

The Anatomy of Cyber Risk

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Merkel blames Russia for 'outrageous' cyberattack on German parliament

German chancellor says that 2015 hacking attack negatively affects relations with Moscow.

WannaCry cyber-attack cost the NHS £92m after 19,000 appointments were cancelled

Chinese military hackers charged with Equifax cyber attack that hit 15m Britons

Members of People's Liberation Army's hacking unit face US charges over 2017 hack

US Treasury department officials subject to hacking campaign

Department confirms breach as attorney-general says Russia likely culprit behind attack

General election 2019: Labour Party hit by second cyber-attack

© 12 November 2019

More than one in four UK cyber attacks related to Covid-19

National centre's findings come days after US warned of threat to hospitals from hackers

Vaccines for sale on dark web as criminals target pandemic profits

Cyber attacks on vaccine infrastructure have been widely documented, with theft and fraud expected to rise

Pfizer/BioNTech say EMA breach exposed vaccine documents

Companies say records related to regulatory submission 'unlawfully accessed' on EU regulator's server

“The ESRB has identified cyber risk as a source of systemic risk to the financial system, which may have the potential for serious negative consequences for the real economy”

— European Systemic Risk Board, 2020

“Cyber risk has become a key issue for stakeholders in the financial system. But its properties are still not precisely characterized and well understood.”

— Carnegie Endowment for International Peace, 2019

“The ability of entities to prepare for the consequences of systemic risk and build common processes, capabilities and capacity to enhance their cyber resilience, and ensure they are able to recover from a systemic cyber event, is therefore more important than ever.”

— World Economic Forum, 2017

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 - 12,000+ firms, 80+ countries, 20+ years, quarterly frequency
- Context
 - Assess **sentiment**: positive or negative
 - Categorize by **topic**: monetary loss, insurance and legal, global event, etc
 - Identify spoken **country names**: North Korea, China, Russia, Israel, Iran

Main Findings

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- Asset pricing
 - Direct and **contagion effects** on stock returns and volatility
 - CyberE - **new factor** for pricing stock portfolios

Textual combinations: “cyber security”, “cyber risk”, “cyber attack”, “cyber threat”, “spyware”, “ransomware”, “malware”, “phishing”, “data breach”, “data loss”, “hacked”, “DDOS attack”, “information theft”, etc (more on next slide)

$$\text{CyberExposure}_{it}^c = \frac{1}{N_{it}} \sum_{j=1}^{J_{it}} \mathbb{1}[j = \text{Cyber}^c]$$

- Count the number of times each term (c) occurs in each transcript and quarter (it)
- Sum the number of mentions per (it) and normalize by total words (N)
- Aggregate (unweighted average) and standardize

Cyber Risk Terms

Sub-Category	Terms
Cyber	cyber, cybersecurity, network security, cyber-attack, cybercrime, cyber threat, cyber incident, cyber event
Data	data loss, data integrity, data security, information theft, data breach, data theft, data leak, data compromise, data fraud
Malware	worm, spyware, phishing, trojan, malware, ddos attack, ransomware
Fraud	hacker, hack, hacked, card fraud, card breach, system outage, email compromise

Note: We follow the Cyber Policy Initiative of the Carnegie Endowment for International Peace to identify relevant terms

Measurement - Context and Topics

- Capture context of each cyber related chatter
- Identify cyber bigrams “c” that are **within 50 words** of any topical word of interest “s”
- **Country names**: “Russia”, “China”, “North Korea”, “Israel”, “Iran”
- **Monetary loss**: “cost”, “loss”, “income”, “reputation”, “damage”, “recover”
- **Sentiment**: positive (“strong”, “great”) or negative (“decline”, “difficult”)
- More in paper!

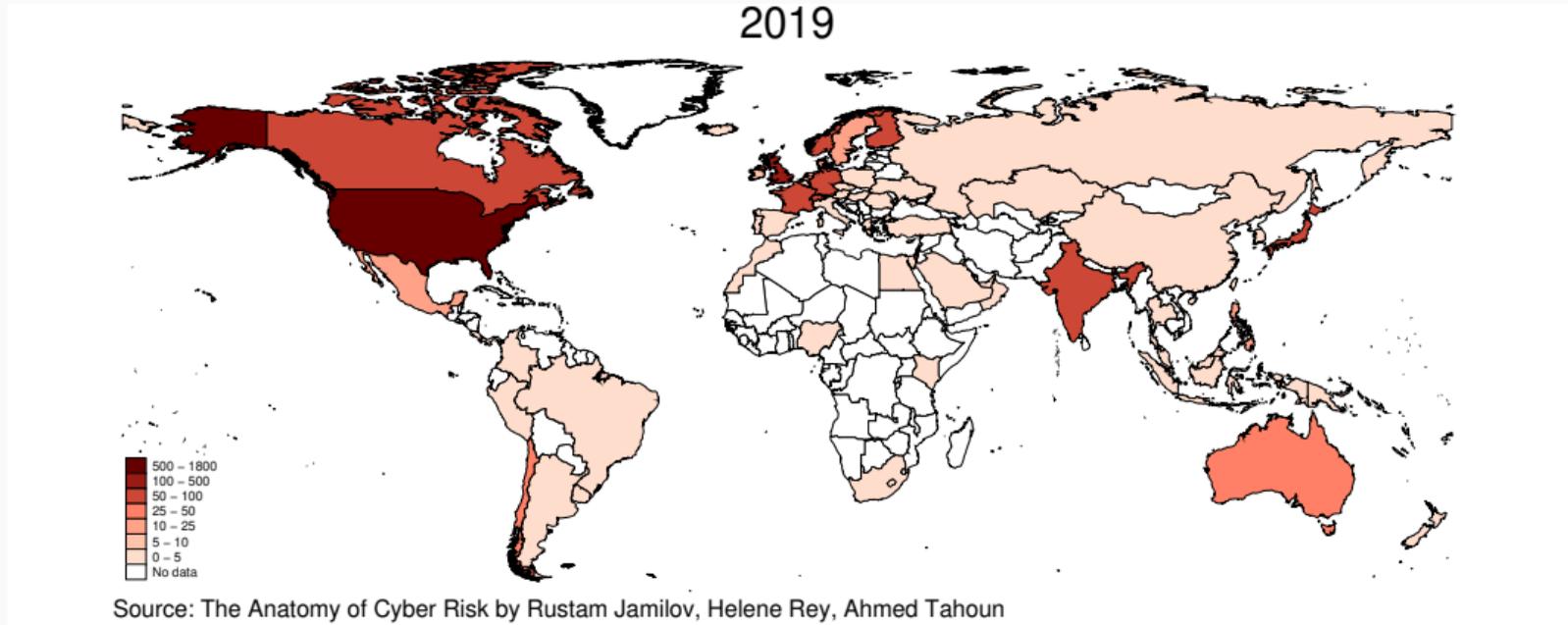
$$\text{CyberTopic}_{it}^c = \frac{1}{N_{it}} \sum_{j=1}^{J_{it}} \{ \mathbb{1}[j = \text{Cyber}^c] \times \mathbb{1}[|j - s| < 50] \}$$

Company	Date	Exposure	Sentiment	Excerpt	Comment
Equifax	10.11.2017	10	-10	...given the impact of –cyber– it is a little more ((difficult)) right now to give ...of the cybersecurity incident These costs were generally for legal –cyber– forensic investigations and other professional services million in accrued expenses ...do we have insurance to cover costs in connection with the – databreach– ((breach)) ((incidents)) with limits in excess of the current amount ...as ((opposed)) to being ...the type of cost that we've incurred	In March 2017, personally identifying data belonging to 147+ million of people was stolen. Incident lead to the company agreeing to a global settlement with the Federal Trade Commission, the Consumer Financial Protection Bureau, and 50 U.S. states and territories. By most accounts, the largest data breach in U.S. commercial history

Company	Date	Exposure	Sentiment	Excerpt	Comment
Target	26.02.2014	19	-19	performance along with costs related to our recent ((restructuring)) and -databreach- ((breach)) along with small accounting and tax matters As weve ...of the recent ((slow-down)) in growth weve seen following the -databreach- ((breach)) In Canada in we generated just over billion in ...headwind and we continue to see the impact of the -databreach- ((breach)) on guest sentiment and traffic We believe that well ...(beneficial) interest asset and any potential costs related to the -databreach- ((breach)) While this has been a ((challenging)) year we are	Over 100 million individuals were exposed in the attack. Target reported that the information compromised in the attack included mailing addresses, names, email address, phone numbers, and credit and debit card account data.

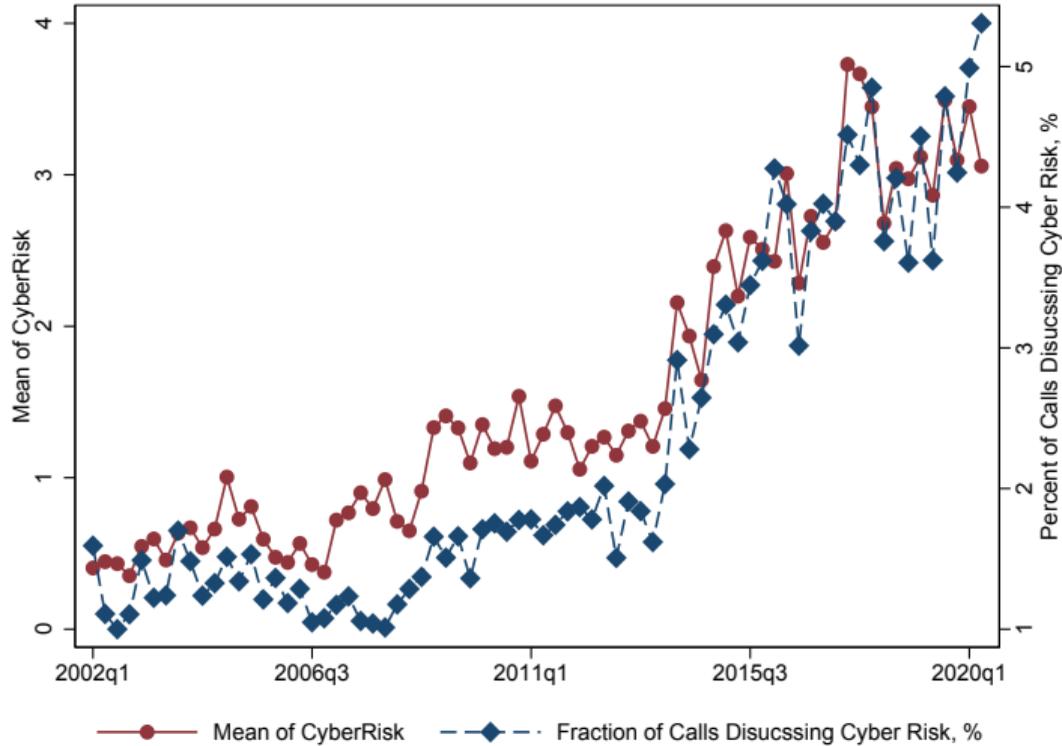
Company	Date	Exposure	Sentiment	Excerpt	Comment
Capital One	24.10.2019	6	-5	And finally we recognized million of charges associated with the -cyber- ((incident)) that we announced at the end of July These ...to million in certain incremental direct costs associated with the -cyber- ((incident)) response and that we expected to record these costs ...expect to make incremental investments in cybersecurity related to the -cyber- ((incident)) and we expect to absorb the estimated incremental investments ...Sanjay with respect to the public cloud and then the -cyber- ((incident)) while the event occurred in the cloud the ((vulnerability))	An outside individual gained unauthorized access and obtained certain types of personal information about Capital One credit card customers and individuals who had applied for our credit card products. The event affected approximately 100 million individuals in the United States and approximately 6 million in Canada.

Global Cyber Risk Exposure: Heatmap

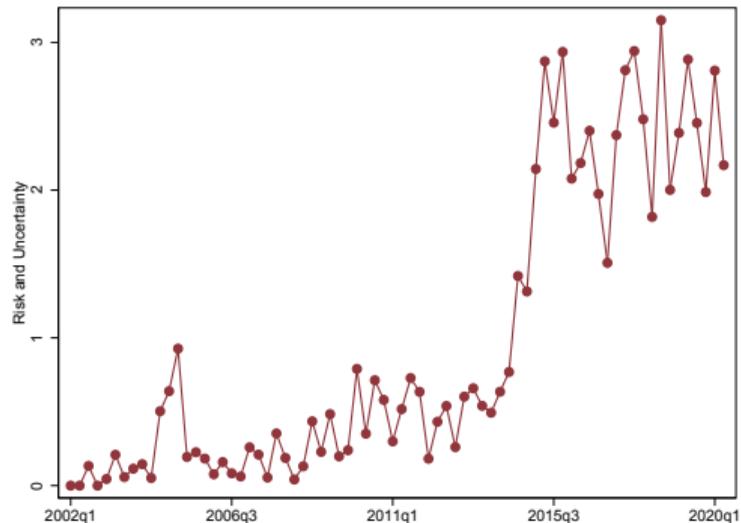


Note: CyberExposure index, aggregated by country for 2019

Global Cyber Risk Exposure: Time Series

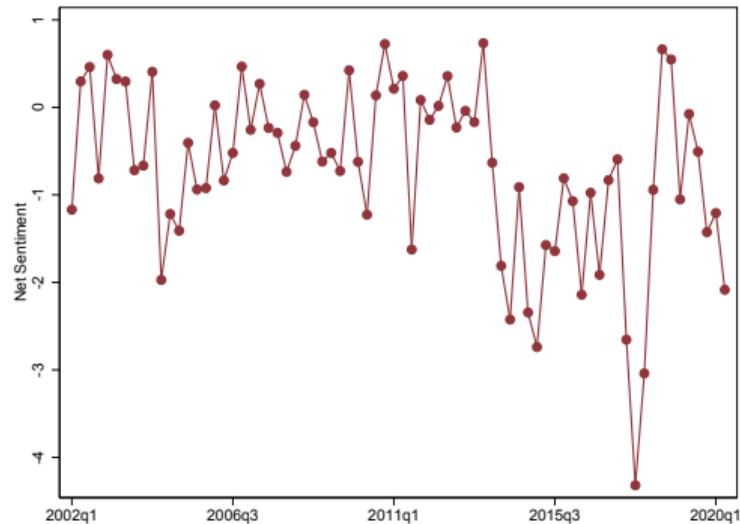


Context: Risk and Sentiment



(a) Risk and Uncertainty

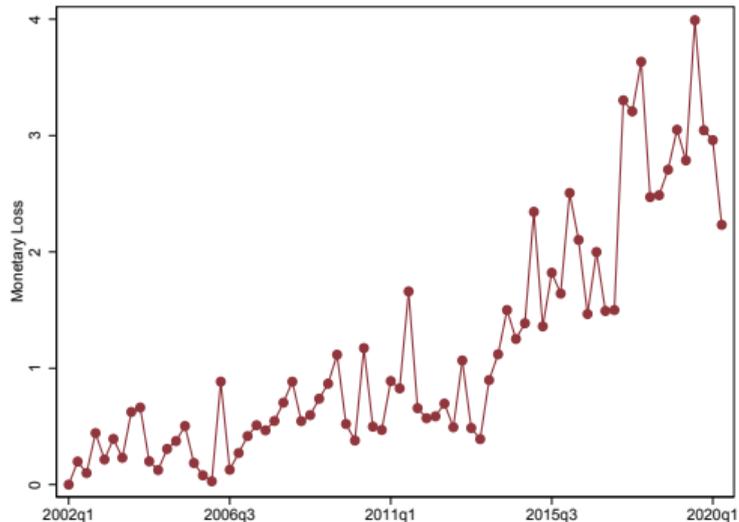
Terms: risk, risks, uncertainty, variable, chance, possibility, pending, uncertainties, uncertain, etc.



(b) Net Sentiment = Positive - Negative

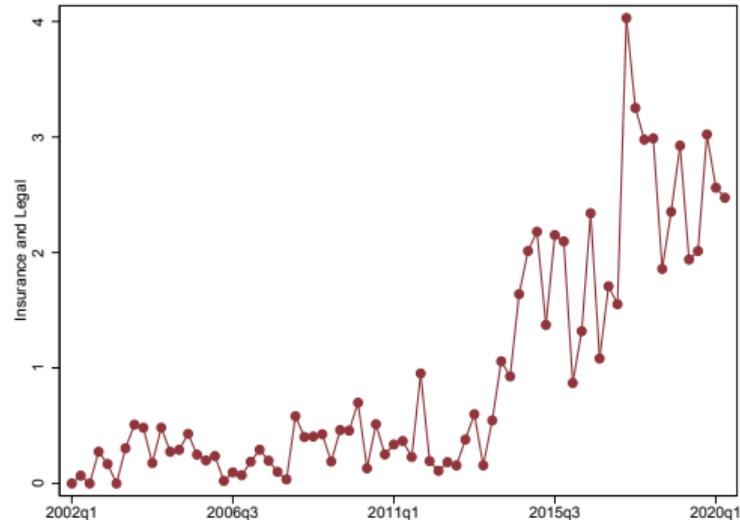
Positive terms: good, strong, great, better, opportunities, able, positive, etc.; Negative terms: decline, difficult, against, negative, restructuring, challenges, etc.

Context: Monetary Loss and Insurance



(a) Monetary Loss

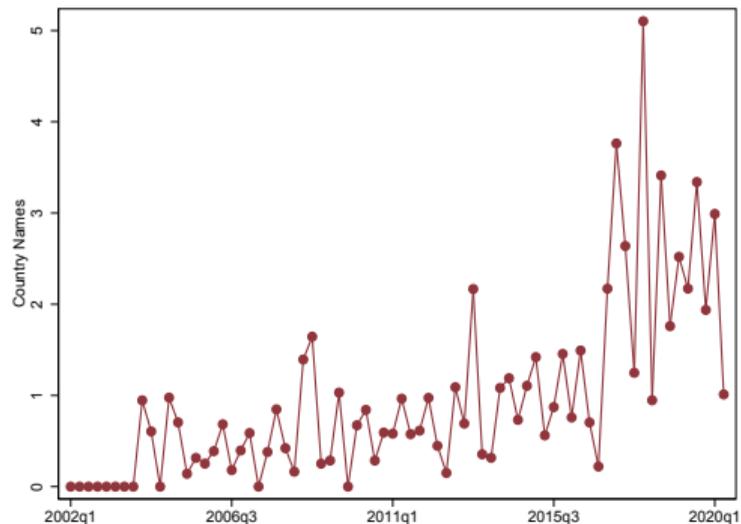
Terms: loss, cost, income, reputation, monetary, damage, re-cover



(b) Insurance and Legal

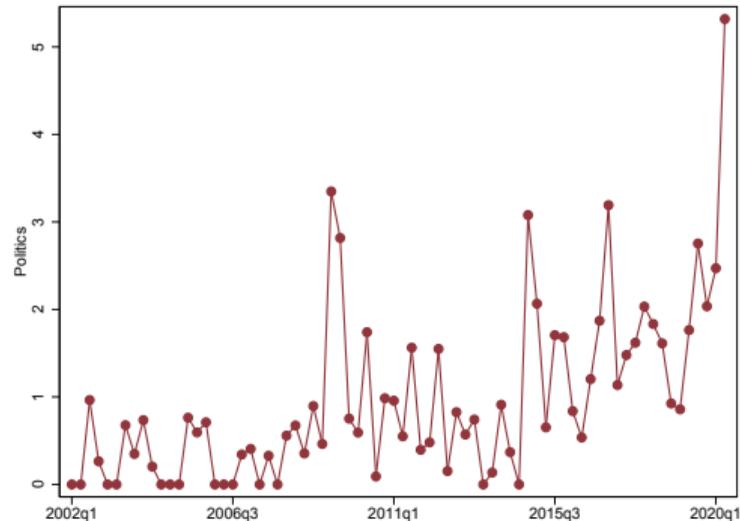
Terms: insurance, liability, coverage, cover, policy, legal, law, settle, settlement

Context: Country Names and Politics



(a) Country Names

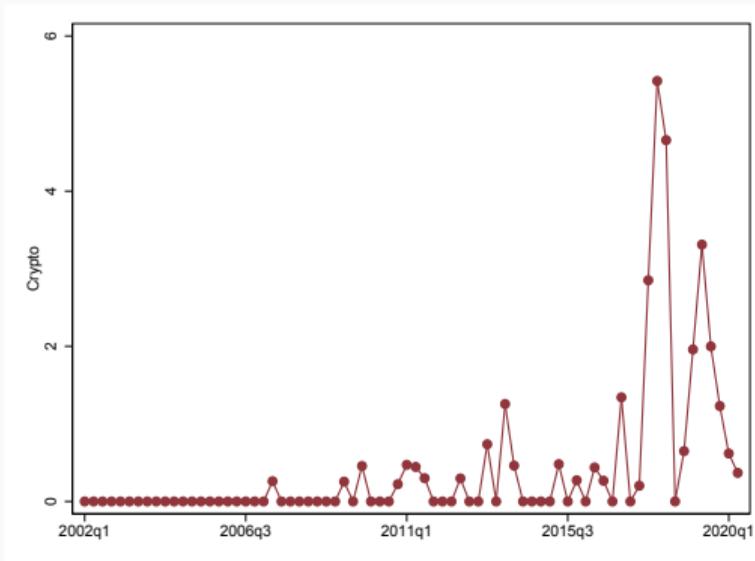
Terms: Russia, Russian, China, Chinese, North Korea, North Korean, Israel, Israeli, Iran, Iranian



(b) Politics

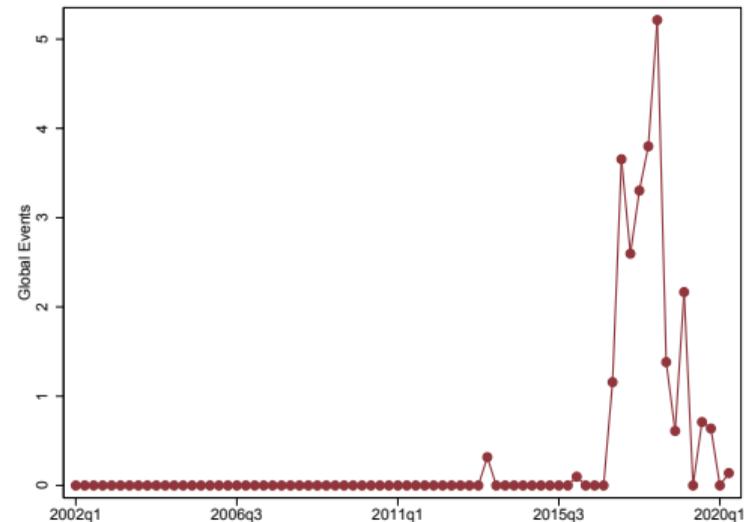
Terms: election, state, sponsor, state sponsored, state-sponsored, espionage

Context: Crypto and Global Incidents



(a) Crypto

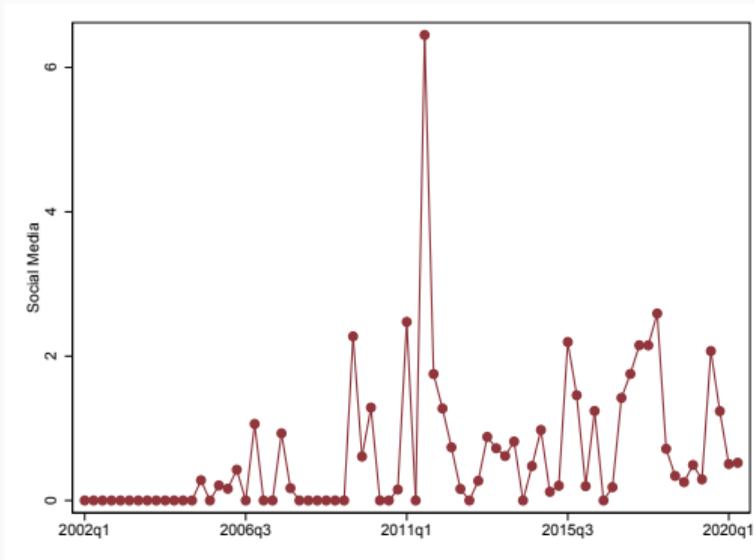
Terms: crypto, crypto currency, cryptocurrency, ledger, cryptography, blockchain, bitcoin, altcoin, token, ethereum, ripple, litecoin, tether, libra, monero, diem



(b) Global Incidents

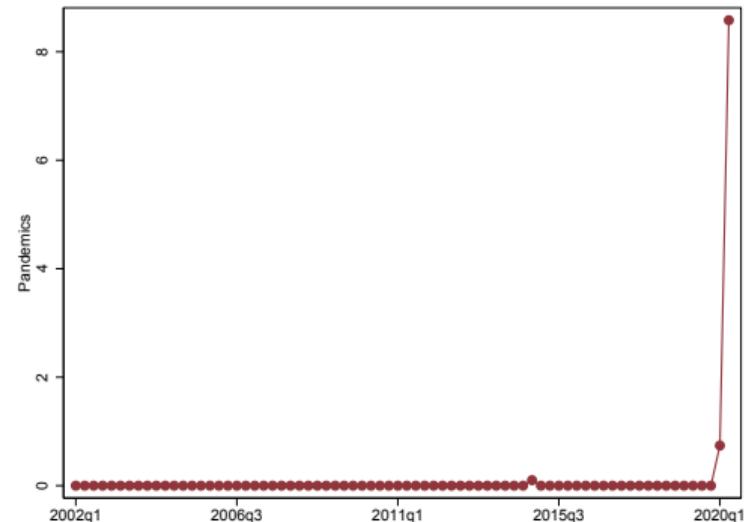
Terms: GDPR, Cambridge, Cambridge Analytica, Notpetya, Wannacry

Context: Social Media and Pandemics



(a) Social Media

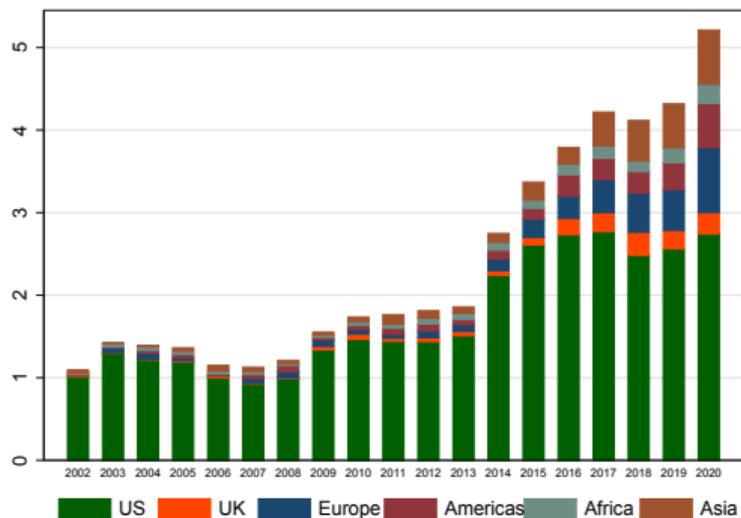
Terms: Zoom, webex, hangouts, Facebook, Google, Twitter, Bing, Snapchat, LinkedIn, MailChip, Baidu, Tencent, Weibo, Yandex, Rambler, Line, whatsapp



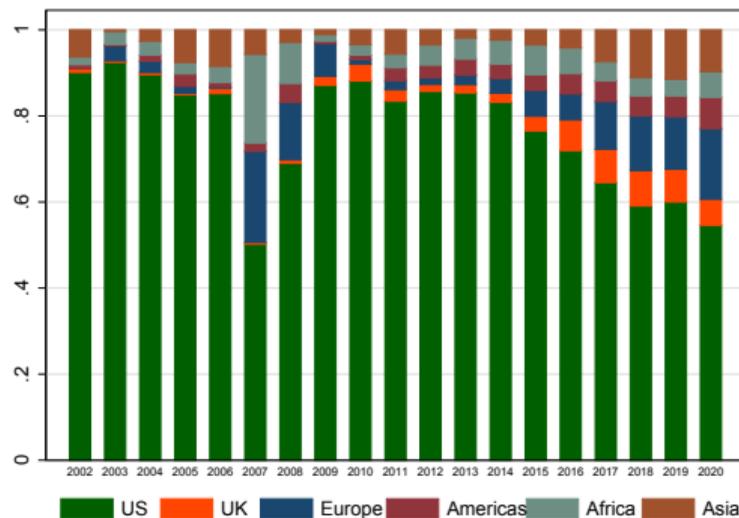
(b) Pandemics

Terms: corona, coronavirus, corona virus, covid, sars

Decomposition by Region

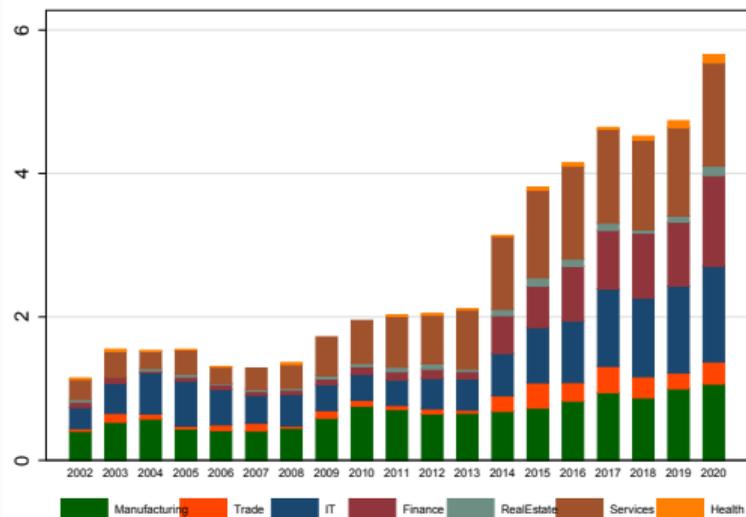


(a) Percent of Calls Discussing Cyber Risk, by Region

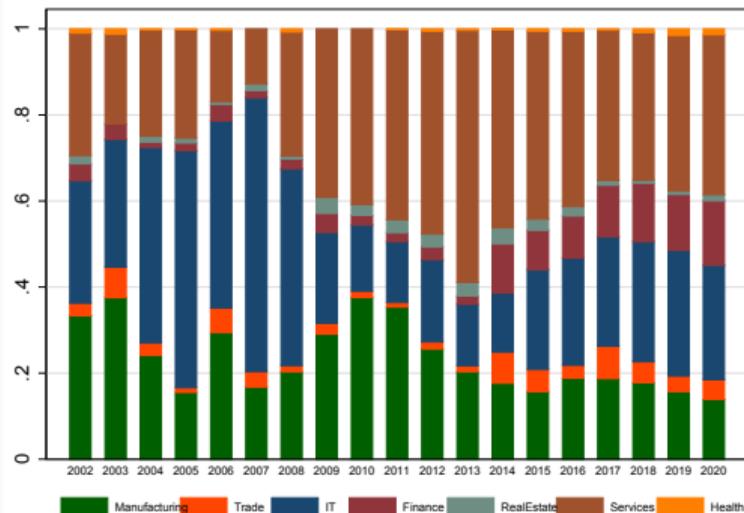


(b) % of All Cyber Risk Discussions, by Region

Decomposition by Industry



(a) Percent of Calls Discussing Cyber Risk, by Industry



(b) % of All Cyber Risk Discussions, by Industry

Determinants of Firm-Level Cyber Risk Exposure

Probit Model	Dependent Variable: Firm-Level Indicator of Cyber Risk Exposure					
	(1)	(2)	(3)	(4)	(5)	(6)
	Total Exposure	Risk	Pos. Sentiment	Neg. Sentiment	Country Names	Pandemics
PP&E / Assets	0.3174 (0.2773)	-0.0166 (0.6211)	0.7522** (0.3203)	0.3184 (0.3021)	-1.4299** (0.5565)	-0.8180 (0.9333)
Intangibles / Assets	1.0436*** (0.1981)	1.1200*** (0.3568)	1.2796*** (0.2349)	1.0140*** (0.2513)	-0.0780 (0.5100)	0.1824 (0.8689)
Liquidity	0.6533*** (0.2475)	0.6190 (0.4732)	0.8040*** (0.2749)	0.9111*** (0.2773)	0.6897 (0.7469)	0.6298 (0.9792)
Log (size)	0.1340*** (0.0182)	0.1199*** (0.0318)	0.1243*** (0.0206)	0.1157*** (0.0231)	0.1606*** (0.0402)	0.0762 (0.0580)
Debt / Assets	-0.5128* (0.3104)	-0.0942 (0.7485)	-0.5298 (0.3824)	-0.4341 (0.4158)	-2.2142 (1.6210)	-4.3139* (2.5995)
Log (age)	-0.0122 (0.0823)	-0.0821 (0.1482)	-0.0731 (0.0970)	-0.0939 (0.1062)	0.3446 (0.2196)	1.0180** (0.4254)
ROA	1.7342 (1.5512)	2.0429 (2.4339)	-0.0310 (2.2917)	0.9963 (2.2038)	-2.9691 (4.0298)	-2.0587 (7.0177)
S&P Rating	0.0133 (0.0181)	0.0174 (0.0386)	0.0161 (0.0210)	0.0119 (0.0212)	0.0007 (0.0383)	0.0020 (0.0573)
Sales / Assets	1.5592* (0.8117)	-0.8245 (1.8714)	1.2149 (0.9898)	1.0772 (1.2390)	-0.8586 (1.6291)	-7.9234*** (2.9788)
Tobin's Q	0.0205 (0.0207)	0.0298 (0.0391)	0.0100 (0.0265)	-0.0132 (0.0350)	0.0711** (0.0361)	0.0224 (0.0434)
Operation Costs / Assets	-1.1786 (0.8236)	1.0940 (1.8716)	-0.6515 (0.9977)	-0.7925 (1.2539)	0.0357 (1.5849)	7.9263*** (3.0319)
Market Beta	-0.0192 (0.0358)	0.0453 (0.0703)	-0.0218 (0.0467)	-0.0049 (0.0442)	0.1553 (0.1135)	-0.1577 (0.2157)
Quarter fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	71872	41053	67145	68757	24331	2361
pseudo R ²	0.227	0.241	0.215	0.231	0.162	0.249

Note: Standard errors are clustered at the firm level. *, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Determinants of Firm-Level Cyber Risk Exposure (Continued)

Probit Model	Dependent Variable: Firm-Level Indicator of Cyber Risk Exposure					
	(7)	(8)	(9)	(10)	(11)	(12)
	Crypto	Insurance & Legal	Monetary loss	Social media	Global Events	Politics
PP&E / Assets	1.4477 (0.9977)	1.3429*** (0.3972)	0.5326 (0.3786)	1.2428 (1.4891)	-10.8338 (10.3080)	0.2090 (0.5486)
Intangibles / Assets	0.7724 (0.4723)	1.6440*** (0.2909)	1.2027*** (0.2980)	1.4237 (1.0077)	-4.0946** (1.9762)	1.3872*** (0.4525)
Liquidity	-0.6139 (1.1085)	0.6427* (0.3792)	0.7575** (0.3261)	1.2297 (1.0809)	-4.6583** (2.2841)	1.5325** (0.6829)
Log (size)	0.1272 (0.1054)	0.1327*** (0.0270)	0.0900*** (0.0241)	0.1183** (0.0569)	0.4703* (0.2766)	0.0649* (0.0359)
Debt / Assets	1.6408 (1.0044)	-0.3758 (0.5608)	-0.7565 (0.5352)	-1.5820 (2.6483)	-18.9469* (10.1898)	-0.1674 (0.8345)
Log (age)	-0.3022 (0.2280)	0.0129 (0.1493)	0.0777 (0.1066)	0.1353 (0.2283)	0.7652 (0.5364)	0.0765 (0.1854)
ROA	3.2724 (3.3084)	4.0679** (2.0494)	3.2508 (2.0088)	2.7640 (1.8588)	-101.5248 (84.9096)	0.0117 (1.6888)
S&P Rating	-0.0709 (0.0742)	0.0538** (0.0269)	0.0522** (0.0255)	-0.0611 (0.0628)	0.0720 (0.1163)	-0.0341 (0.0297)
Sales / Assets	3.8379 (3.2035)	1.1792 (2.0216)	0.7638 (1.7922)	-0.1817 (3.9810)	3.7960 (9.7856)	0.3261 (1.4191)
Tobin's Q	-0.2769* (0.1530)	0.0263 (0.0419)	-0.0324 (0.0511)	-0.1021 (0.1194)	-0.4238* (0.2182)	-0.0405 (0.0585)
Operation Costs / Assets	-3.3168 (3.3098)	-0.7857 (2.0307)	-0.5552 (1.7958)	1.3441 (3.9936)	10.6942 (6.8290)	0.1617 (1.4567)
Market Beta	-0.0580 (0.1568)	-0.0148 (0.0685)	-0.0420 (0.0482)	-0.0077 (0.1207)	0.4286 (0.2722)	0.0964 (0.0757)
Quarter fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	5399	40576	59885	7484	766	29255
pseudo R ²	0.174	0.207	0.197	0.192	0.452	0.165

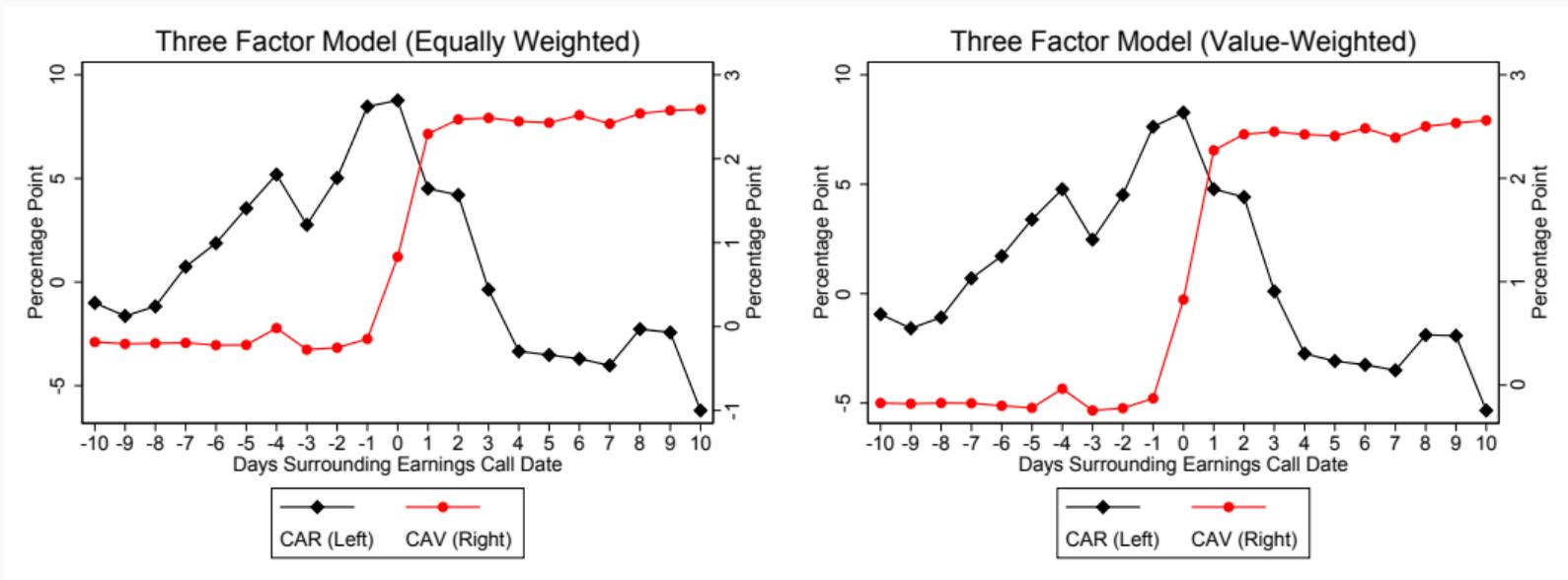
Note: Standard errors are clustered at the firm level. *, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Predicting Future Cyber Attacks

Logit Model	Dependent Variable: Firm-Level Indicator of Being Cyber Attacked in t+8 Quarters							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Total Exposure	0.0700** (0.0276)	0.0658** (0.0275)						
Risk			-0.2029 (0.4072)					
Pos. Sentiment				0.0977 (0.0997)				
Neg. Sentiment					0.0624** (0.0271)			
Net Sentiment						-0.0808** (0.0353)		
Insurance and Legal							0.0844** (0.0359)	
Monetary Loss								0.0758** (0.0368)
Firm controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	151386	60506	60506	60506	60506	60506	60506	60506
pseudo R ²	0.151	0.171	0.170	0.170	0.171	0.171	0.170	0.170

Note: Probability of experiencing a realized cyber attack anytime over the next 8 quarters. Standard errors are clustered at the firm level. *, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively. Realized cyber attack data from PRC.

Cumulative Abnormal Returns (CAR) and Average Volatility (CAV) and Average Volatility (CAV)



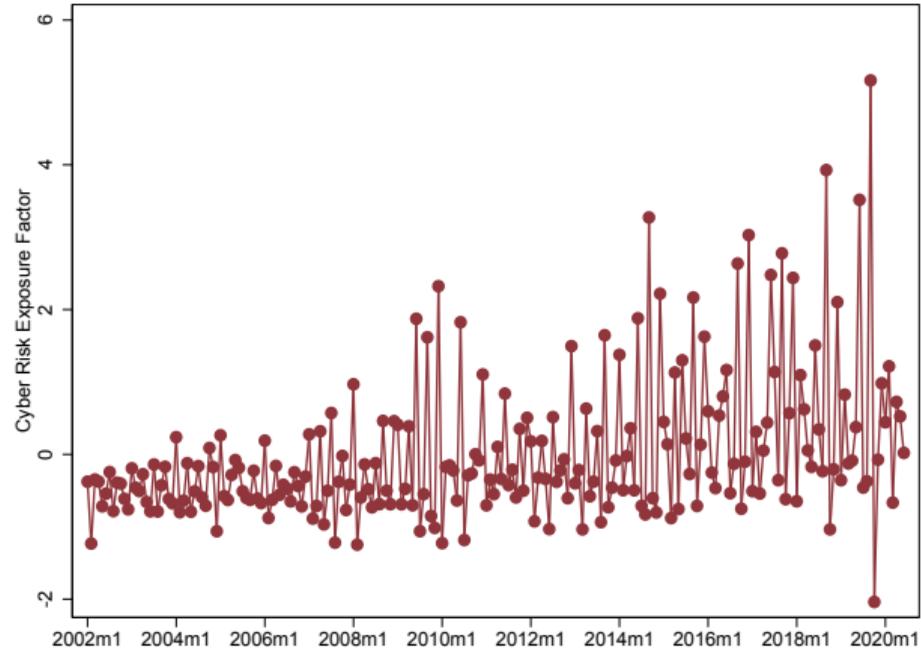
Note: Cumulative abnormal returns (CAR) and average volatility (CAV) surrounding earnings call dates with a positive cyber risk total exposure. Predicted returns are estimated based on the Fama and French (1993) three-factor model over the -60 to -10 day period prior to each event. Firm-level abnormal returns and volatility are defined as actual minus predicted returns and volatility. Values are in monthly percentage terms.

Stock Market Contagion Effects

	(1)	(2)	(3)	(4)	(4)	(6)	(7)
	Dependent variable: weekly return of peer firms with no cyber risk exposure						
Total Exposure	-0.0336** (0.0152)						
Risk		-0.0757** (0.0273)					
Pos. Sentiment			-0.0592*** (0.00473)				
Neg. Sentiment				-0.0604*** (0.00780)			
Net Sentiment					0.00615 (0.00844)		
Insurance and Legal						-0.0896** (0.0305)	
Monetary Loss							-0.0823*** (0.0234)
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Week fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2724	309	1275	1150	1659	251	445
pseudo R^2	0.391	0.503	0.434	0.431	0.432	0.403	0.437

Note: Linear regression of firm-lever cyber risk total exposure on weekly stock returns of firms with zero exposure which are in the same industry and country as the affected peer. Standard errors are clustered at the country level. *, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Cyber Risk Exposure (CyberE) - Monthly Pricing Factor



Note: The monthly pricing factor is defined as residuals from an AR(1) which is fit into the monthly average of firm-level total cyber risk exposure. The series is then standardized over the entire sample.

Cyber Risk Sorted Portfolios

Panel A: Value Weighted						
	L (1)	(2)	(3)	(4)	H (5)	H-L
Panel B: Average Excess Returns (%)	0.9586	0.781	0.706	0.674	0.654	-0.305
Volatility (%)	5.6365	4.5801	4.513	4.849	6.023	2.179
Alpha CAPM	-0.266*	-0.083	0.002	0.062	0.092	-0.358**
Alpha FF	-0.0854	0.0608	0.12	0.171**	0.216*	-0.301*
Average Market Cap (\$bn)	20.743	21.179	21.04	20.85	20.33	
Cyber Exposure beta	-3.408	-1.131	-0.015	1.104	3.511	
Number of Months	192	192	192	192	192	192

Panel B: Equally Weighted						
	L (1)	(2)	(3)	(4)	H (5)	H-L
Average Excess Returns (%)	0.9699	0.7818	0.706	0.68	0.664	-0.306
Volatility (%)	5.6524	4.5767	4.502	4.832	6.022	2.173
Alpha CAPM	-0.254	-0.072	0.006	0.067	0.104	-0.358**
Alpha FF	-0.0729	0.0754	0.128	0.181**	0.235*	-0.308*
Average Market Cap (\$bn)	20.743	21.179	21.04	20.85	20.33	
Cyber Exposure beta	-3.408	-1.131	-0.015	1.104	3.511	
Number of Months	192	192	192	192	192	192

Note: CyberE-sorted stock portfolios. Firm-level monthly excess returns are regressed on the CyberE pricing factor in 30-month rolling regressions. Five value- and equal-weighted tradeable portfolios are formed based on the beta. The H-L portfolio is long high- and short low-CyberE beta stocks. Price data is from CRSP. Betas are scaled by 100 for readability.

	Unweighted			Value Weighted		
Market	0.22	0.131	0.553***	0.185	0.0529	0.491***
Cyber Risk Exposure		1.077**	0.337**		1.167**	0.321**
HML			-1.868***			-1.757***
SMB			0.0139			0.048
Constant	0.51	0.393	0.577*	0.548	0.467*	0.583*
Number of Portfolios	10	10	10	10	10	10
R^2	0.06	0.474	0.966	0.044	0.497	0.977
MAPE	1.11	0.902	0.187	1.11	0.867	0.147

Note: The Fama-MacBeth cross-sectional regressions. Firm-level monthly excess returns are regressed on the CyberE pricing factor in 30-month rolling regressions. Ten value- and equal-weighted test portfolios are formed. Each portfolio return is regressed on the factors specified in each column. Cross-sectional regressions of average returns on the factor betas are then run. MAPE refers to the mean average pricing error, in annualized percentage terms. Price data is from CRSP.

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- Next steps:
 - What are the **aggregate/welfare** effects of cyber risk?
 - **Policy** recommendations?

Thank You