Pirates without Borders: the Propagation of Cyberattacks through Firms’ Supply Chains

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Paper Session: Networks and Contagion

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The views expressed are solely my own and do not necessarily reflect those of the Board of Governors of the Federal Reserve System or of the Federal Reserve Bank of New York
1. **Cyberattacks** are one of the most pressing concerns for firms

- As opposed to other shocks (e.g., natural disasters), cyberattacks are extremely rapid and not necessarily geographically clustered
- Ever-changing threat → different actors, objectives, techniques
  - *Hackers*: ransomware and denial-of-service attacks for financial gains
  - *State-actors*: more sophisticated techniques to obtain strategic information or, in more extreme cases, disrupt critical infrastructure of a target country
- Severe cyberattacks can damage firms’ productive capacity, thereby potentially affecting their customers and suppliers

2. Production of goods and services structured around complex and global supply chain networks

- Customer-supplier relationships are *key for the transmission of shocks* e.g., natural disasters (Barrot and Sauvagnat, 2016); credit supply shocks (Costello, 2020); pandemics (Bonadio et al., 2020)
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This Paper: examines the economic impact and supply chain effects of the most damaging cyberattack in history so far

Research Questions

1. Can the effects of cyberattacks on directly hit firms propagate downstream to their customers and upstream to their suppliers?

2. If so, how do the firms in the supply chain cope with the shock? Are there any real effects? Do banks play a role in mitigating its impact?

3. Do customer-supplier networks change in response to cyberattacks?
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*Reduction in revenues and profits among customers* ($10bn loss vs. $2.2bn for directly hit firms) and *lower trade credit from suppliers*. But no upstream effects.

2. *If so, how do the firms in the supply chain cope with the shock? Are there any real effects? Do banks play a role in mitigating its impact?*

Affected customers depleted liquidity buffers and increased borrowing through *bank credit lines*, which allowed them to maintain investment and employment.

3. *Do customer-supplier networks change in response to cyberattacks?*

Affected customers more likely to form *new relations with alternative suppliers* (wake-up call) and to *end relations with directly hit suppliers*.
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Preview of Results

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- Unexpected, large-scale cyberattack in June 2017 ("NotPetya")

- Effort by the Russian military intelligence targeted at Ukraine (CIA, 2018)
- Initial vector of infection was a software widely used for tax reporting
  - Appeared to be a ransomware, but true intent was to encrypt and paralyze the computer networks of Ukrainian organizations
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Cyberattack inadvertently spread beyond its original target and infected global firms through their Ukrainian subsidiaries.

10 DIRECTLY HIT FIRMS – large, global, and public (costs: $2.2bn)

- Merck (US): $670mn
- FedEx (US): $400mn
- Saint-Gobain (France): $387mn
- Maersk (Denmark): $300mn
- Mondelez (US): $180mn
- Reckitt Benckiser (UK): $117mn
- Nuance Communications (US): $92mn
- Beiersdorf (Germany): $43mn
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Introduction Background Data Identification Strategy Results Conclusion

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▶ 209 INDIRECTLY AFFECTED CUSTOMERS

Matteo Crosignani (New York Fed)
Background

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- 331 indirectly affected suppliers.
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E.g., Merck

Suppliers

94 firms from 24 countries, including:

- GE Healthcare
- IMA

Directly hit firm

Merck

Customers

45 firms from 17 countries, including:

- Cardinal Health
- Diplomat Specialty Pharmacy
1. **Directly hit firms**: SEC filings and Dow Jones Factiva

   - Scraping SEC filings in 2017 and 2018 (keywords: “Petya”, “NotPetya”, and “Cyber”)
   - Manually check over 4,500 newspaper articles worldwide citing NotPetya – available in the Dow Jones Factiva database
   - Cross-check the list of directly hit firms with Greenberg (2019), a book about NotPetya and other cyberattacks

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   - Almost 1 million relationships between large (mostly publicly-listed) firms around the world
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- B/S information for more than 350 million firms worldwide
- Orbis and FactSet merged using ISINs → disregard firms not present in both data sets to avoid selection bias
  - 47,651 firm-year observations
  - 10,640 firms; 2014 to 2018
  - 209 customers, 331 suppliers

4. **Loan-level data for the US:** Federal Reserve Y-14Q

- Information at the quarterly frequency on all credit exposures exceeding $1 million for banks with more than $50 billion in assets
- Merged with Orbis-FactSet sample using TINs and CUSIPs
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  - 37 banks and 1,997 firms; 2014:Q1 to 2018:Q4
  - 85 customers → 41% of global customers and 87% of US customers in Orbis-FactSet sample
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Identification strategy

▶ **Difference-in-differences** comparing, before and after the shock:

1. Firms indirectly affected by cyberattack through their supply chain
2. Unaffected firms operating in the same industry, country, and size quartile in the same year

**Firm-level Analysis**

\[ Y_{ijt} = \alpha + \beta \text{Post}_t \times \text{Affected}_i + \xi_i + \eta_{jt} + \epsilon_{ijt} \]  

- \( Y_{ijt} \): ratio of operating revenues, EBITDA, trade credit, and long-term debt to total assets, and the liquidity ratio (current assets-inventories/current liabilities)
- \( \text{Post}_t \): equals 1 for 2017 and 2018, and 0 otherwise
- \( \text{Affected}_i \): equals 1 if a firm is connected (as a supplier or as a customer) to a directly hit firm, and 0 otherwise
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**Part 1**

Can the effects of cyberattacks on directly hit firms propagate downstream to their customers and upstream to their suppliers?
1.1. Downstream Propagation to Customers

Disruption caused by the cyberattack strongly propagated downstream:

- Economically significant impact: a 5% drop in operating revenues and 2% drop in EBITDA – a conservative estimate suggests drop in profits of at least $10bn.
1.1. Downstream Propagation to Customers

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<thead>
<tr>
<th></th>
<th>Operating Revenues/Assets</th>
<th>EBITDA/Assets</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>$Post_t \times \text{Affected Customer}_i$</td>
<td>-0.036*** (0.014)</td>
<td>-0.047*** (0.014)</td>
</tr>
</tbody>
</table>

Fixed Effects

- Firm ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓
- Country-Year ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓
- Industry-Year ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓
- Size Bucket-Year ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓
- Ind-Cou-Year ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓
- Ind-Cou-Size-Year ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓

<table>
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<tr>
<th>Observations</th>
<th>47,651</th>
<th>44,207</th>
<th>40,704</th>
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<tbody>
<tr>
<td>R-squared</td>
<td>0.931</td>
<td>0.942</td>
<td>0.944</td>
<td>0.809</td>
<td>0.820</td>
<td>0.823</td>
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- Parallel trends assumption holds $\rightarrow$ firm characteristics are also similar across treatment and control group within size quartiles
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Customers of Customers & Suppliers

1) No effects further downstream to customers of customers

2) No statistically significant upstream effects to suppliers of directly hit firms
   - Shock impaired the directly hit firms’ ability to deliver products to their customers, but not the suppliers’ ability to deliver products to directly hit firms
   - Consistent with Alfaro et al. (2020) in the context of credit supply shocks

3) Magnitude of the supply chain disruption is larger for customers with fewer suppliers in the same industry of the directly hit supplier

4) Disruptions among customers more severe when directly affected firm (the supplier) produces a more specific, less substitutable product
   - Supplier producing a highly specific input if it has a high ratio of R&D expenditure to sales (Barrot and Sauvagnat, 2016) – Nuance and Merck
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– Part 2 –

How do the firms in the supply chain cope with the shock? Are there any real effects? Do banks play a role in mitigating its impact?
### 2.1. Cyberattack and Trade Credit

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<tr>
<th></th>
<th>Post(_t) × Affected(_i)</th>
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<tr>
<td>Customer(_i) (i)</td>
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| Observations         | 47,651   | 44,207       | 40,704        |
| R-squared            | 0.913    | 0.923        | 0.925         |

- Affected customers received less trade credit, further straining their liquidity conditions → trade credit is a key source of short-term financing (Barrot, 2016)
- Trade credit contraction (as a share of purchases) only affects customers fully dependent on the directly hit suppliers → reduction driven by directly hit firms
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</tr>
</thead>
<tbody>
<tr>
<td>0.913</td>
<td>0.923</td>
<td>0.925</td>
</tr>
</tbody>
</table>

- Affected customers received less trade credit, further straining their liquidity conditions → trade credit is a key source of short-term financing (Barrot, 2016)

- Trade credit contraction (as a share of purchases) only affects customers fully dependent on the directly hit suppliers → reduction driven by directly hit firms
2.1. Cyberattack and Trade Credit

<table>
<thead>
<tr>
<th></th>
<th>Trade Credit/Assets</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
</tr>
<tr>
<td>( Post_t \times \text{Affected} )</td>
<td>-0.467** -0.539** -0.792***</td>
</tr>
<tr>
<td>( \text{Customer}_i )</td>
<td>(0.207) (0.227) (0.303)</td>
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</table>

**Fixed Effects**
- Firm ✓ ✓ ✓ ✓
- Country-Year ✓ ✓ ✓
- Industry-Year ✓ ✓
- Size Bucket - Year ✓ ✓
- Ind-Cou-Year ✓ ✓
- Ind-Cou-Size-Year ✓ ✓

<table>
<thead>
<tr>
<th>Observations</th>
<th>47,651</th>
<th>44,207</th>
<th>40,704</th>
</tr>
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<tbody>
<tr>
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## 2.2. Cyberattack and Liquidity Risk Management

<table>
<thead>
<tr>
<th>Long-Term Debt/Assets</th>
<th>Liquidity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Post _t \times \text{Affected}_i</td>
<td>1.410***</td>
</tr>
<tr>
<td></td>
<td>(0.431)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Firm FE</td>
</tr>
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<tr>
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<tr>
<td>Size Bucket-Year</td>
</tr>
<tr>
<td>Ind-Cou-Year</td>
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<td>Ind-Cou-Size-Year</td>
</tr>
</tbody>
</table>

| Observations | 47,651 | 44,207 | 40,704 | 47,651 | 44,207 | 40,704 |
| R-squared | 0.876 | 0.889 | 0.895 | 0.741 | 0.752 | 0.758 |

To deal with this decline in both revenues and trade credit from suppliers, affected customers (i) increased external borrowing and (ii) relied on their pre-existing internal liquidity.
To deal with this decline in both revenues and trade credit from suppliers, affected customers (i) increased external borrowing and (ii) relied on their pre-existing internal liquidity.
2.2. Disruptions and Liquidity Risk Management

Effect on Liquidity Ratio

Effect on Long-Term Debt/Assets

Effect on Trade Credit/Assets
Affected customers have similar employment growth and wages after the shock relative to firms in the control group.

Affected customers also did not have to reduce investment following the shock.
**Identification strategy**

**Loan-level Analysis**

\[ Y_{ibjt} = \alpha + \beta Post_t \times Affected_i + \xi_i + \eta_{jt} + \gamma_{bt} + \epsilon_{ibjt} \]  

- $Y_{ijt}$: total committed credit, total committed credit lines, share of the committed line of credit that is drawn down, interest rate spread, bank’s subjective default probability of the borrower, dummy equal to one if the loan is non-performing, maturity of the committed exposure, amount of collateral
- $Post_t$: equals 1 after 2017:Q2, and 0 otherwise
- $Affected_i$: equals 1 if a firm is a customer of a directly hit firm, and 0 otherwise
- $\xi_i$: firm FE to control for unobserved time-invariant firm characteristics
- $\eta_{jt}$: peer group of firm $i$ – industry (SIC2)-state-size quartile-quarter combination
- $\gamma_{bt}$: bank-quarter FE to control for time-varying bank characteristics and absorb bank-specific shocks to credit supply
Identification strategy

\[ Y_{ibt} = \alpha + \beta Post_t \times Affected_i + \xi_i + \eta_{jt} + \gamma_{bt} + \epsilon_{ibjt} \] (2)

- \( Y_{ibt} \): total committed credit, total committed credit lines, share of the committed line of credit that is drawn down, interest rate spread, bank’s subjective default probability of the borrower, dummy equal to one if the loan is non-performing, maturity of the committed exposure, amount of collateral

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2.4. Role of banks – loan-level evidence from the US

<table>
<thead>
<tr>
<th></th>
<th>Log(Tot Committed)</th>
<th>Log(Committed Line)</th>
<th>Share Drawn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Post&lt;sub&gt;t&lt;/sub&gt; × Affected Customer&lt;sub&gt;i&lt;/sub&gt;</td>
<td>-0.037 (0.078)</td>
<td>-0.199 (0.128)</td>
<td>-0.018 (0.055)</td>
</tr>
<tr>
<td></td>
<td>0.097 (0.067)</td>
<td>0.045** (0.021)</td>
<td>0.084** (0.040)</td>
</tr>
</tbody>
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Fixed Effects

<table>
<thead>
<tr>
<th></th>
<th>✓</th>
<th>✓</th>
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<tbody>
<tr>
<td>Firm</td>
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<tr>
<td>Bank-Quarter</td>
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<td>Ind-State-Quarter</td>
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Observations 137,630 131,428 129,756 123,936 129,756 123,936

R-squared 0.581 0.583 0.624 0.623 0.586 0.620

- Affected customers significantly increase credit line draw downs to cope with the pressing liquidity needs → highlights the liquidity insurance function of banks
- Increase in the interest rate affected customers are charged
  - No bias arising from affected customers matching with banks offering less competitive pricing → results are within bank-quarter, comparing the rate charged by the same bank to affected and unaffected firms
- Consistent with the fact that banks perceive affected customers as being riskier
## 2.4. Role of banks – loan-level evidence from the US

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**Fixed Effects**

- **Firm**: ✓ ✓ ✓ ✓ ✓ ✓
- **Bank-Quarter**: ✓ ✓ ✓ ✓ ✓ ✓
- **Ind-State-Quarter**: ✓ ✓ ✓
- **Ind-State-Size-Quarter**: ✓ ✓

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- Firm ✓ ✓ ✓ ✓ ✓ ✓
- Bank-Quarter ✓ ✓ ✓ ✓ ✓ ✓
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Do customer-supplier networks change in response to cyberattacks?
### 3. Dynamic Supply Chain Responses

<table>
<thead>
<tr>
<th></th>
<th>New Relations</th>
<th></th>
<th>Ended Relations</th>
<th></th>
<th>Ended Relations excl. Hit Supplier</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>Post\textsubscript{2017} × Affected Customer\textsubscript{i}</td>
<td>0.203*** (0.056)</td>
<td>0.220*** (0.073)</td>
<td>0.097** (0.041)</td>
<td>0.102** (0.051)</td>
<td>0.095** (0.041)</td>
<td>0.102** (0.050)</td>
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<tr>
<td>Post\textsubscript{2018} × Affected Customer\textsubscript{i}</td>
<td>-0.066 (0.044)</td>
<td>-0.081 (0.059)</td>
<td>0.197*** (0.049)</td>
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<td>0.102* (0.057)</td>
</tr>
</tbody>
</table>

#### Fixed Effects

<table>
<thead>
<tr>
<th></th>
<th>Firm</th>
<th>Size Bucket-Year</th>
<th>Ind-Cou-Year</th>
<th>Ind-Cou-Size-Year</th>
<th>Observations</th>
<th>R-squared</th>
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<tbody>
<tr>
<td></td>
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<td>✓</td>
<td>✓</td>
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<td>0.670</td>
</tr>
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<td></td>
<td>12,727</td>
<td>0.677</td>
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Affected customers more likely to form new relations with alternative suppliers (wake-up call) and to end relations with directly hit suppliers.
3. Dynamic Supply Chain Responses

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- Affected customers more likely to form new relations with alternative suppliers (wake-up call) and to end relations with directly hit suppliers.
We examine the economic impact and supply chain effects of the most damaging cyberattack in history so far.

1. Downstream propagation effects → reduction in revenues, profits, and trade credit among customers of directly hit firms.

2. Affected customers depleted pre-existing liquidity buffers and increased borrowing through bank credit lines, which allowed them to maintain investment and employment.

3. There are persisting adjustments to the supply chain network following the shock.
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Summary

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<table>
<thead>
<tr>
<th>Top ten risks in North America</th>
<th>Top ten risks in Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cyberattacks</td>
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</tr>
<tr>
<td>2. Data fraud or theft</td>
<td>2. Asset bubble</td>
</tr>
<tr>
<td>3. Terrorist attacks</td>
<td>3. Interstate conflict</td>
</tr>
<tr>
<td>infrastructure breakdown</td>
<td></td>
</tr>
<tr>
<td>5. Failure of critical</td>
<td>5. Fiscal crises</td>
</tr>
<tr>
<td>infrastructure</td>
<td></td>
</tr>
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<td>7. Failure of national</td>
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<tr>
<td>governance</td>
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</tr>
<tr>
<td>8. Failure of climate-change</td>
<td>8. Unemployment or</td>
</tr>
<tr>
<td>adaptation</td>
<td>underemployment</td>
</tr>
<tr>
<td>9. Extreme weather events</td>
<td></td>
</tr>
<tr>
<td></td>
<td>instability</td>
</tr>
</tbody>
</table>

Maersk, WPP and FedEx still struggling with cyber attack fallout

Global companies ranging from shipping lines to advertising firms are still struggling with the havoc wreaked by the huge cyber attack that last week swept from Ukraine to organisations in more than 60 countries.

AP Moller-Maersk, WPP, Reckitt Benckiser and FedEx all said their businesses were still not back to normal after the ransomware attack last week compromised hundreds of thousands of computers, industrial equipment and other technology.

Some ports remain hobbled, packages are going missing and customers are struggling to place and track orders, the companies said.

US charges 6 Russian military intelligence officers over cyberattacks

The hackers attacked the 2017 French elections, the 2018 Winter Olympics, the Ukraine's power grid and investigations into a Novichok poisoning, claims the US. They may also have used the destructive NotPetya malware.

Big Companies Thought Insurance Covered a Cyberattack. They May Be Wrong.

Mondelez was deemed collateral damage in a cyberwar. When the United States government assigned responsibility for NotPetya to Russia in 2018, insurers were provided with a justification for refusing to cover the damage. Just as they wouldn't be liable if a bomb blew up a corporate building during an armed conflict, they claim not to be responsible when a state-backed hack strikes a computer network.
Stock Price of Directly Hit Firms

Stock Price Index

96 97 98 99 100 101

-6 -4 -2 0 +2 +4 +6