Cyber (macroeconomic) risk

PRELIMINARY VERSION, DO NOT CIRCULATE

Riccardo Degasperi* Bank of Italy

Andrea Gazzani† Bank of Italy

Filippo Natoli‡ Bank of Italy

Federico Scabbia§ Pompeu Fabra

11 December 2024

Paper proposal

Digital crime has become one of the most urgent challenges for businesses. Cybercriminals often carry out frequent attacks, primarily motivated by financial incentives, while government-affiliated entities typically employ more advanced methods to acquire strategic data such as proprietary information. The financial literature has found negative effects of cyberattacks on the targeted firms either by impacting operational efficiency or by eroding their reputation and raising litigation risks (Kamiya et al., 2021). Stocks that are highly exposed to cyber risk hold a premium with respect to the least exposed ones, revealing that cyber risk is priced in ex-ante by the markets (Florackis et al., 2023; Celeny and Maréchal, 2024; Jiang et al., 2024).

*DG Economics, Statistics and Research; via Nazionale 91, 00184 Rome, Italy. Email: riccardo.degasperi@bancaditalia.it Web: www.riccardo-degasperi.com

†DG Economics, Statistics and Research; via Nazionale 91, 00184 Rome, Italy. Email: andreagiovanni.gazzani@bancaditalia.it Web: https://sites.google.com/site/aggazzani/

‡DG Economics, Statistics and Research; via Nazionale 91, 00184 Rome, Italy. Email: filippo.natoli@bancaditalia.it Web: https://sites.google.com/site/filipponatoli/

§Department of Economics and Business, Universitat Pompeu Fabra, Jaume I Building, Ramon Trias Fargas 25-27, 08005 Barcelona, Spain. Email: federico.scabbia@upf.edu

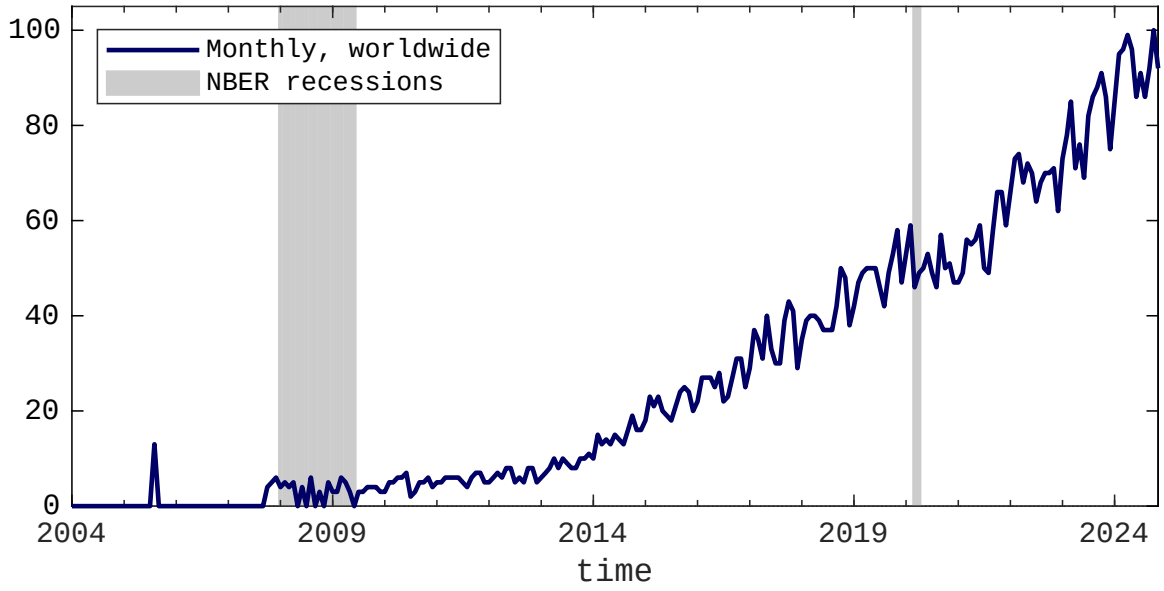
The views expressed herein are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Bank of Italy.

While cyberattacks are known to be impactful at the firm level, the extent to which cyber risk can have aggregate economic implications has not received attention so far. Two observations suggest that this can be the case. First, as entities of all scales are highly interlinked in many ways, cyberattacks can propagate rapidly compromising the reliability of IT infrastructures of multiple firms, as they already did through banks' networks (Duffie and Younger, 2019; Eisenbach et al., 2022) or supply chains (Crosignani et al., 2023). Second, the concern of the general public about cyber risk has steadily intensified (Figure 1), and following new attacks cyber risk perception can spill over from the hit firms to their peers in the same countries and sectors (Jamilov et al., 2021). Overall, unexpected events raising cyber risk can generate widespread uncertainty about future attacks and their consequences, possibly inducing costly protective actions by a large number of actors in the private sector.

We take up this issue by identifying shocks to cyber risk and estimating their macroeconomic effects within a time series framework. For this purpose, we rely on the market price fluctuations of the First Trust Cybersecurity ETF, a popular exchange-traded fund tracking the stocks of the main cybersecurity services providers at the global level. In general, the fund should appreciate with respect to the market when the cybersecurity threat increases (e.g., following a new attack or the disclosure of material consequences caused by a past event) as investors foresee higher profitability for firms selling security products, and depreciate when such concern decreases. While the timing of each cyberattack is not easily detectable at the firm level – announcements can be strategically timed to receive the least attention by the media (Foerderer and Schuetz, 2022) – we identify investors' reactions to changes in cyber risk by matching the top 100 largest daily variations in the ETF price in our sample with media news obtained through Factiva. In particular, we isolate 41 events in which a large swing in the daily excess returns of the ETF (i.e., the difference between the daily return of the ETF with that of the Nasdaq 100 index) was associated with an important news on a cyber attack or cyber risk more generally. In the identified 41 episodes, the variance of excess returns is 13 times larger the variance on a non-event day (Figure 2).

The resulting daily series of excess returns is then used to identify a cyber risk shock in proxy-VAR frameworks. We performed our empirical analysis in two steps: first, we test the effects of our identified cyber risk shock on the main variables in financial markets at

Figure 1: Index of web searches including "cyber risk"

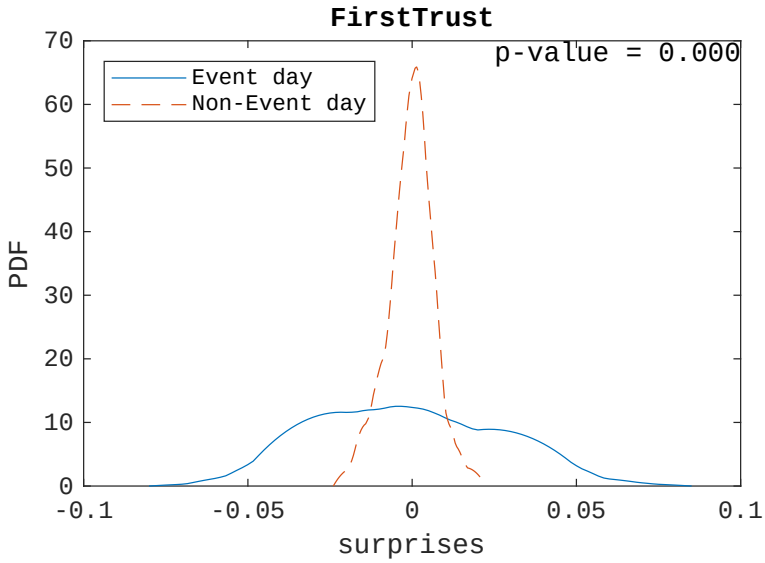


Notes: Numbers represent search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. A score of 0 means that there was not enough data for this term. Source: Google trends.

the daily frequency. Then, we aggregate our measure at the monthly frequency and plug it into a monthly VAR framework. Our sample begins in July 2015, when cyber threats escalated significantly, numerous prominent cyberattacks captured widespread attention, and ends in July 2024. The proxies of cyber risk shocks used in the analysis at the daily and monthly frequency, together with the autocorrelation tests, are shown in Figures 3 and 4. Table 1 also shows that our monthly measure of the cyber risk shocks is not significantly correlated with the main structural macroeconomic shocks identified in the literature.

Focusing on the propagation of a cyber risk shock to US financial variables at daily frequency, we find that it has a negative impact on the stock market, it increases credit spreads and financial uncertainty measured by the VIX index (Figure 5). Long-term government bond yields decline relative to short-term ones, suggesting fixed-income investors rebalancing from short to long-term maturities. Moreover, there is a positive impact on inflation expectations proxied by the quote of inflation-linked swaps, especially at the long end of the term structure.

Figure 2: Announcement vs. non-announcement excess returns

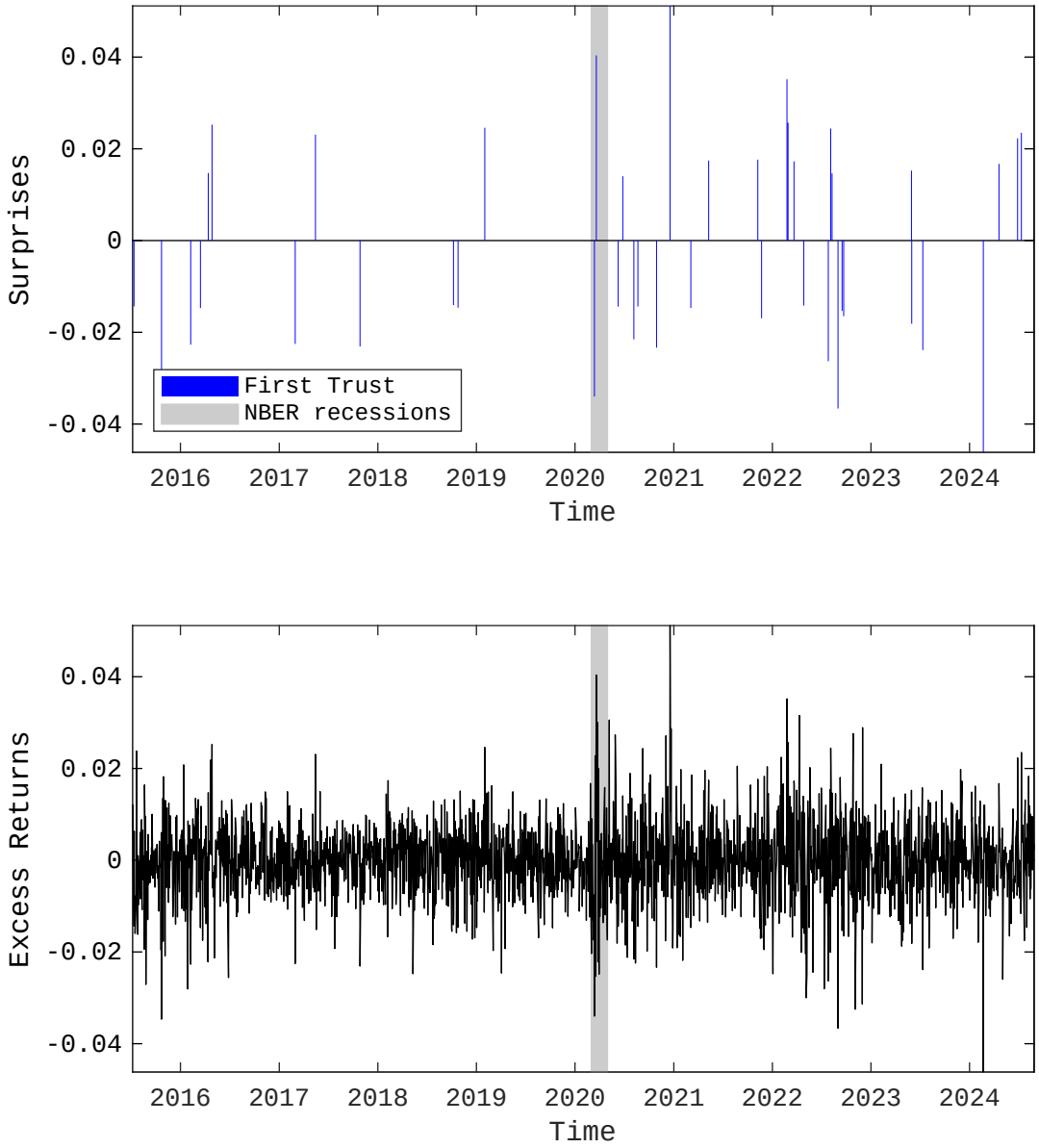


Notes: comparison between daily excess returns on cyber event days (solid blue) compared to non-event days (dashed red). If the dashed-red bell is 'higher' than the solid-blue one, then surprises on event days are larger in magnitude than on any other day. Reported p-values are for Brown–Forsythe tests for the equality of group variances. Announcement and non-announcement groups contain the same number of observations.

As cyber risk shocks have a clear negative effect on the financial markets, we then explore their macroeconomic implications. Cyber risk is global in nature, so we first explore its broad macroeconomic impact on monthly measures of global economic activity. As Figure 6 shows, cyber risk shock has a negative effect on global industrial production, where three different measures of global economic activity all point to similar conclusions.

We then move to explore the implications for the US economy by testing the response of a broader number of macroeconomic variables. We find that increases in cyber risk depress US industrial production and raise unemployment, where the contraction in US industrial production is similar in magnitude and persistence to what found before at the global and global ex-US level. Consumer prices measured by the US CPI index increase following a cyber risk shock, although such reaction is only significant at the 68% confidence level. The inflationary effect is in line with the positive effect on inflation expectations found at the daily frequency (Figure 7). All in all, increases in cyber risk are found to have implications that go beyond the effects on the hit firms: in particular, unexpected increases in cyber risk are found to be recessionary, and to heightened uncer-

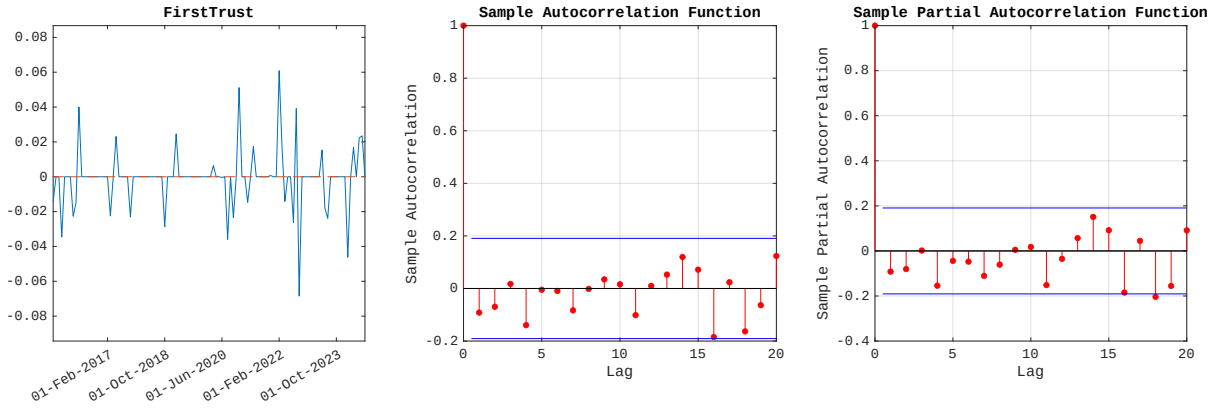
Figure 3: Proxy for cyber risk shocks



Notes: daily proxy for cyber risk shocks constructed taking the excess returns of the ETF First Trust relative to the Nasdaq 100 on days of cyber events (top panel). Daily time series of the excess returns of the ETF First Trust relative to the Nasdaq 100 (bottom panel).

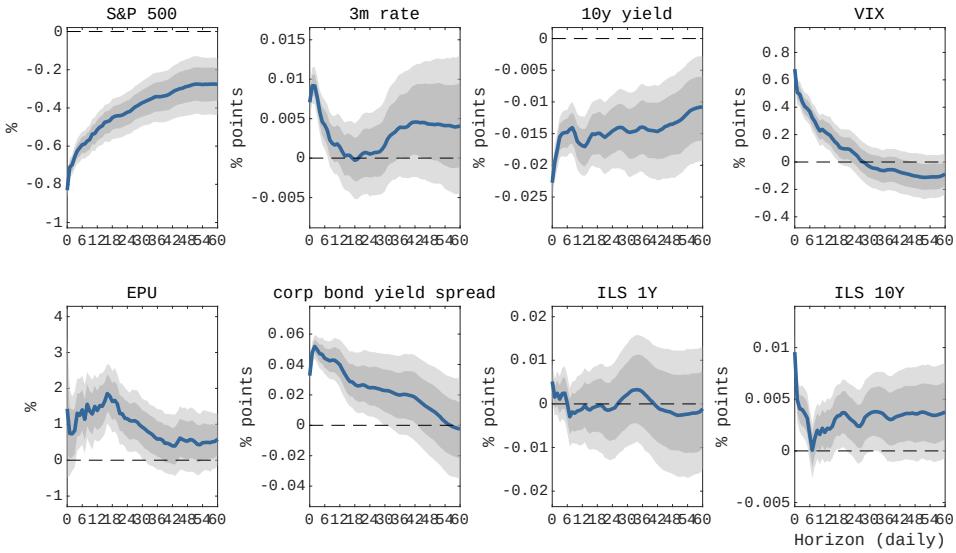
tainty in financial markets. The next step of the analysis is to investigate the transmission channels of cyber risk to the macroeconomy. In particular, we aim at testing the effects on aggregate measures of private investment to understand whether concerns on cyber risk can spur a recomposition towards IT-related investments, diverting private capital from more profitable opportunities in the short run.

Figure 4: Autocorrelation



Notes: time series of the proxy for cyber risk shocks aggregated at monthly frequency (left); autocorrelation of the monthly proxy (center); partial autocorrelation of the monthly proxy (right).

Figure 5: Daily SVAR

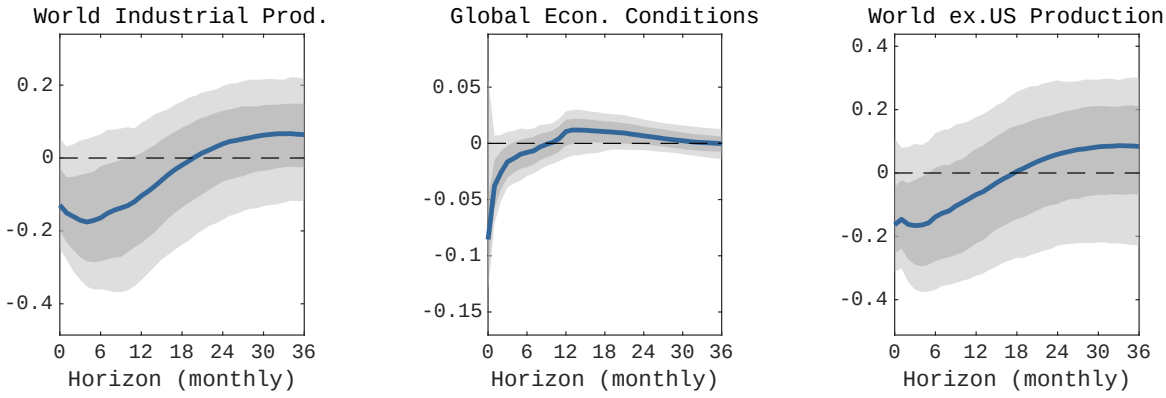


Notes: impulse response functions to a one-standard-deviation shock to cyber risk. Grey bands represent 90% and 68% credibility regions. Daily (business days) sample from 18/06/2007 to 26/09/2024. The VAR includes 60 lags of the endogenous variables.

Table 1: Correlation of First Trust series with other shocks

Series	Source	Rho	p-value	Start	End
Oil supply shocks	Baumeister and Hamilton (2019)	-0.0166	0.8667	01-Jul-2015	01-Mar-2024
Economic activity shocks	Baumeister and Hamilton (2019)	-0.0341	0.7302	01-Jul-2015	01-Mar-2024
Oil consumption demand shocks	Baumeister and Hamilton (2019)	0.1383	0.1594	01-Jul-2015	01-Mar-2024
Oil inventory demand shocks	Baumeister and Hamilton (2019)	-0.1654	0.0918	01-Jul-2015	01-Mar-2024
IGREA	Kilian (2019)	-0.0448	0.7384	01-Jul-2015	01-Apr-2020
Oil news shocks	Känzig (2021)	0.1127	0.2595	01-Jul-2015	01-Dec-2023
OPEC surprises	Känzig (2021)	-0.0887	0.3751	01-Jul-2015	01-Dec-2023
MP proxy	Degasperi and Ricco (2021)	0.0490	0.7581	01-Jul-2015	01-Dec-2018
CBI	Degasperi and Ricco (2021)	0.0869	0.5844	01-Jul-2015	01-Dec-2018
MP proxy	Bauer and Swanson (2023)	0.0609	0.6616	01-Jul-2015	01-Dec-2019
CBI	Bauer and Swanson (2023)	0.0966	0.4870	01-Jul-2015	01-Dec-2019
MP median	Jarociński and Karadi (2020)	-0.2200	0.0256	01-Jul-2015	01-Jan-2024
CBI median	Jarociński and Karadi (2020)	0.1396	0.1597	01-Jul-2015	01-Jan-2024
Risk appetite	Gazzani et al. (2024)	-0.0198	0.8380	01-Jul-2015	01-Jul-2024
Demand	Gazzani et al. (2024)	-0.0383	0.6927	01-Jul-2015	01-Jul-2024
Supply and geopolitical risk	Gazzani et al. (2024)	0.1927	0.0447	01-Jul-2015	01-Jul-2024
EPU	Baker et al. (2016)	0.0136	0.8883	01-Jul-2015	01-Aug-2024

Figure 6: Global effects of a cyber risk shock



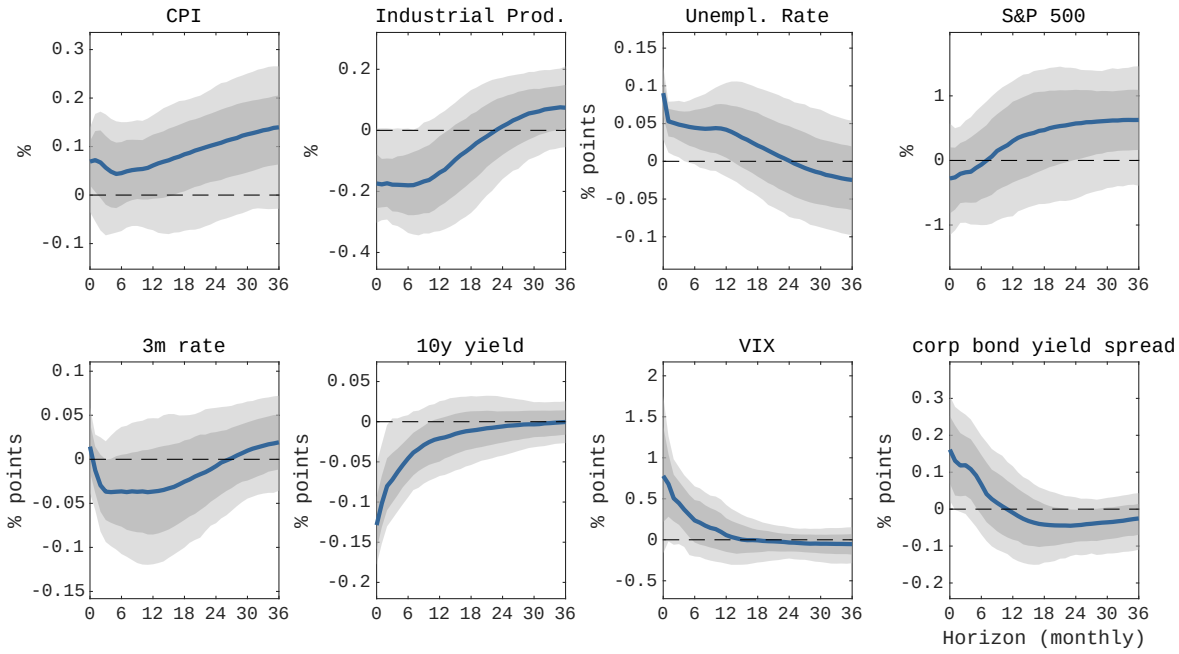
(a) Baumeister and Hamilton (2019) OECD+6NME IP

(b) Baumeister et al. (2022) Global Econ. Conditions

(c) Dallas Fed World ex. US Production

Notes: impulse response functions to a one-standard-deviation shock to cyber risk. Same specification as in Figure 7 adding one of the reported variables at the time. Grey bands represent 90% and 68% credibility regions. Covid period corrected using pandemic priors (Cascaldi-Garcia, 2022). Monthly sample from 2000:1 to 2024:9. The VAR includes 12 lags of the endogenous variables.

Figure 7: Monthly SVAR



Notes: impulse response functions to a one-standard-deviation shock to cyber risk. Grey bands represent 90% and 68% credibility regions. Covid period corrected using pandemic priors (Cascaldi-Garcia, 2022). Monthly sample from 2000:1 to 2024:9. The VAR includes 12 lags of the endogenous variables.

References

Baker, Scott R, Nicholas Bloom, and Steven J Davis, "Measuring economic policy uncertainty," *The quarterly journal of economics*, 2016, *131* (4), 1593–1636.

Bauer, Michael D and Eric T Swanson, "A reassessment of monetary policy surprises and high-frequency identification," *NBER Macroeconomics Annual*, 2023, *37* (1), 87–155.

Baumeister, Christiane and James D Hamilton, "Structural interpretation of vector autoregressions with incomplete identification: Revisiting the role of oil supply and demand shocks," *American Economic Review*, 2019, *109* (5), 1873–1910.

_ , Dimitris Korobilis, and Thomas K Lee, "Energy markets and global economic conditions," *Review of Economics and Statistics*, 2022, *104* (4), 828–844.

Cascaldi-Garcia, Danilo, "Pandemic priors," *International Finance Discussion Paper*, 2022, (1352).

Celeny, Daniel and Loïc Maréchal, "Cyber risk and the cross-section of stock returns," *arXiv preprint arXiv:2402.04775*, 2024.

Crosignani, Matteo, Marco Macchiavelli, and André F Silva, "Pirates without borders: The propagation of cyberattacks through firms' supply chains," *Journal of Financial Economics*, 2023, *147* (2), 432–448.

Degasperi, Riccardo and Giovanni Ricco, "Information and policy shocks in monetary surprises," Technical Report, Working Paper 2021.

Duffie, Darrell and Joshua Younger, *Cyber runs*, Brookings, 2019.

Eisenbach, Thomas M, Anna Kovner, and Michael Junho Lee, "Cyber risk and the US financial system: A pre-mortem analysis," *Journal of Financial Economics*, 2022, *145* (3), 802–826.

Florackis, Chris, Christodoulos Louca, Roni Michaely, and Michael Weber, "Cybersecurity risk," *The Review of Financial Studies*, 2023, *36* (1), 351–407.

Foerderer, Jens and Sebastian W Schuetz, "Data breach announcements and stock market reactions: a matter of timing?," *Management Science*, 2022, *68* (10), 7298–7322.

Gazzani, Andrea, Fabrizio Venditti, and Giovanni Veronese, "Oil price shocks in real time," *Journal of Monetary Economics*, 2024, *144*, 103547.

Jamilov, Rustam, Hélène Rey, and Ahmed Tahoun, "The anatomy of cyber risk," Technical Report, National Bureau of Economic Research 2021.

Jarociński, Marek and Peter Karadi, "Deconstructing monetary policy surprises—the role of information shocks," *American Economic Journal: Macroeconomics*, 2020, *12* (2), 1–43.

Jiang, Hao, Naveen Khanna, Qian Yang, and Jiayu Zhou, "The cyber risk premium," *Management Science*, 2024.

Kamiya, Shinichi, Jun-Koo Kang, Jungmin Kim, Andreas Milidonis, and René M Stulz, "Risk management, firm reputation, and the impact of successful cyberattacks on target firms," *Journal of Financial Economics*, 2021, *139* (3), 719–749.

Känzig, Diego R, "The macroeconomic effects of oil supply news: Evidence from OPEC announcements," *American Economic Review*, 2021, *111* (4), 1092–1125.

Kilian, Lutz, "Measuring global real economic activity: Do recent critiques hold up to scrutiny?," *Economics Letters*, 2019, *178*, 106–110.