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ANALYSIS OF THE EFFECTS OF SECURITY BREACHES ON FIRM VALUE

ABSTRACT

The purpose of this study is to examine, on intradaily market microstructure basis, fifteen recent occurrences of corporate security breaches to extend our understanding of market efficiency. We document minor average price responses to announcements of a security breach in the firms' target of an attack, contrary to many other corporate announcement studies, which document immediate price reaction to an announcement. Surprisingly, we find that the matching firms in our study have a stronger market microstructure response to the announcement of the attack instead. This study suggests to high-frequency investors, such as hedge funds, that they should focus their attention and scarce resources on developing trading strategies on other corporate events and announcements rather than on the announcement of security breaches.

Key Words: Market Microstructure, Bid-ask Spread, Hack, Security Breach

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INTRODUCTION

On September 7, 2017 Equifax announced that 143 million customer accounts have been accessed by hackers. There was uproar among citizens and congressional inquiries. A few days after the attack on September 11, 2017, Andrew Nusca wrote the following in an article in Fortune magazine (Nusca, 2017):

"On September 7, Equifax announced that it had discovered a months-long cybersecurity breach that potentially impacted 143 million people in the US. Four days later, its stock is still reeling from the news. Equifax shares were trading at almost US$143 ahead of the announcement. At midday Monday, September 11, its shares were down more than 18% from that price, to slightly more than US$116 each."

The uproar about this particular security breach was due to the fact that it affected almost half of the US population and because of the special role that Equifax plays in financial markets in the US. Equifax Inc is a US based consumer credit reporting agency, which aggregates and sells information on close to a billion individual consumers around the world. Equifax, along with Experian and TransUnion, provides the backbone of consumer lending in the US. For example, in order to obtain a mortgage and buy a home lenders, this paper used information from Equifax, Experian, and TransUnion to determine whether to extend a loan to a consumer or not. Equifax has approximately three billion dollars in annual revenue and close to 10,000 employees in 14 countries and is publicly traded on the NYSE with a ticker symbol EFX. The security breach at Equifax is just one recent event of multiple cyber security attacks of late. Security breaches erode the trust of customers in institutions, corporations and markets, and thus needs to be studied and understood better.

The purpose of this study is to examine, on intradaily basis, 15 recent occurrences of corporate security breaches and assess the impact on shareholder wealth before, during and after the event of announcement of the breach. The main contribution of this study is in using high-frequency data and market microstructure methodology, while prior studies have focused on daily return analysis. To the best of our knowledge this has not been done in the market efficiency literature so far. Usually, high frequency studies, like this one, are used by traders to identify profitable trading strategies. These strategies are of interest to hedge fund traders in particular who use price fluctuations due to specific corporate events and announcements to trade and generate profits. This study is special because it shows to those traders and speculators that their attempts to profit from the ever more frequent announcements of corporate security breaches, on average, would be

futile and cannot be exploited to make money. We document minor responses to the announcement of a breach in firms' target of an attack and that the matching firms in our study seem to respond stronger instead. The matching firms seem to exhibit higher levels of volatility and average adverse selection and inventory holding cost components of their bid-ask spread relative to target firms. The reason for this could be that typically the target of an attack are usually the industry leaders. This finding is consistent with the findings of Muntermann and Guettler (2007): in German stock markets, that stock prices of larger firms have a weaker price reaction to corporate news than smaller firms. The conclusions in this study suggest to traders and speculators, such as hedge funds, that they should focus their attention and scarce resources on other corporate events and announcements for profit rather than attempting to profit from the announcement of security breaches.

LITERATURE REVIEW

This study expands our knowledge in the area of market efficiency. Many studies examine the speed of information incorporation into security prices and document market efficiency in that stock prices respond to new information very quickly. For example, recent studies by Patell and Wolfson (1984), Barclay and Litzenberger (1988), Huberman and Regev (2001), Kalev et al. (2004), Vega (2006), and Muntermann and Guettler (2007) study market efficiency and stock price reaction to corporate events around the world on intra-daily basis and document that new information gets incorporated into stock prices within minutes (up to 30 minutes in the case of Germany and within 15 minutes in the US) of the new information announcement. Patell and Wolfson (1984) study the effects of dividends and earnings announcements on stock prices and find that stock prices have stronger response to earnings announcements than to dividend announcements. They find that the price response occurs within five minutes of the announcement.

Vega (2006) also studies earnings announcements and the formation of the post earnings announcement drift and the role that informed and uninformed investors play in markets. Their study also shows fast incorporation of news into stock prices. Barclay and Litzenberger (1988) study the effects of new stock issue announcements on stock prices. They find that the stock price reacts within 15 minutes of the announcement. They also document, surprisingly, a price reaction an hour before the announcement of the new stock issue. Huberman and Regev (2001) study the effects of a Sunday positive cancer drug news announcement on Monday stock prices. They document permanent and large

positive increase in pharmaceutical stock prices immediately at the opening of trading on Monday, even though the news turned out not to be true. Kalev, Liu, Pham and Jarnecic (2004) study the effects of 11 different corporate announcement categories, such as announcements of earnings, dividends, change in substantial shareholdings, and takeovers on stock prices in Australia. They find that simply because many such announcements happen after hours there are significant and pronounced price reactions in the beginning of a trading day. Muntermann and Guettler (2007) study the effects on stock prices in Germany of corporate disclosures. They find that stock prices respond within 30 minutes to a corporate announcement. They also document that larger firms exhibit weaker stock price reactions than smaller firms.

In contrast to all these recent market efficiency studies, which are conducted on intradaily basis, all studies in the field of security breaches focus on stock market reaction on a daily basis. The lack of studies on intradaily basis hinders our understanding of security breaches in todays' hi-tech high-frequency of trading world. Garg, Curtis and Halper (2003) attempt to quantify the effects of security breaches on the accounting position of firms. They provide a good summary of the different types of attacks which corporations could experience. Harrald, Schmitt and Shrestha (2004) examine stock performance after occurence of a corporate virus attack. However, their study focuses on the performance of anti-virus firms' stock price. Harrald, Schmitt and Shrestha (2004) document an increase in the stock price of anti-virus firms such as Symantec, Network Associates, and Trend Micro around the anouncement of virus atacks.

Campbell et al. (2003), Cavusoglu, Mishra, and Raghunathan (2004), Kannan, Rees, and Sridhar (2007), and Goel and Shawky (2009) focus on stock market reaction after the announcement of a security breach. All these studies use daily data and event study methodology. Cavusoglu, Mishra and Raghunathan (2004) use older (1996-2001) and Goel and Shawky (2009) use more recent sample (2004–2008) of breaches and document that, on average, the announcement of a corporate security breach had a consistently negative impact on the market value of the firm announcing the security breach after the announcement. Campbell, Gordon, Loeb and Zhou (2003) use an older sample of security breaches and find a negative stock price reaction however they document that the negative reaction is associated with some security breaches but not others. Spanos and Angelis (2016) provide a comprehensive literature review of security breaches on firm value, by identifying 37 unique papers with 75% of the evidence in support of statistically significant price reaction to a security breach. And then there are the remaining 25% of

papers which do not document a price reaction. In contrast to the majority of the findings surprisingly studies such as by Hovav and D'Arcy (2003) and Kannan, Rees and Sridhar (2007) document no stock market reaction associated with security breaches with a relatively newer sample of breaches and by using both excess returns and matching sample of firms methodologies.

It seems that the evidence is mixed on the effects of security breaches on the daily value of firms after the announcement of a breach. Combined with the market efficiency literature, which suggests that the announcement of a such major corporate event as a company security breach, having negative connotation in that firms would suffer major legal and security upgrade costs, should have an almost immediate negative effect on security prices. Therefore, our a priori expectation is for an immediate price drop after the announcement of a security breach to the firm target of an attack thus our null hypothesis is:

Hypothesis 1: Companies with a security breach will have larger stock price drop after the announcement of a security breach relative to matching firms which have not experienced a security breach.

Again, the lack of studies on security breaches on intradaily basis hinders our understanding of security breaches and market efficiency in todays' hi-tech and high-frequency world. To the best of our knowledge no study has examined the stock price reaction to the announcement of a security breach on intradaily basis. Therefore, we attempt to add to the existing market efficiency literature with this paper by examining a newer sample of security breaches.

DATA AND METHODOLOGY

We employ ANOVA methods, correlation and regression analysis on a newer sample of security breaches to test our null hypothesis. We also identify a matching sample of firms without a security breach and examine the stock price behavior of attacked firms relative to firms which are not-attacked in the time period between the time of the attack and the announcement of the attack by the target firm. It is very typical for firms target of an attack, similar to the Equifax breach in the introduction, to take a while to realize that they have been a target of an attack and also to make the announcement of the attack. This potentially might lead to a price reaction prior to the announcement of the attack to the

public. As Barclay and Litzenberger (1988) suggest prices react to new security issue an hour prior to the announcement, which suggests trading on private information. The same could be happening in the area of security breaches too even earlier than an hour before the announcement. Hence, for the lack of specific prior on earliest possible date we focus on the day before of announcement of an attack only. Some might argue that this is not far back, but the randomness and illegality of trading on private information do not give an indication to how far back should we look. Nevertheless, the focus in this study is on announcement dates and trading activity on and around those days with millions of high-frequency observations on these three days.

Another reason why this study is necessary is due to the fact that the majority of studies so far have used security breaches dated over 10 years ago and on daily basis, and both technology and nature of attacks have changed very much since that time. We atempt to fill this void in the literature by studing the stock price reaction of firms with recent security breaches relative to a sample of matching firms. The matching firms are identified based on four digit Standard Industry Classification Codes (SIC Codes) and Market Capitalization. As well established in the literature we use Huang and Stoll (1997) bid-ask spread decomposition methodology. Huang and Stoll (1997) use the following regression model to identify the two main bid-ask spread components - adverse selection and order processing costs components:

$$\Delta P_t = \frac{S}{2}(Q_t - Q_{t-1}) + \lambda \frac{S}{2} Q_{t-1} + e_t \quad (1)$$

Where ΔP is the intradaily price change, S is the intradaily traded spread, Q is an indicator variable with value of (1) if the transaction is buyer initiated and with value of (-1) if the transaction is seller initiated, λ captures the adverse selection and inventory holding costs, whereas (1-λ) is the order processing cost component of the bid-ask spread.

Indeed, in the market microstructure literature there are two competing methods of identifying the bid-ask spread components - trade indicator and covariance models. Trade indicator models are identified in Glosten (1987): Glosten and Harris (1988): Lee and Ready (1991): Ellis, Michaely and O'Hara (2000) and Bessembinder (2003): whereas covariance models are addressed in Roll (1984): Choi, Salandro and Shastri (1988): Hasbrouck (1988, 1991): George, Kaul and Nimalendran (1991) and Madhavan, Richardson and Roomans (1997. The Huang and Stoll (1997) methodology encompasses

both trade indicator and covariance market microstructure models, therefore, in this study we use the Huang and Stoll (1997) methodology of estimating the bid-ask spread components.

In addition to the univariate analysis we use regression models to examine if additional patterns can be discerned in the matched sample of firms with and without security breaches. The model that we test is presented in equation (2):

$$DV_i = \alpha_i + \beta_{1,i} lMC_i + \beta_{2,i} WSB_i + \varepsilon_i, \quad (2)$$

where the average bid-ask spread, standard deviation of the bid-ask spread or bid-ask spread components as identified in equation (1) are the dependent variable (DV): and log of market capitalization (lMC) and dummy variable (WSB) with value of one for firms with an attack and zero otherwise as independent variables and ε is the error term. In order to fail to reject our null hypothesis H0 the coefficient on the WSB variable needs to be statistically significant and negative, alternatively, we will reject the null hypothesis.

The data in this study come from the NYSE TAQ database. We study firms on intradaily basis a day before, the day of the attack and a day after. This seems like a small sample but to put things in perspective there are millions of observations on the three days surrounding the event of an attack when using intradaily data. For example, the sample of intradaily data for Under Armour, the smallest by market cap firm among the firms with a security breach, has 1,305,724 observations on the three days surrounding the event of the attack. Despite the millions of observations per firm used in this market microstructure study, a major limitation is that it focuses on only 15 breaches and 15 matching firms. Unfortunately, the NYSE TAQ data available to us covers the period 2015-2018 so we cannot cover security breaches, which have occurred prior to 2015. The 15 firms target of an attack and the 15 matching firms are sufficient for statistical analysis, and the argument can be made that this is the most recent sample of attacks and that prior attacks belong to a structurally different technological period. The firms and the attacks that they have experienced that we have identified so far are presented in Table 1. The table also reports matching firms' information. The firms with breaches and without have an average market capitalization of approximately $102 billion, whereas the matching firms' average market cap is approximately $71 billion. Unfortunately, Walmart, AT&T and Verizon are by far the largest firms in their industries, thus without Walmart, AT&T

and Verizon the average is $65 billion for firms with a breach and $78 billion for firms without a breach.

Table 1. List of Firms and Type of Attack that They Have Experienced.

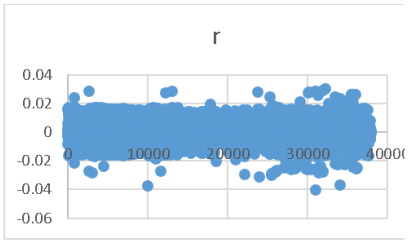
SIC	Company Name	Ticker Symbol	Market Cap (in 000 USD)	Date Announced	Type of Attack	Matching Firm Ticker	Matching Firm Name	Market Cap (in 000 USD)
2329	Under Armour	UA	2,912,111	03/29/2018	Hacked	RL	Ralph Lauren Corp	5,722,857
4833	Orbitz	EXPE	16,808,102	03/20/2018	Hacked	IAC	IAC Interactive Corp	9,484,116
7323	Equifax	EFX	14,383,063	9/7/2017	Hacked	TRU	TransUnion	10,107,943
4512	United Airlines	UAL	19,884,434	5/14/2017	Internal Security procedures	DAL	Delta Air Lines, Inc.	40,012,045
9999	Sabre Corp	SABR	5,691,564	5/2/2017	hack	UBNT	Ubiquity Networks Inc	5,523,668
4512	United Airlines	UAL	19,884,434	1/22/2017	computer related problem	DAL	Delta Air Lines Inc	40,012,045
9999	SS&C Technology	SSNC	8,322,960	9/19/2016	Hacked	BLUE	Bluebird Bio Inc	8,244,996
7370	Amazon	AMZN	569,697,996	7/8/2016	Hacked	MSFT	Microsoft Corp	661,217,509
4813	Verizon	VZ	217,352,617	3/24/2016	Hacked	AMT	American Tower Corp	60,708,855
7011	Hyatt Hotel Corp	H	3,372,698	12/23/2015	Malware/hack/breach	STAY	Extended Stay America Inc	3,539,148
4813	AT&T	T	238,745,710	8/4/2015	Customer info stolen	EQIX	Equinix Inc	35,337,515
5331	Walmart	WMT	296,509,671	7/17/2015	Credit card info stolen	TGT	Target Corp	35,408,345
5912	CVS	CVS	73,705,298	7/17/2015	Credit card info stolen	WBA	Walgreens Boots Alliance Inc	72,157,338
4512	American Airlines	AAL	25,073,348	1/12/2015	hack	LUV	Southwest Airlines Co	39,139,872
4512	United Airlines	UAL	19,884,434	1/12/2015	hack	DAL	Delta Air Lines Inc	40,012,045
Average			102,148,563					72,799,976

Note: Market Cap from The Center for Research in Security Prices (CRSP) as of December 27, 2017.

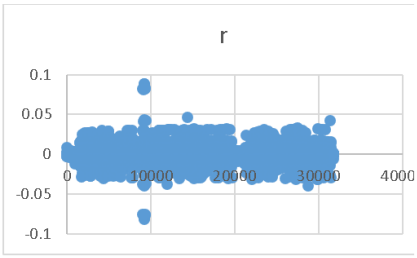
EMPIRICAL FINDINGS

After winsorizing the return data of National-Best-Bid-And-Offer (NBBO) minute mid-quotes the plots of the data are presented in Figure 1. Clearly, Equifax's intradaily return and bid-ask spread do not exhibit any pattern or a drop for that matter, the same is observed with the matching firm TransUnion. However, both Equifax and TransUnion mid-quotes exhibit a drop on the day of the announcement of the breach. Only four other firms, EXPE, UAL (January 2017 announcement): WMT and AAL exhibit a price decline but not an abrupt price drop as observed for EFX after the announcement. This implies that the security breach has potentially impacted both the firm target of the breach and the matching firm/competitor. Surprisingly, when we examine individually each of the rest of the firms target of a security breach, this drop is not observed, all firms' mid-quotes charts are presented in the Appendix.

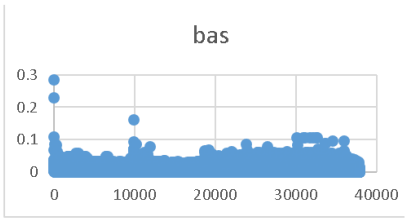
Figure 1. Equifax and TransUnion Intradaily Returns, Bid-Ask Spreads and Mid-quotes



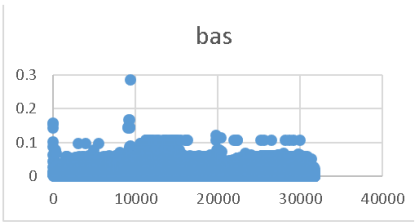
EFX R



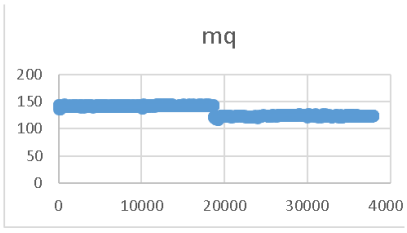
TRU R



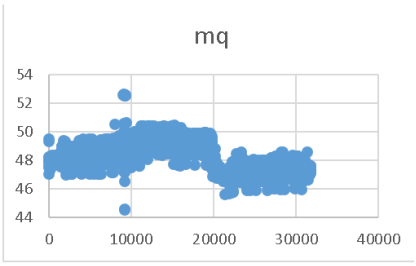
EFX BAS



TRU BAS



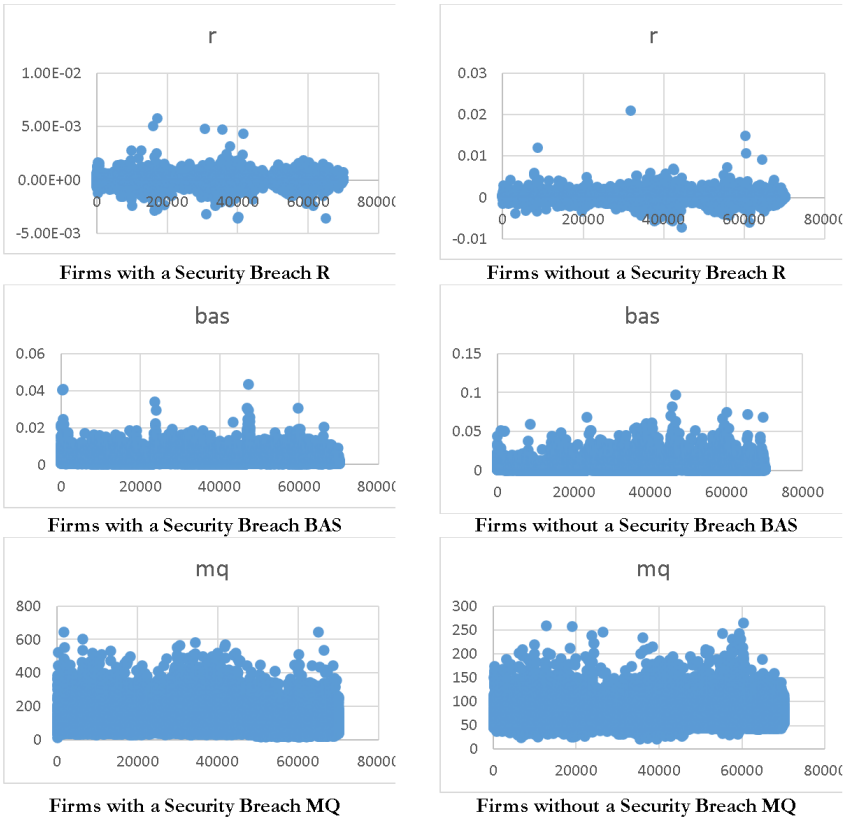
EFX MQ



TRU MQ

When we examine all firms target of a breach and matching firms, presented in Figure 2, again no significant difference is observed between target and matching firms returns, bid-ask spreads and mid-quotes. These findings are in agreement with the findings of Hovav and D'Arcy (2003) and Kannan, Rees and Sridhar (2007) who document no stock market reaction associated with security breaches. However, these findings are in stark contrast to the findings of studies of other significant corporate events, such as by Patell and Wolfson (1984): Barclay and Litzenberger (1988): Huberman and Regev (2001): Kalev, Liu, Pham and Jarnecic (2004): Vega (2006) and Muntermann and Guettler (2007): who document very fast adjustment in prices after announcement of an event.

Figure 2. All Firms Target of a Breach and Matching Firms Intradaily Returns (r): Bid-Ask Spreads (bas) and Mid-quotes (mq)



If we cannot identify strong responses in prices at the time of announcement of a security breach it might be helpful to look at and explore the behavior of bid-ask spreads around the time of the announcement. It might be that the spread would reflect the negative impact of the breach instead. Table 2 Panel A shows intradaily average bid-ask spreads of all firms in the study both firms target of an attack and firms not target of an attack. Average bid prices, ask prices and traded prices are also reported for comparison and scale purposes. The table shows that on the day before the attack firms with an attack have an average bid-ask spread of 0.0019, whereas on the days of the attack and the day after the attack the spreads are a bit higher at 0.0022 and 0.0021, respectively. Contrary to our expectations, on the same days, matching firms surprisingly have higher average bid-ask spreads of 0.0030, 0.0046 and 0.0053, respectively.

This could be driven by the fact that the matching firms tend to be smaller than the firms target of the attack. It seems that there is no stock price reaction to the announcement of a security breach, contrary to prior findings in daily data studies such as in papers by Campbell, Gordon, Loeb and Zhou (2003): Cavusoglu, Mishra and Raghunathan (2004): Kannan, Rees and Sridhar (2007) and Goel and Shawky (2009. Our findings of lack of reaction after announcement, even though on intradaily basis, are in agreement with findings in recent studies by Hovav and D'Arcy (2003) and Kannan, Rees and Sridhar (2007) also of no reaction but using daily data. The fact that there is no reaction could be because financial markets might take longer to respond to the information, which in todays' high frequency world seems a bit naive. What is more plausible is that markets could have figured out ahead of the announcement that a company has been subject of an attack. After all, hackers try to sell the stolen data sometimes before a company even realizes that it has been breached. Or it could be also possible that investors are using private information to trade before the announcement is made similar to the findings of Barclay and Litzenberger (1988) that prices react to new security issue prior to the announcement of the new issue. Even though illegal, trading on private information might be still occurring.

To delve deeper into the issue we examine volatility next. Table 2 Panel B reports standard deviations bid-ask spreads before, during and after the day of the attack for firms with and without an attack. Standard deviation of bid prices, ask prices and traded prices are also reported for comparison and scale purposes. Results appear consistent with the average bid-ask spread findings. The standard deviation value for bid-ask spread before announcement of an attack for firms with an attack is 0.0062, during the attack the value is 0.0072 and after the attack the value is 0.0068. For firms without an attack the values of standard deviation of bid-ask spread are 0.0099, 0.0149 and 0.0169, before, during and after the attack, respectively. Again the matching firms exhibit much higher values for volatility of bid-ask spread. What this means is that volatility seems not to dissipate after the spike of the initial announcement shock for matching firms, i.e. volatility seems to keep rising after the announcement. On the other hand, for attacked firms on the day of the attack volatility increases but then subsides the day after the announcement. This is another indication that the reaction in stock prices of matching firms is stronger than in the firms target of an attack, reinforcing the notion of

rejection of our null hypothesis.

Table 2. Averages and Standard Deviations of Firms with an Attack and Matching Firms Bid, Ask, Traded Prices and Bid-Ask Spreads Before, During and After the Day of the Attack

Panel A. Firms with an Attack and Matching Firms Average Bid, Ask, Traded Prices and Bid-Ask Spreads Before, During and After the Day of the Attack

	before bid	before ask	before price	before bas	during bid	during ask	during bas	after bid	after ask	after price	after bas
UA	14.2417	14.2721	14.2577	0.0021	14.4309	14.4542	0.0016	13.9687	13.9948	13.9808	0.0019
EXPE	111.0258	111.3392	111.1988	0.0028	109.5506	110.4325	0.0080	109.9042	110.1893	110.0282	0.0026
EFX	141.4486	141.7809	141.6512	0.0023	142.4894	142.8749	0.0027	122.2399	123.4045	122.8683	0.0094
UAL	76.4650	76.5257	76.4995	0.0008	77.7020	77.7850	0.0011	78.3269	78.4280	78.3803	0.0013
SABR	23.7479	23.7629	23.7562	0.0006	24.2111	24.2452	0.0014	24.3443	24.3589	24.3512	0.0006
UAL	75.0001	75.0713	75.0410	0.0009	73.1873	73.2817	0.0013	73.1404	73.2460	73.2069	0.0014
SSNC	31.4850	31.5370	31.5131	0.0016	32.0629	32.1134	0.0016	31.8705	31.9395	31.9103	0.0022
AMZN	728.7835	735.4655	734.4044	0.0091	740.8139	746.1411	0.0071	751.3045	755.6409	753.8471	0.0057
VZ	52.9924	53.0035	52.9977	0.0002	53.1470	53.1584	0.0002	53.4481	53.4595	53.4538	0.0002
H	47.8871	48.0570	47.9530	0.0035	48.7812	48.9828	0.0041	48.3990	48.5615	48.4787	0.0033
T	34.6410	34.6517	34.6469	0.0003	34.6047	34.6155	0.0003	34.6302	34.6413	34.6358	0.0003
WMT	73.9306	73.9453	73.9379	0.0002	73.6763	73.6886	0.0002	73.1750	73.1879	73.1806	0.0002
CVS	110.3158	110.3957	110.3656	0.0007	110.0442	110.0928	0.0004	110.6550	110.7011	110.6802	0.0004
AAL	52.4029	52.5118	52.4765	0.0021	49.9737	50.0394	0.0013	50.6418	50.6953	50.6670	0.0011
UAL	65.5571	65.6060	65.5821	0.0007	65.5306	65.5933	0.0010	66.9337	66.9812	66.9550	0.0007
average	109.3283	109.8617	109.7521	0.0019	110.0137	110.4999	0.0022	109.5322	109.9620	109.7749	0.0021
st dev	174.9245	176.6059	176.3422	0.00224	177.9872	179.3262	0.002425	180.4461	181.5407	181.0884	0.002515
min	14.2417	14.2721	14.2577	0.0002	14.4309	14.4542	0.0002	13.9687	13.9948	13.9808	0.0002
max	728.7835	735.4655	734.4044	0.0091	740.8139	746.1411	0.0080	751.3045	755.6409	753.8471	0.0094

	before bid	before ask	before price	before bas	during bid	during ask	during bas	after bid	after ask	after price	after bas
RL	109.3936	110.2592	109.7803	0.0079	111.6250	112.2242	0.0053	108.2205	108.9609	108.6173	0.0068
IAC	160.6523	161.6264	161.2106	0.0060	163.2536	164.1985	0.0058	162.2688	163.8766	163.3313	0.0098
TRU	48.3198	48.4016	48.3583	0.0017	49.0514	49.1700	0.0024	47.1701	47.4551	47.3112	0.0060
DAL	49.1641	49.1801	49.1720	0.0003	49.4716	49.4874	0.0003	49.2066	49.2234	49.2144	0.0003
UBNT	51.8716	52.0628	51.9656	0.0037	51.3133	51.7823	0.0091	50.0023	50.4984	50.3384	0.0098
DAL	50.2487	50.2685	50.2579	0.0004	49.2690	49.2851	0.0003	49.4100	49.4246	49.4176	0.0003
BLUE	69.6987	70.7040	70.2544	0.0142	70.7812	73.4802	0.0367	72.6939	75.2500	73.8380	0.0340
MSFT	51.3085	51.3237	51.3162	0.0003	52.1711	52.1879	0.0003	52.6617	52.6758	52.6678	0.0003
AMT	100.2669	100.7434	100.1030	0.0047	100.0314	100.3116	0.0028	100.3297	100.6833	100.3779	0.0035
STAY	15.9496	15.9817	15.9666	0.0020	16.3023	16.3244	0.0014	16.2787	16.3432	16.3073	0.0039
AMT	95.4529	95.5639	95.2410	0.0012	96.3982	96.5928	0.0020	96.8482	97.0070	96.6096	0.0016
TGT	85.0167	85.0428	85.0303	0.0003	84.7320	84.7577	0.0003	84.4814	84.5165	84.4982	0.0004
WBA	95.4625	95.6261	95.5582	0.0017	95.6689	95.8299	0.0017	95.5212	95.6806	95.6244	0.0017
LUV	41.0713	41.0857	41.0783	0.0003	40.2448	40.2616	0.0004	40.7599	40.7737	40.7668	0.0003
DAL	47.2630	47.2787	47.2705	0.0003	46.1093	46.1280	0.0004	46.7867	46.8090	46.7950	0.0005
average	71.4093	71.6766	71.5042	0.0030	71.7615	72.1348	0.0046	71.5093	71.9452	71.7144	0.0053
st dev	36.27802	36.53403	36.38028	0.003895	36.98869	37.2052	0.009244	36.65187	36.99171	36.84307	0.008635
min	15.9496	15.9817	15.9666	0.0003	16.3023	16.3244	0.0003	16.2787	16.3432	16.3073	0.0003
max	160.6523	161.6264	161.2106	0.0142	163.2536	164.1985	0.0367	162.2688	163.8766	163.3313	0.0340

Panel B. Firms with an Attack and Matching Firms Standard Deviation of Bid, Ask, Traded Prices and Bid-Ask Spreads Before, During and After the Day of the Attack

	before bid	before ask	before price	before bas	during bid	during ask	during bas	after bid	after ask	after price	after bas
UA	0.1000	0.0968	0.0807	0.0063	0.0846	0.0778	0.0047	0.0628	0.0677	0.0498	0.0048
EXPE	0.8958	0.8815	0.5874	0.0083	1.4149	1.4131	0.0182	0.7837	1.0065	0.6736	0.0081
EFX	0.7505	0.4926	0.2142	0.0063	0.9712	1.0683	0.0118	2.6533	2.2160	1.4928	0.0242
UAL	0.3396	0.3116	0.2454	0.0043	0.4327	0.4343	0.0062	0.5670	0.4839	0.4101	0.0065
SABR	0.1038	0.0995	0.0928	0.0024	0.2936	0.2963	0.0068	0.0542	0.0675	0.0496	0.0024
UAL	0.3447	0.2947	0.2500	0.0043	0.6033	0.6429	0.0069	0.4943	0.3124	0.0977	0.0086
SSNC	0.2106	0.2030	0.1657	0.0059	0.2329	0.1806	0.0077	0.2236	0.2040	0.1205	0.0089
AMZN	12.0081	4.4692	1.4238	0.0177	9.4873	7.4581	0.0177	8.3866	6.3653	1.4381	0.0148
VZ	0.0746	0.0744	0.0735	0.0003	0.2986	0.2987	0.0002	0.0965	0.0970	0.0965	0.0001
H	0.2314	0.4001	0.1111	0.0098	0.7076	0.6282	0.0176	0.4037	0.4616	0.1770	0.0131
T	0.0911	0.0938	0.0903	0.0010	0.0604	0.0623	0.0009	0.0738	0.0736	0.0651	0.0018
WMT	0.1472	0.1239	0.0786	0.0022	0.2191	0.2192	0.0002	0.0548	0.0985	0.0542	0.0011
CVS	0.6475	0.3743	0.1502	0.0067	0.3081	0.3249	0.0034	0.4952	0.4097	0.3486	0.0038
AAL	0.9072	0.4617	0.4030	0.0164	0.4458	0.5136	0.0047	0.4933	0.4844	0.4869	0.0018
UAL	0.3877	0.3984	0.3882	0.0014	0.5063	0.5059	0.0013	0.7814	0.7791	0.7790	0.0014
average	1.1493	0.5850	0.2903	0.0062	1.0711	0.9416	0.0072	1.0416	0.8752	0.4226	0.0068
stdev	3.0181	1.0956	0.3471	0.0052	2.3549	1.8391	0.0063	2.1317	1.6165	0.4841	0.0066
min	0.0746	0.0744	0.0735	0.0003	0.0604	0.0623	0.0002	0.0542	0.0675	0.0496	0.0001
max	12.0081	4.4692	1.4238	0.0177	9.4873	7.4581	0.0182	8.3866	6.3653	1.4928	0.0242

	before bid	before ask	before price	before bas	during bid	during ask	during bas	after bid	after ask	after price	after bas
RL	1.1615	1.2758	0.5755	0.0144	0.9586	0.9952	0.0130	1.3342	1.3118	0.9569	0.0126
IAC	1.8811	1.7088	1.2401	0.0122	1.8269	1.2688	0.0132	2.4766	1.7731	0.8368	0.0181
TRU	0.3425	0.3206	0.1388	0.0112	0.3118	0.3620	0.0100	0.6892	0.7828	0.2373	0.0262
DAL	0.1737	0.1791	0.1697	0.0017	0.1024	0.1047	0.0018	0.1453	0.1557	0.1336	0.0022
UBNT	0.6685	0.9804	0.1911	0.0221	1.4365	1.7126	0.0485	1.8346	1.1367	0.1497	0.0444
DAL	0.1784	0.1977	0.1565	0.0032	0.3484	0.3566	0.0023	0.1446	0.1395	0.1333	0.0017
BLUE	1.9619	2.0660	0.9705	0.0364	4.0372	3.9597	0.0841	3.2657	3.8812	0.4300	0.0793
MSFT	0.1467	0.1332	0.1323	0.0013	0.1818	0.1769	0.0016	0.0682	0.0657	0.0620	0.0008
AMT	1.2000	1.8220	0.3429	0.0175	0.8362	1.5514	0.0138	1.1847	1.4517	0.2638	0.0208
STAY	0.1562	0.1289	0.1101	0.0103	0.0730	0.0780	0.0032	0.1604	0.2109	0.0229	0.0203
AMT	1.3325	1.6084	0.4475	0.0062	1.4514	1.9360	0.0149	1.3887	1.7420	0.4540	0.0103
TGT	0.2399	0.2224	0.1914	0.0022	0.1421	0.1751	0.0021	0.2488	0.2491	0.1733	0.0031
WBA	0.8187	0.6551	0.5110	0.0088	0.6659	0.5813	0.0094	0.7004	0.2411	0.1488	0.0076
LUV	0.2912	0.2942	0.2924	0.0003	0.2088	0.1578	0.0035	0.5482	0.5486	0.5484	0.0004
DAL	0.3494	0.3552	0.3520	0.0005	0.2134	0.2441	0.0024	0.5044	0.5654	0.5043	0.0054
average	0.7268	0.7965	0.3881	0.0099	0.8530	0.9107	0.0149	0.9796	0.9504	0.3370	0.0169
stdev	0.6344	0.7105	0.3290	0.0099	1.0465	1.0585	0.0225	0.9463	1.0093	0.2802	0.0211
min	0.1467	0.1289	0.1101	0.0003	0.0730	0.0780	0.0016	0.0682	0.0657	0.0229	0.0004
max	1.9619	2.0660	1.2401	0.0364	4.0372	3.9597	0.0841	3.2657	3.8812	0.9569	0.0793

Maybe we do not document any reaction in the stock prices and bid-ask spreads of target firms because we are examining the event in very aggregate terms, at the stock price level. Therefore, next we examine the response to the announcement of security breaches at a market microstructure level. We proceed by studying the components of the bid-ask spread next. The adverse selection and inventory holding cost components of the bid-ask spread of firms' target of a breach and matching firms are presented in Table 3. The average adverse selection and inventory holding cost component of the bid-ask spread for firms with a breach on the day of the attack is 0.8207 whereas the same component for matching firms is higher at 0.8393; this is different in the sense that on both the day before and the day after the attack this component for attacked firms is higher than the component for matching firms.

Table 3. Adverse Selection and Inventory Holding Cost (ASIHC) Component of the Bid-Ask Spread Estimated Based on Equation (1)

	Firms with a Security Breach				**Firms without a Security Breach**		
	before	day of	after		before	day of	after
UA	0.8839	0.7867	0.8270	RL	0.9101	0.8944	0.8482
EXPE	0.8486	0.8198	0.7653	IAC	0.7356	0.5992	0.7355
EFX	0.7936	1.7583	0.5597	TRU	0.9979	0.9205	0.8153
UAL	1.2279	0.9381	1.0780	DAL	0.9893	0.7651	0.8210
SABR	0.7168	0.9408	0.8637	UBNT	1.0780	0.8768	1.0095
UAL	0.9455	0.9059	1.1473	DAL	0.6447	1.2850	1.0934
SSNC	0.7986	0.9330	0.7080	BLUE	0.8753	0.8215	0.8825
AMZN	0.7579	0.7354	0.7092	MSFT	1.0514	0.8046	0.8210
VZ	0.2749	0.3745	0.1976	AMT	0.7345	0.2034	0.2666
H	1.0638	0.9525	0.8341	STAY	1.4508	0.5127	0.4549
T	1.4044	0.0608	1.0261	EQIX	0.7996	1.0151	1.0669
WMT	0.9921	0.2892	1.1675	TGT	0.8055	0.9774	1.1640
CVS	1.1008	1.0194	1.1256	WBA	0.9055	0.9116	1.1228
AAL	0.9354	1.0269	0.9250	LUV	0.6025	0.8945	0.6523
UAL	0.5536	0.7688	0.9574	DAL	0.6179	1.1083	1.0567
average	0.8865	0.8207	0.8594		0.8799	0.8393	0.8540
stdev	0.2708	0.3869	0.2566		0.2198	0.2557	0.253519
min	0.2749	0.0608	0.1976		0.6025	0.2034	0.2666
max	1.4044	1.7583	1.1675		1.4508	1.2850	1.1640

Regression results based on equation (2) with the average bid-ask spread (mbas): standard deviation of the bid-ask spread (sdbas) and adverse selection and inventory holding cost component (asihcc) of the bid-ask spread as dependent variables are reported in Table 4 Panels A, B and C, respectively. The results, suggest that market cap is the only factor affecting the average bid-ask spread after the attack, and the higher the market cap the lower the spread, i.e. the lower the market cap the higher the spread. What this implies is that matching firms being smaller than the target of an attack firms tend to get affected more than the firms target of the attack. This is indicated in the table by the statistical significance of the market cap variable and lack of significance of the dummy variable WSB, which has the value of one for firms with security breach and zero otherwise. This finding is consistent with the findings of Muntermann and Guettler (2007) that larger firms' stock prices have a weaker price reaction to corporate news than smaller firms.

Similarly, when the standard deviation of the bid-ask spread is examined, the smaller firms and matching firms experience higher volatility in the bid-ask spread after the attack relative to the firms target of the attack. Additionally, the only factor affecting the component of the bid-ask spread on the day of a security breach is a company's market capitalization rather than the security breach announcement. This is indicated by the lack of statistical significance in the WSB variable (even though having the correct sign): which points towards rejection of our null hypothesis of a stronger negative stock price reaction to the announcement of a security breach by a firm. This is in direct contrast to the findings of studies by Patell and Wolfson (1984): Barclay and Litzenberger (1988): Huberman and Regev (2001): Kalev, Liu, Pham and Jarnecic (2004): Vega (2006) and Muntermann and Guettler (2007): among many, of almost immediate stock price reaction to the announcement of a corporate event.

Table 4. Regression Results

Panel A. Average Bid-Ask Spread

Dependent Variable: MBAS	Before		During		After	
	coef	p-value	coef	p-value	coef	p-value
Intercept	0.0103	0.1422	0.0226	0.1263	**0.0276**	**0.0457**
lmc	-0.0004	0.2910	-0.0011	0.2167	**-0.0013**	**0.0995**
wsb	-0.0010	0.3758	-0.0023	0.3640	-0.0029	0.2019
N		30		30		30
R-sq		0.0724		0.0884		0.1545

Panel B. Standard Deviation of Bid-Ask Spread

Dependent Variable: SDBAS	Before		During		After	
	coef	p-value	coef	p-value	coef	p-value
Intercept	**0.0363**	**0.0366**	**0.0714**	**0.0473**	**0.0821**	**0.0151**
lmc	-0.0016	0.1187	-0.0033	0.1092	**-0.0038**	**0.0475**
wsb	-0.0034	0.2421	-0.0071	0.2388	**-0.0094**	**0.0937**
N		30		30		30
R-sq		0.1374		0.1422		0.2249

Panel C. Adverse Selection and Inventory Holding Cost Component

Dependent Variable: ASIHCC	Before		During		After	
	coef	p-value	coef	p-value	coef	p-value
Intercept	**1.2354**	**0.0286**	**2.0569**	**0.0052**	0.7258	0.2030
lmc	-0.0209	0.5083	**-0.0715**	**0.0808**	0.0075	0.8182
wsb	0.0106	0.9081	-0.0049	0.9662	0.0040	0.9672
N		30		30		30
R-sq		0.0166		0.1094		0.0021

CONCLUSIONS

The purpose of this study is to examine, on intradaily basis, fifteen recent occurrences of corporate security breaches and assess the impact on shareholder wealth before, during and after the event of announcement of the breach. To the best of our knowledge this has not been done in the market efficiency literature so far. We document, on intradaily basis, minor price responses to announcements of a security breach in the firms' target of

an attack, with only five out of fifteen firms showing a price drop. EXPE, UAL (January 2017 announcement): WMT and AAL exhibit a price decline but not an abrupt price drop as observed for EFX after the announcement. The findings in this study, documented on intradaily basis, are somewhat in agreement with the findings of Hovav and D'Arcy (2003) and Kannan, Rees and Sridhar (2007) who document no stock market reaction associated with security breaches of target firms on daily basis. This is in direct contrast to the findings of many studies of an immediate stock price reaction to the announcement of a corporate event such as the studies by Patell and Wolfson (1984): Barclay and Litzenberger (1988): Huberman and Regev (2001): Kalev, Liu, Pham and Jarnecic (2004): Vega (2006) and Muntermann and Guettler (2007.

Surprisingly, we also document that the matching firms in our study seem to respond to the attack instead. The matching firms exhibit higher levels of volatility and higher levels of average adverse selection and inventory holding cost component of the bid-ask spread. The reason for this could be that typically the industry leaders are the target of the attack and thus in multivariate setting market capitalization seems to be an important factor affecting average bid-ask spreads, volatility and the formation of the bid-ask spread and not the security breach. This finding is consistent with the findings of Muntermann and Guettler (2007): even though their study focuses on German stock markets, that stock prices of larger firms have a smaller reaction to corporate news than smaller firms' prices.

A major limitation of this study is that it focuses on only 15 breaches and 15 matching firms. Unfortunately, the NYSE TAQ data available to us covers the period 2015-2018 so we cannot cover security breaches, which have occurred prior to 2015. The 15 firms target of an attack and the 15 matching firms are sufficient for statistical analysis, however, we intend to extend the study once more breaches occur after the end of the study in March of 2018. Another limitation of this study is in the use of intradaily data over a three-day window around the announcement of a security breach. Potentially, it might take longer for the announcement to be incorporated in the price. Alternatively, the market could have figured out that the firm has been attacked earlier than the announcement of the attack and the price could have adjusted many days before the announcement.

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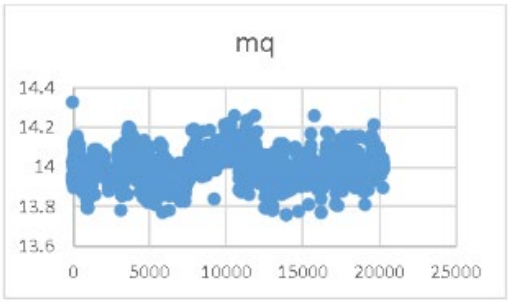
Appendix



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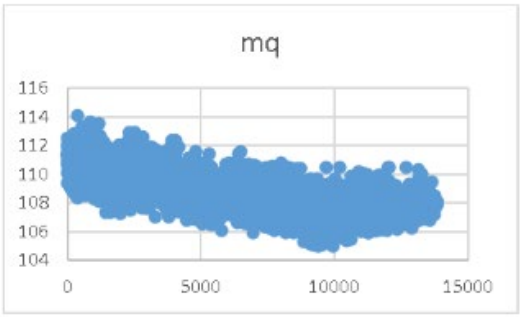

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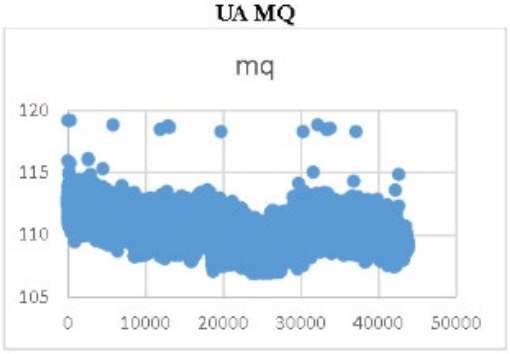

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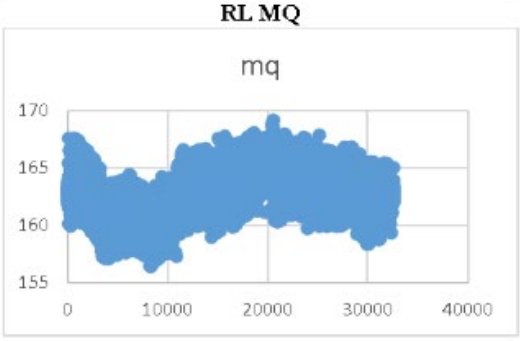

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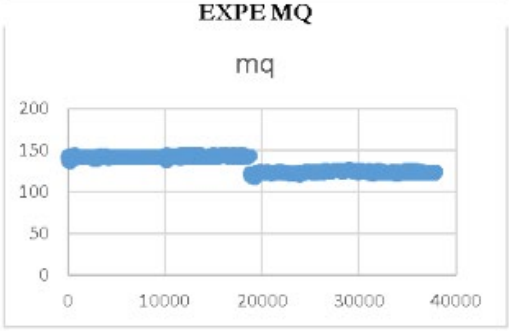
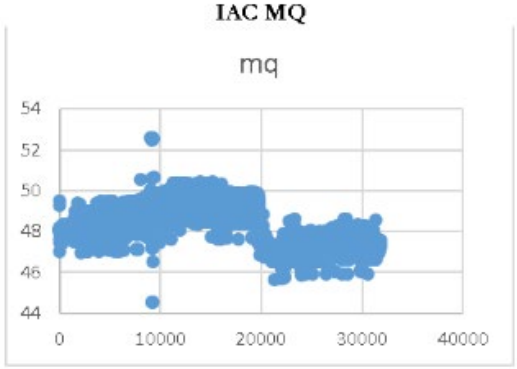


EFX MQ



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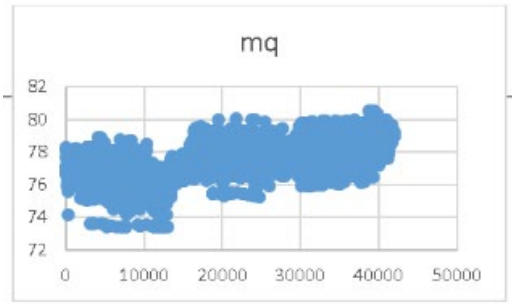

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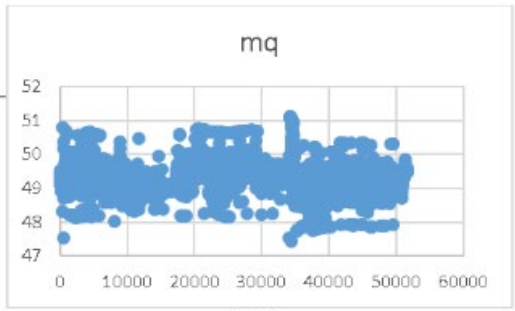
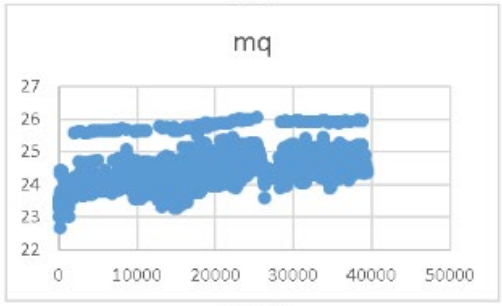


DAL



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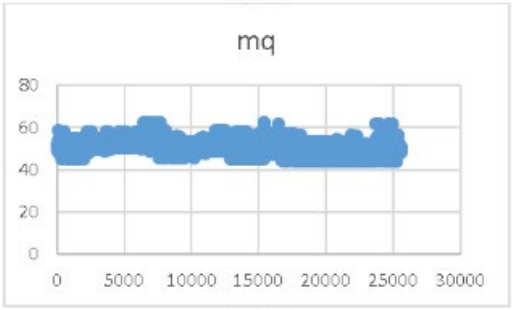

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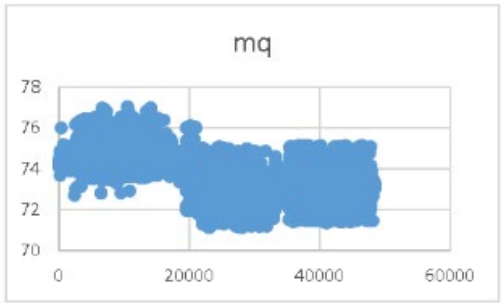

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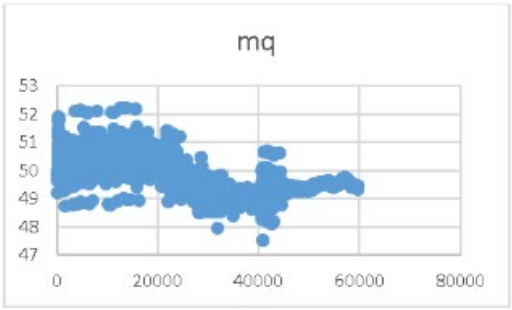

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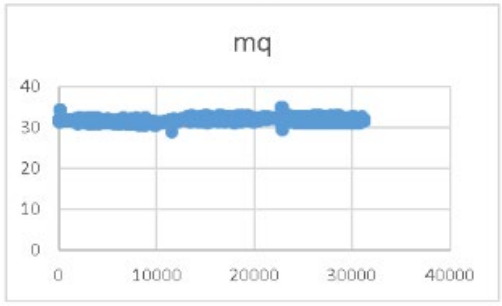

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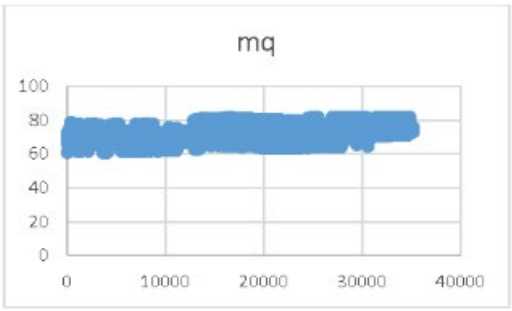

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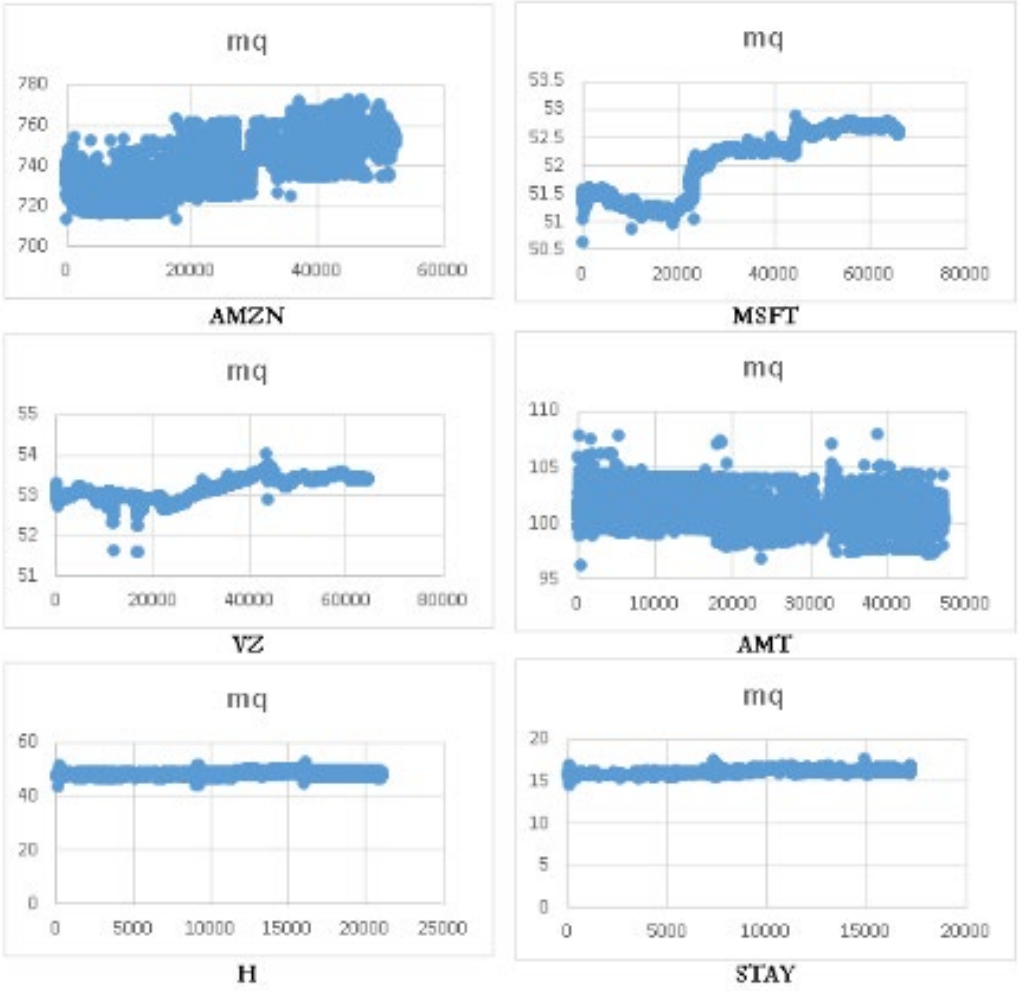
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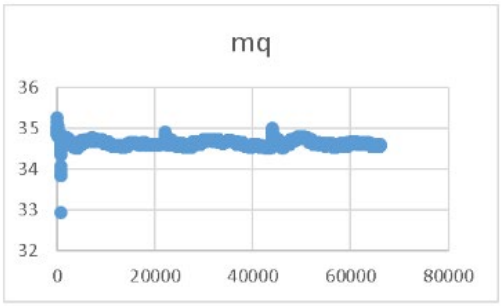

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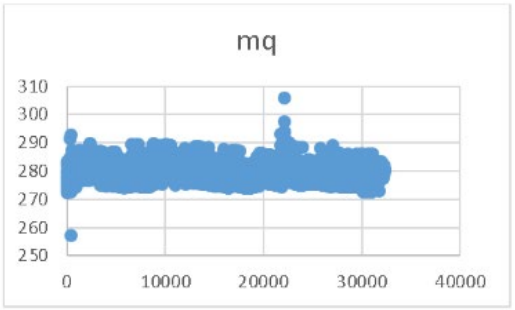

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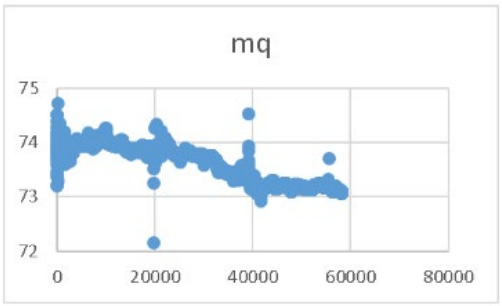

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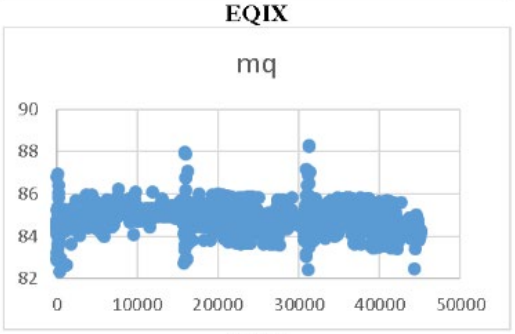

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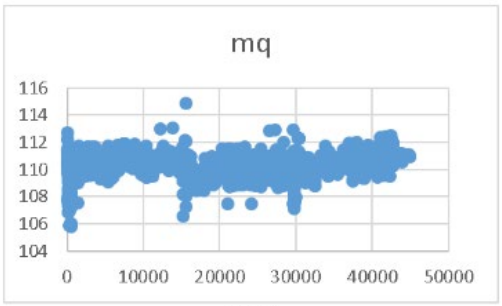
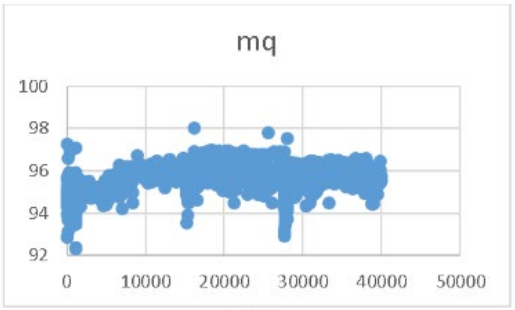


CVS



WBA