

**Figure A.3.** Event distribution of the final sample 1995-2015



Notes: The figure shows the distribution of the cyber-attacks in our sample from 1995 to 2015.