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Working Paper

When it rains, it pours: Cyber risk and financial conditions

Staff Reports, No. 1022

Provided in Cooperation with:

Federal Reserve Bank of New York

Suggested Citation: Eisenbach, Thomas M.; Kovner, Anna; Lee, Michael Junho (2022) : When it rains, it pours: Cyber risk and financial conditions, Staff Reports, No. 1022, Federal Reserve Bank of New York, New York, NY

This Version is available at:

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NO. 1022
JUNE 2022

When It Rains, It Pours: Cyber Risk and Financial Conditions

Thomas M. Eisenbach | Anna Kovner | Michael Junho Lee

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June 2022

JEL classification: G12, G21, G28

Abstract

We analyze how systemic cyber risk in the wholesale payments network relates to adverse financial conditions. We show that at the onset of the COVID-19 pandemic, payment activity increased, became more concentrated, and showed intraday liquidity stress. Cyber vulnerability was elevated in late February and early March 2020, with the potential impact of a cyberattack about 40 percent greater than in the remainder of 2020. Policy interventions to stabilize markets mitigated cyber vulnerability, particularly corresponding to large increases in aggregate reserves. We observe that cyber vulnerability and other financial shocks cannot be treated as uncorrelated risks and policy solutions for cyber security need to be calibrated for adverse financial conditions.

Key words: cyber, banks, networks, payments, COVID-19

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This paper presents preliminary findings and is being distributed to economists and other interested readers solely to stimulate discussion and elicit comments. The views expressed in this paper are those of the authors and do not necessarily reflect the position of the Federal Reserve Bank of New York or the Federal Reserve System. Any errors or omissions are the responsibility of the authors.

To view the authors' disclosure statements, visit
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1 Introduction

Much attention has been paid to the way in which cyber risk may be amplified by the financial system (e.g. [Duffie and Younger, 2019](#); [Kashyap and Wetherilt, 2019](#); [Aldasoro et al., 2020a](#)). Researchers have studied the frequency of cyber attacks and how they may be mitigated by bank lending (e.g. [Aldasoro et al., 2020b](#); [Crosignani et al., 2021](#)). Existing work tends to treat cyber incidents and financial conditions as independent factors, or looks only at how cyber incidents may negatively affect financial conditions. In this paper, we explore how systemic cyber risk is related to financial system disruptions, to see whether we can continue to view cyber and other financial shocks as uncorrelated vulnerabilities. In other words, when it rains and negative shocks lead to financial market dislocations, does it also pour by increasing the risks posed by a cyber attack?

A priori, it is unclear if systemic cyber risk is correlated with other types of financial risk. The two may be causally related, for example, if a cyber incident affects financial institutions or financial markets directly. Vice versa, a cyber attack may be timed to coincide with a period of financial stress. Finally, cyber and financial stress may be driven by a common third factor. For example, if a cyber attack arises from geopolitical conflict, financial markets may be experiencing increased volatility, just as cyber warfare becomes increasingly likely. The Russian invasion of Ukraine at the end of February 2022 is a case in point, both negatively impacting financial markets and increasing the threat level of cyber risk.

If cyber attacks are likely to occur at times when markets are more volatile or when financial intermediary balance sheets are strained, then policy solutions need to be calibrated for extreme market conditions. We explore these questions using the financial turmoil at the onset of the Covid-19 pandemic in March 2020 and the scenario-based analysis of [Eisenbach, Kovner, and Lee \(2021, hereafter EKL\)](#) and examine whether amplifications of a cyber event are correlated with adverse economic and financial conditions.

The onset of the Covid-19 pandemic offers a unique opportunity to study how cyber vulnerability varies with an exogenous shock to financial markets. This period is unique in that it marks the first economic downturn since the global financial crisis, and the first episode of extreme market turmoil in an ample reserves regime.¹ The shift to working from home also presented potential vulnerabilities to the system due to increased need for remote access to accommodate the measures taken to contain the pandemic. However, in this time period the increased market volatility is exogenous to any cyber incident as the pandemic shock was not related to any preceding change in cyber risk. The episode also

¹Under the ample reserves regime, the aggregate quantity of reserves is intended to be above what is needed for payment purposes, at least during normal times (e.g. [Logan, 2020](#)).

highlights the importance of access to technology, as many financial institutions shifted to working from home, potentially increasing the points at which cyber vulnerabilities can be exploited.

The scenario based approach of EKL focuses on amplification of cyber shocks through the Fedwire Funds wholesale payment network. To date, there has not been a cyber event with systemic consequences on the U.S. financial system. In the absence of actual examples, the wholesale payment system is a natural setting to study cyber vulnerabilities in a financial system. Activity in the wholesale payment system is intimately linked to financial system activity more broadly, provides a holistic view of liquidity flows between key financial institutions, and offers high-frequency information on aggregate and institution-level liquidity stress.

The onset of the Covid-19 pandemic was marked by sudden severe stress across asset classes and global financial markets (e.g. [Haddad, Moreira, and Muir, 2021](#); [Vissing-Jorgensen, 2021](#)). Along with the increased uncertainty of the path of the disease and the measures taken to contain it, we show that wholesale payment activity increased, became more concentrated, and showed signs of intraday liquidity stress. The financial market stresses in this time period were unusually large, and the speed of the market reaction as well as the global coordination of the financial market deterioration was unprecedented. Despite the extreme nature of the shock, the market deterioration was consistent with past episodes of market stress. In particular, the correlation between uncertainty and wholesale payment activity is typical for times of increased financial market volatility: We document that there is a strong relation between payment activity and financial volatility throughout the past two decades.

We find that cyber vulnerability, defined through the scenario based approach of EKL, was elevated in late February and early March 2020, with the average impact of a cyber attack on one of the largest 5 banks about 50 percent greater than the impact of an attack would have been in the rest of 2020. In scenarios where banks hoard liquidity in response to irregular payment flows, forgone payment activity in March 2020 is nearly three times greater than levels outside of March, implying that an attack at a time when financial markets are dislocated could be particularly painful. Further, we find that delayed recovery from an attack can significantly increase system-level impact: The liquidity shortfall of other banks in the system jumps from \$160 billion to roughly \$1.5 trillion if an attack lasts for five days instead of one.

The financial markets' dash for cash resulted in a 50 percent increase in payments to facilitate the movement of financial assets as investors reallocated in response to the shock. We find that there is an accompanying increase in cyber risk, as any disruption to financial

intermediaries at this time would have potentially further prevented these reallocations. This highlights an additional policy concern when real shocks roil financial markets. To the extent that the shock arises from a geopolitical conflict, any accompanying cyber warfare might be particularly destabilizing, and means that policy solutions and expected liquidity in the system may need to focus on dates with higher payments flows. This estimate is likely an underestimate as we focus on the amplification in the system.

While March 2020 showed both increasing potential amplification from a cyber attack and increasing financial market volatility, any cyber attack would have to come relatively quickly to achieve maximum damage. This is because official sector interventions to stabilize markets also had a mitigating effect on cyber vulnerability, with a decline in network impact that starts in the second week of March, corresponding to large liquidity injects by the Federal Reserve. Intuitively, as banks accumulate more reserves, they also build additional liquidity that would allow them to better withstand the loss of liquidity from a cyber attack on a counterparty. This, however, may underestimate the impact on markets should a cyber attack impair the trading books and records of a bank and delay trade settlement or create uncertainty about it. Since a significant amount of market transactions are cleared and settled within bank holding companies, an attack on bank holding companies with a high concentration of market participant accounts would also have a direct impact on market operations.

The paper proceeds as follows. Section 2 shows the effects of market stress in early 2020 on payment activity. Section 3 studies applies cyber scenarios to understand the vulnerabilities during adverse market conditions. Section 4 discusses the mitigating effects of policy responses and Section 5 concludes.

2 Wholesale payment activity and market uncertainty

We first document several patterns in wholesale payment activity during adverse financial conditions that relate to the amplification channels of cyber risk. We make use of confidential data on payments sent through Fedwire Funds Service, the U.S. wholesale payment system operated by the Federal Reserve.

Level of payment activity. In March 2020, market volatility indices peaked, with the CBOE Volatility Index (VIX) reaching its all-time high of 82.69, above the previous high reached during the financial crisis of 2007–09. Correspondingly, trading volumes were exceptionally high across various markets. Because Fedwire supports the settlement of

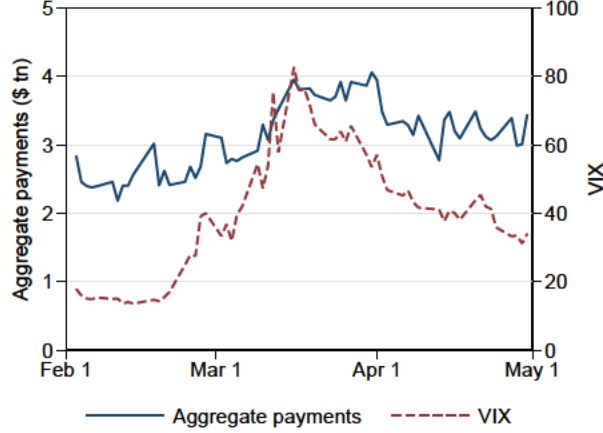


Figure 1: Wholesale payment activity and market uncertainty. The figure shows aggregate payment activity in Fedwire Funds and the CBOE Volatility Index.

large-value transactions and trading volumes tend to increase in times of high market uncertainty, we expect a positive relation between market uncertainty and payment system activity. This is what we see in Figure 1, which shows the daily aggregate Fedwire payment value and the VIX in February March and April 2020. Over the full year of 2020, aggregate Fedwire payment value is highly correlated with the VIX, with a correlation of 0.72 at daily frequency. From February to April 2020, during the time in which market stress is most acute, aggregate payment activity spikes with the VIX. From the beginning of February to the end of April, the correlation between payment value and the VIX is even greater, at 0.87.

Table 1 shows regressions of payment activity on the VIX over a longer sample period from 1997 to 2020. The regressions are at monthly frequency with year fixed effects and control for the level of aggregate reserves, which strongly correlates with payment activity after 2008 (Eisenbach, Frye, and Hall, 2019). The relation between payment activity and the VIX is highly significant, and the coefficient of about 7 implies that for a 10-point increase in the VIX, payments increase by about \$70 billion per day. Overall, wholesale payment activity increases in times of high market uncertainty.

Concentration of payment activity. Historically, activity in the wholesale payment network is highly concentrated, with roughly 50 percent of payment value accounted for by the top-5 banks (EKL). While this concentration may endogenously arise to facilitate efficient financial transactions, it also increases systemic risk through greater interconnect-edness (Erol and Vohra, 2020). In particular, the dependence on core institutions of the network to settle large-value transactions and assist in the flow of liquidity makes the sys-

Table 1: Wholesale payment activity and market uncertainty. The table shows linear regressions of aggregate Fedwire payments value on the VIX and aggregate reserves, all averaged to monthly frequency, and year fixed effects. Heteroskedasticity-consistent standard errors are reported in parentheses. Sample is April 1997 to December 2020.

	Agg. payments	
	(1)	(2)
VIX	7.688*** (2.033)	6.854*** (2.634)
Agg. reserves		0.162* (0.087)
Year FEs	Yes	Yes
Observations	285	285
Adj. within- R^2	0.121	0.157

tem susceptible to large liquidity dislocations and payment issues if the operations of any key payment bank fail.

Over the course of March 2020, the concentration of payment activity increased. Figure 2 plots the trailing 5-day average share of payment value of the top-5 banks. The top-5 banks' share of daily payment value rises by about 3 percentage points at its peak on March 18 (roughly two times the share's standard deviation in 2020), before falling and stabilizing at levels comparable to the beginning of the year. In sum, not only is there more payment activity, but payment activity becomes more concentrated in times of high market uncertainty.

Risk of coordination failure. A regime with ample reserves should, among other things, satiate liquidity needs associated with payment activity. When liquidity needs are satisfied, banks may send payments asynchronously without concern for their overall liquidity positions, as the exact timing of payments expected to be received is unlikely to adversely affect overall liquidity positions.

As liquidity becomes scarce, banks more closely manage intraday liquidity by strategically timing payments to better match inflows and outflows, effectively avoiding liquidity shortages (McAndrews and Rajan, 2000). Under intraday liquidity stress, the propensity for banks to delay or halt payment activity in response to irregular payment flows increases (Bech and Garratt, 2003). This form of liquidity hoarding can, in turn, trigger other institutions to hoard liquidity. Individual banks' attempts to preserve their liquidity thus

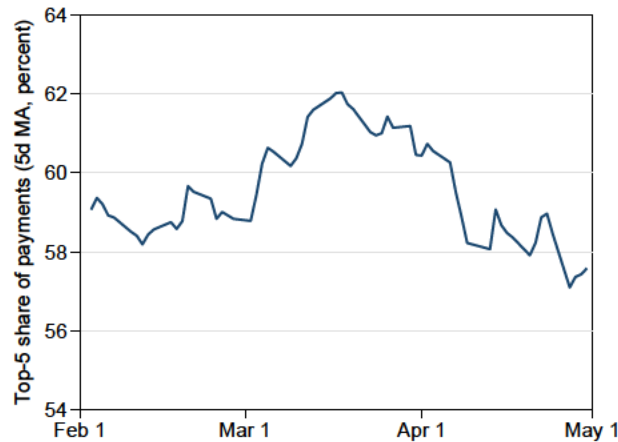


Figure 2: Concentration of payment activity. The figure shows the trailing 5-day average share of payment value of the top-5 banks.

represents a form of coordination failure.

There were several indications that the wholesale payment system became more susceptible to coordination failure in the Covid-19 market turmoil. To start, at an institution level, liquidity needs associated with payment activity grew significantly. One way to see this is to examine a bank's payment activity relative to its reserves. For the top-5 banks, the ratio of daily payments over reserves increased by almost 50 percent, from about 4 to almost 6 in March 2020 before dropping to about 2 in April. In contrast, the ratio didn't change notably for non-top-5 banks (Figure 3, left panel).

Banks typically manage their reserve balance to maintain a desirable level of liquidity. In theory, payments volume could increase but could do so predictably and banks may still be able to manage their reserve balances. However, if greater and more volatile payments made reserve management more difficult, individual banks would have faced greater liquidity risks to processing payments. The increase in payment-related liquidity needs appear to have affected banks' abilities to manage a stable reserve balance. The right panel of Figure 3 plots the trailing 30-day standard deviation in reserve balances for the most active banks in Fedwire. From mid-February to mid-April, the standard deviation in daily reserves for the top-5 banks increases by roughly a factor of 4.

An informative signal of intraday liquidity stress is delays in settlement times. When banks think their reserves may be scarce, they tend to delay payments until later in the day in order to secure sufficient reserve balances at the end of the day. This coordinated payment behavior was more prevalent pre-2008, when reserves were scarce. These strategic considerations had noticeably diminished post-crisis, due to the dramatic increase in aggregate reserves (Bech, Martin, and McAndrews, 2012).

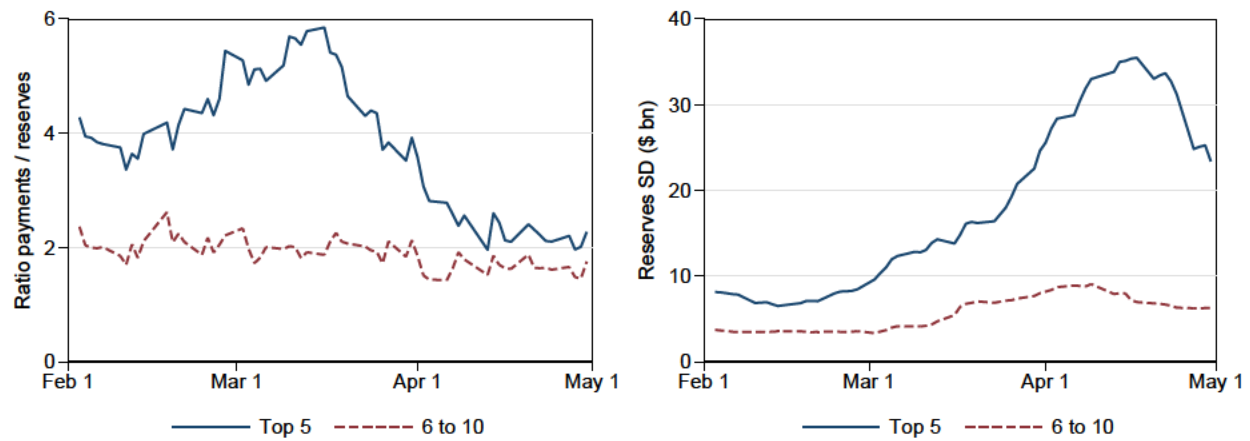


Figure 3: Payment-related liquidity needs and reserve balance volatility. The left panel shows the ratio of average payment value to average reserves for the top-5 banks and for the banks ranked 6 to 10. The right panel shows the trailing 30-day standard deviation of banks' reserve balance, averaged across the top-5 banks and for the banks ranked 6 to 10.

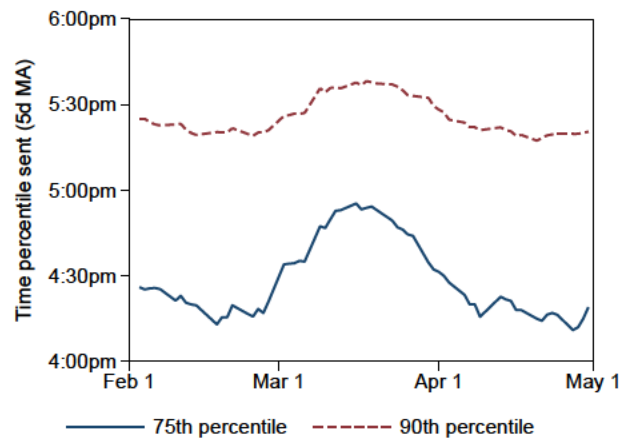


Figure 4: Settlement times of late payments. The figure shows the 5-day moving average of the times by which 75% and 90% of intraday payment value are sent.

However, in March 2020, settlement times of late payments noticeably stretched to the end-of-day. Figure 4 shows the timing of the 75th and 90th percentiles of intraday payment value. Delays begin in late February, around the mark where the VIX increases, and continue to rise until mid-March. In sum, the wholesale payment system is more susceptible to coordination failure in times of high market uncertainty.

Heightened payment activity, concentration of payments, and intraday liquidity stress during market turmoil have implications for the amplification of a cyber attack through the financial system. In the context of the wholesale payment system, a cyber attack could be timed at periods where payment activity is heightened. As shown in EKL, the system-level impact of an attack varies over time, and increases when payment activity is greater. An attacker could view periods of high financial market uncertainty as a proxy for greater impact to the system as a whole and use it to time attacks. The greater concentration in payment activity could mean that a pointed attack on a key institution could have a greater impact on the network as well. The shock could be further exacerbated by other banks' reactions, especially with greater intraday liquidity stress. This seems likely to occur when payments volumes are high and volatile and banks may be incentivized to conserve reserves or think strategically about payments timing.

3 Cyber vulnerability during adverse market conditions

We adopt the cyber scenario approach used in EKL in a form modified for the analysis of adverse market conditions in 2020. A scenario specifies (i) the target institution, (ii) the reaction function of other banks, and (iii) the time it takes to recover. In a scenario, a cyber attack is assumed to compromise normal functioning of a target institution at the beginning of a Fedwire day, by affecting the availability or integrity of the attacked institution's systems or data. For example, a cyber attack may impair the availability of relevant data or communication and messaging systems of an institution, or may compromise the integrity of its operations either by manipulating or corrupting the data. In both instances, the attack may stifle the attacked institution's ability or willingness to perform large-value payments on behalf of its clients and its own operations. See EKL for a detailed discussion.

As a consequence of the attack, the target institution is assumed to be able to receive but unable to send any payments on Fedwire. This assumption reflects an institutional feature of Fedwire, where payments are actualized when Fedwire receives a payment request from the sender. An institution's balance in Fedwire changes with incoming payments, even if the institution is unable to observe or interact with the Fedwire network due to a

cyber incident. For the duration of the impairment, an attacked institution soaks up liquidity without releasing payments, restricting the flow of liquidity — a problem which was observed following the attacks on September 11, 2001 (Lacker, 2004).

Evaluating the severity of a cyber event requires pinning down conditions under which the liquidity positions of other banks, which are not directly attacked, should be considered as materially impaired. Our analysis follows a variation of the approach used by EKL: Bank i is impaired if its counterfactual end-of-day reserve balance r_t^i drops below a time-varying threshold b_t^i given by

$$b_t^i = \left(1 - \frac{2\sigma_{\text{ref}}^i}{\bar{r}_{\text{ref}}^i}\right) \bar{r}_t^i,$$

where \bar{r}_t^i is the past 30-day average reserve balance of bank i at time t , and σ_{ref}^i and \bar{r}_{ref}^i are the trailing 30-day standard deviation and average of bank i 's reserve balance at a reference date. The reference date is set to February 19, the point at which the VIX begins to rise.² Here, \bar{r}_t^i is meant to capture a time-varying target reserve balance of bank i , and the ratio $2\sigma_{\text{ref}}^i/\bar{r}_{\text{ref}}^i$ represents a liquidity buffer ratio of two standard deviations during normal times. Because the effective liquidity buffer scales with the trailing average balance, the threshold adjusts to the changing quantity of reserves observed in the latter part of the sample. Results are not sensitive to the details of the impairment threshold, and remain similar using the same threshold definition as in EKL.³

3.1 Baseline scenario

The baseline scenario examines the impact of an attack on a top-5 bank, assuming no reaction by other banks and focusing only on the first day. Figure 5 summarizes the impact of attacks on each of the five institutions, showing the average across all days in 2020 (bars) as well as percentiles of the distribution across days (whiskers) and the maximal impact during the month of March 2020 (dots). The unweighted share is the raw fraction of impaired institutions, and the weighted share is the fraction of impaired institutions weighted by

²The reference date was chosen to pin down a relevant buffer prior to market turmoil. The specific reference date does not matter for the results.

³The threshold differs in two ways from that used in EKL, which is given by $b_t^i = \bar{r}_t^i - 2\sigma_t^i$, where σ_t^i represents the standard deviation in the past 30-day reserve balance of bank i at time t . First, a reference date is used to pin down the buffer for all dates. This is because the variation in end-of-day balance during a period of severe market turmoil is unlikely to reflect a bank's tolerance toward reserve volatility but rather reflects intraday liquidity stress. Second, the buffer is taken to be proportional to the trailing average balance at time t , to account for changes in the quantity of reserves held by banks.

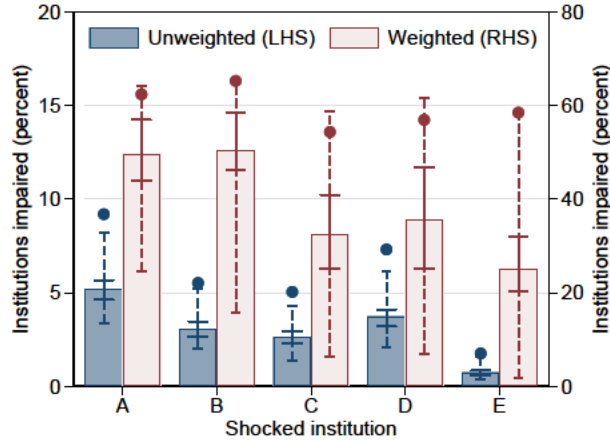


Figure 5: Impact of an attack on a top-5 bank. The figure shows the distribution across days of the unweighted share of institutions impaired by a shock to each of the top-5 institutions and of the share weighted by payments (excluding the attacked institution). Bars represent the average impact; solid whiskers represent the p25/p75 range; dashed whiskers the p1/p99 range; dots show the maximum impact days in March.

their payments in 2020 (not including the attached institution itself).⁴ As in EKL, where a similar scenario is considered on 2018 data, the weighted shares are considerably larger than the unweighted shares, reflecting the concentration of payment activity, and the variation across days is at least as large as the variation across attacked institution. Our focus is on the maximal impact during the month of March 2020, as represented by the dots in the figure. As anticipated, the worst impact in the time of market turmoil is close to or even above the 99th percentile across all of 2020, both in terms of raw share and weighted share.

Figure 6 shows the time series of the impact of an attack, averaged across the top-5 banks. The weighted impact starts out fairly high and, after a dip in mid-February it steadily climbs until March 3, when the first cut of the Federal Funds target rate of 50 basis points was announced. At the peak, around 60 percent of institutions by payment share would have been impaired in an attack on a top-5 bank, compared to around 40 percent on average across all of 2020. While the raw share of impaired banks increased throughout March and peaks on March 30, the weighted share decreases dramatically through the end of March, which we explore in greater detail when discussing the mitigating effects of policy interventions in Section 4.

⁴Similar results are obtained when institutions are weighted by assets. Weighting by payment share enables the analysis to take into account the impact on branches of FBOs, which account for a significant fraction of both payments and reserves.

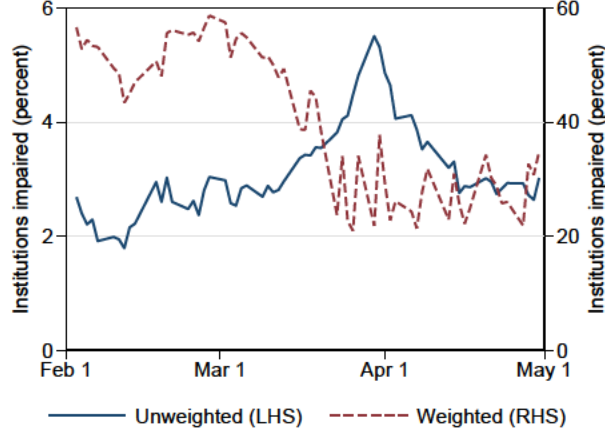


Figure 6: Average impact of an attack on a top-5 bank. The figure shows the daily time series of the impact of an attack, averaged across the top-5 banks.

3.2 Cascade scenario and coordination failure

The analysis in the previous section assumes that all institutions, other than the directly attacked institution continue to make payments as usual. This non-reaction of banks assumes that banks may not be sensitive to intraday liquidity conditions, and hence, may not react to abnormal conditions experienced throughout the course of a day. However, in Section 2 we show evidence of intraday liquidity stress in late February and March which suggests that other banks are likely to react to large deficits in intraday liquidity positions by delaying or halting payment activity. Furthermore, relative to a typical operational outage, a suspected cyber attack may be accompanied by greater uncertainty and a lack of common knowledge regarding the source, magnitude, and recovery. This uncertainty could be exacerbated by attacked banks, who may be reluctant to disclose to counterparties and clients the exact state of their internal systems or data.

To evaluate the potential impact when banks react, this section considers the cascade scenario as in EKL. Banks are assumed to react to severely adverse intraday liquidity positions by hoarding liquidity. Specifically, banks are assumed to follow a trigger strategy: Whenever the counterfactual net payment deficit passes some liquidity-hoarding threshold, the bank is assumed to halt payments for the remainder of the Fedwire day. As in EKL, the liquidity-hoarding threshold is set to equal the maximum realized net payment deficit of the institution in the entire year of 2020.⁵

A priori, it is not clear if the impact should be greater in the cascade scenario as it involves some banks actively preserving their liquidity position which helps them but hurts

⁵Given the high value of payments that occurred, particularly in March 2020, the liquidity-hoarding threshold is a conservative cutoff.

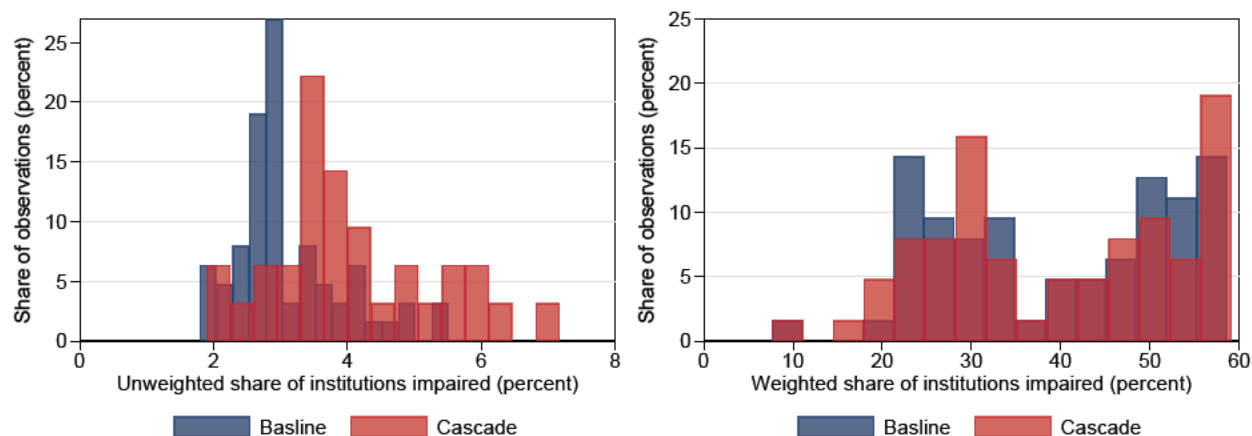


Figure 7: Comparison of simple and cascade scenario for February to April 2020. The figure shows the distribution across days of the impact for the baseline scenario and the cascade scenario for February to April 2020, averaged across the top-5 institutions. The left panel shows the unweighted share of impaired institutions. The right panel shows the share of impaired institutions weighted by payments (excluding the attacked institution).

others. Figure 7 compares the impact in the simple and cascade scenario involving top-5 banks, for the period of February to March. Impact is slightly greater under the cascade scenario with a more notable shift in the distribution of the raw share of institutions. This is consistent with the core periphery structure of the payments network and suggests that the large core banks’ hoarding at the expense of more periphery banks becoming impaired.

An additional risk in the cascade scenario pertains to the payments that are not made as a result of hoarding behavior. In contrast to the simple scenario, systemic risk sprouts not only from the compromised liquidity positions of banks, but also from system-level disruptions in payment activity that supports financial markets and the broader economy. Figure 8 shows the average daily forgone payment value in the cascade scenario, both the payments foregone by the attacked institution and the payments foregone by other institutions due to the cascade. Both increase considerably in March but the foregone payments from the cascade notably more so, reaching close to the level of the foregone payments of the attacked institution.

3.3 The consequences of delayed recovery

So far, the analysis focused on the single-day impact of a cyber attack. An extended cyber incident, due to delays in operational recovery, however, may result in deeper consequences for the system. Recovery is one of five functions of the NIST cybersecurity framework, along with Identify, Protect, Detect, and Respond, and pertains to timely recover to

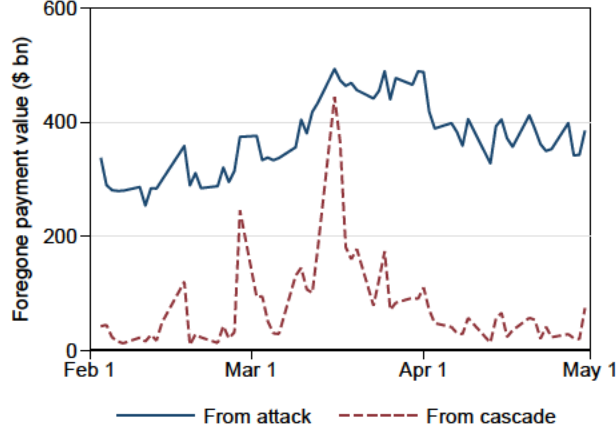


Figure 8: Foregone payment value in cascade scenario. The figure shows the payments foregone by the attacked institution and the payments foregone by other institutions due to the cascade., averaged across the top-5 institutions.

normal operations to reduce the impact from a cybersecurity incident. The extent to which an attacked institution is able to restore its capabilities and services that were impaired depends on the strengths of its recovery function.

We examine the impact of delayed recovery from a cyber attack by extending the baseline one-day scenario to consider a multi-day scenario, following the approach of EKL. The multi-day scenario maintains the assumption that banks other than the attacked institution continue to make payments as usual. This allows us to analyze the severity of liquidity dislocations grows with each day, and the emergency liquidity support that may be required.

Starting with the day of the attack, we cumulate the set of impaired institutions across additional days, such that the n -day share impaired is equal to the share of institutions that become impaired as a result of payment deficits arising from day 1 to day n . The results are summarized in the left panel of Figure 9. The impact of an attack averaged across the top-5 banks substantially increases with a delayed recovery in late February to mid March, with the net weighted share increasing from about 45 percent on day one, to over 70 percent by day five. In other words, by the fifth day, the vast majority of the network (by payment share) is put in a compromised liquidity position as a result of the cyber attack.

However, the increase in the share of impaired institutions provides only a partial picture of the severity of a prolonged disruption to a top-5 bank, especially during the period of adverse market conditions. In particular, delayed recovery increases the severity of liquidity dislocations as many institutions' reserve balance can drop below zero in the scenario. It is therefore instructive to quantify the short-term liquidity support that would be

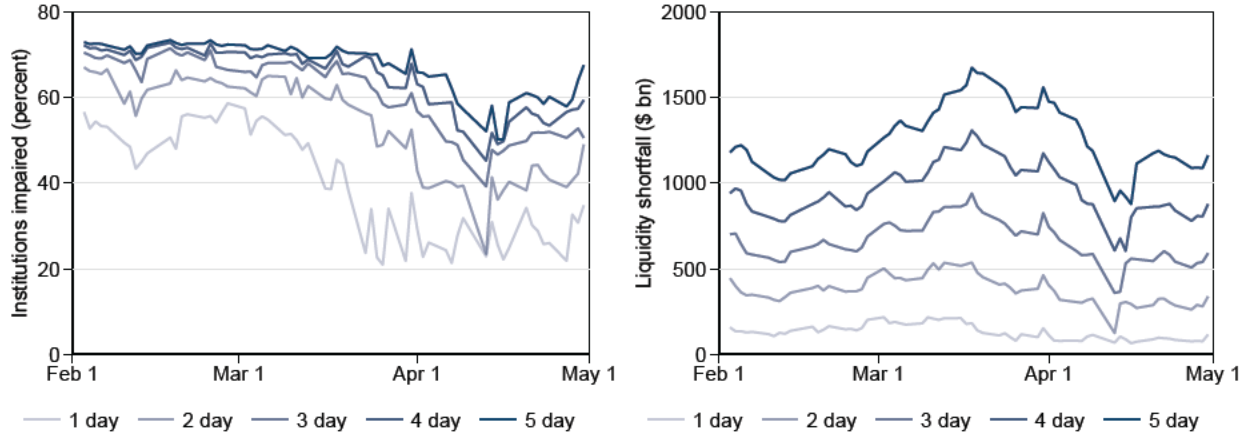


Figure 9: Multi-day scenario. The left panel shows the weighted share of impaired institutions for each multi-day scenario, averaged across the top-5 institutions. The right panel shows the total liquidity shortfall of impaired institutions for each multi-day scenario, averaged across the top-5 institutions.

required to restore the reserve balances of impaired banks back to the impairment threshold. The right panel of Figure 9 shows the aggregate liquidity shortfall, defined as the gap between institutions' impairment thresholds and their counterfactual reserve balance, aggregated across all impaired institutions. Averaged across 2020, the liquidity shortfall grows from \$120 billion on day one to \$1.1 trillion on day five. By comparison, in March, the liquidity shortfall increases from \$164 billion to almost \$1.5 trillion over the five days, reaching a peak of almost \$1.7 trillion.

3.4 Attack on DFMUs

Finally, we consider a scenario involving an attack on designated financial market utilities (DFMUs) that impairs the systems of the attacked institution, as in the baseline scenario. We focus on two DFMUs: CHIPS, a wholesale payment system that offers multilateral netting benefits, and CLS, which provides settlement across different currencies' payment systems and is a key part of the infrastructure for global foreign exchange markets. In the event that either DFMU were to be rendered inoperable, banks could attempt to divert relevant payments to Fedwire. However, both DFMUs offer specific benefits that Fedwire does not. In particular, member institutions would no longer be able to realize the liquidity and capital savings associated with netting (CHIPS and CLS) and counterparty risk protections (CLS).

Although we cannot analyze directly the transactions between institutions on DFMUs, both CHIPS and CLS depend on Fedwire to settle participants' net payment obligations.

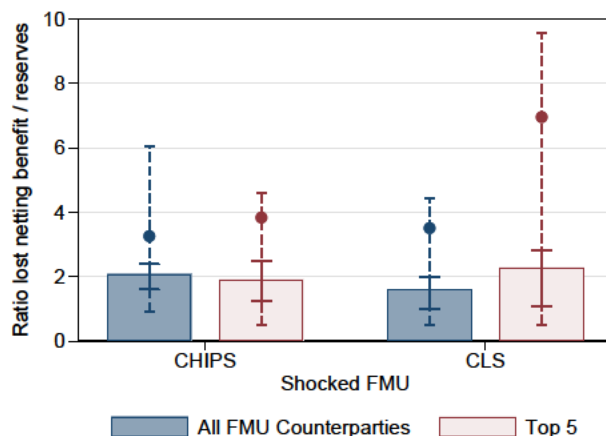


Figure 10: Lost netting benefits in DFMU scenario. The figure shows the distribution of the estimated value of failed payments on CHIPS and CLS, scaled by daily reserve balances of each bank. Bars represent the average ratio; solid whiskers represent the p25/p75 range; dashed whiskers represent the p1/p99 range; dots show the maximum impact days in March.

Using the observed flows between banks and the DFMUs on Fedwire, and the gross value of payments processed within CHIPS and CLS from public data, we can approximate the netting benefits of a DFMU by taking the ratio of the (gross) activity on the DFMU to the (net) flows to the DFMU on Fedwire. To approximate an individual bank’s daily netting benefits, we scale the daily aggregate gross-to-net ratio by the bank’s daily payments to the DFMU.

Figure 10 summarizes the lost netting benefits, normalized by banks’ reserves for CHIPS and CLS. The additional payment value that would need to be executed in Fedwire is significant, about two times banks’ reserve balances on average. The dots correspond to the largest impact days in March 2020, which are in the right tail of the distribution for both CHIPS and CLS.

4 Mitigating factors and policy response considerations

The previous section showed that system-level cyber vulnerability was generally elevated during the market turmoil in early 2020. These results may be an underestimate as they do not incorporate any feedback effect on financial markets trading in response to a cyber attack. Perhaps surprisingly, the largest impact as measured by the weighted share of institutions impaired was in late February and early March and then declined dramatically through the end of March (Figure 6). Policy interventions intended to stabilize financial

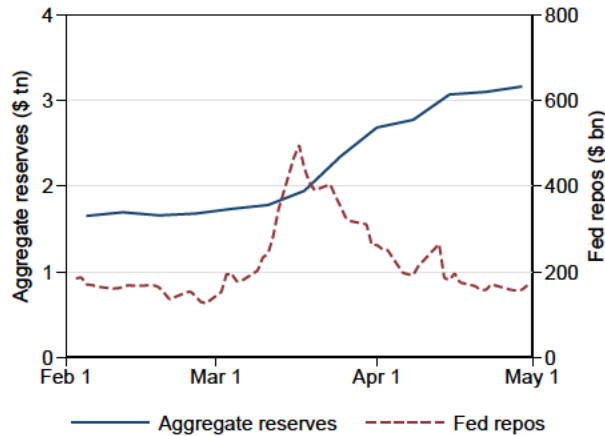


Figure 11: Aggregate reserves and Fed repo operations. The figure shows the level of aggregate reserves and the outstanding amount of Federal Reserve repo operations (overnight and term).

markets therefore had the unintended benefit of also mitigating systemic cyber vulnerability. In particular, the steep decline in network impact that starts in the second week of March coincides with the large increase in aggregate reserves resulting from Federal Reserve asset purchases (Figure 11). With the steep increase in reserves across the system, banks’ liquidity positions became more resilient to disruptions in payment flows.

As pointed out earlier, the weighted impact of an attack on a top-5 bank begins to drop even earlier, in the first week of March while the unweighted impact continues to increase through the end of March. A potential explanation is the liquidity injected through the Fed’s repo operations that started increasing at the beginning of March and were further expanded on March 9 and March 16.⁶ Dealers’ repo activity during this time has been linked to trades with affiliated large banks (Carlson, Saravay, and Tian, 2021). If these operations increased mainly the liquidity positions of the largest banks, they can explain the disconnect between the weighted and unweighted impacts over the course of March.

Indeed, in an environment with abundant reserves, the potential for a cyber attack to have broader systemic impact is dramatically reduced by some measures. For one, the significant increase in aggregate reserves contributed to a lower average impact in the post-March period. From an ex-ante standpoint, operating under an abundant reserves regime can improve the resiliency of the system to illiquidity episodes caused by a cyber event. Another potential benefit of an abundant reserve environment is lowering the propensity for banks to strategically hoard liquidity in response to abnormal payment activity result-

⁶See statements https://www.newyorkfed.org/markets/opolicy/operating_policy_200309 and https://www.newyorkfed.org/markets/opolicy/operating_policy_200316, respectively

ing from a cyber event. From an ex-post standpoint, offering easy access to emergency liquidity to banks experiencing short-term shortages reduce the risk of coordination failure and of transmission to other counterparties and markets.

The provision of liquidity is an effective, if blunt solution to improving resiliency to systemic cyber risk. However, as shown in the multi-day scenario analysis, a cyber event that goes unresolved for an extended period of time can require extraordinary levels of emergency liquidity injections (Figure 9). Although the discount window could, in principle, facilitate short-term access to liquidity, the levels required could quickly exceed permissible amounts based on impaired banks' unencumbered collateral. Furthermore, the multi-day scenario does not account for run-like behavior in other financial markets. The failure to remedy the operational issues sprouting from a cyber event could trigger financial instability across markets.

Another potential policy response involves directly addressing payment disruptions by using an emergency payment processor that can make payments on behalf of a bank directly impaired by an attack.⁷ This form of response, which targets the root of the operational issue, has the advantage of containing the impact to those directly affected by a cyber event, and can reduce the set of counterparties with whom regulators must coordinate to maintain normal functioning. In addition, it has a stabilizing effect on the wholesale payment system by negating potential spillovers to other banks, thereby reducing the scope for coordination failures among other banks.

Implementation could involve a combination of an emergency payment processing system and a latent data back-up system for key institutions of the network, e.g., in the spirit of Sheltered Harbor.⁸ When activated, clients of the impaired institution could be granted access to submit payment requests directly to the payment processing system. The data back-up system could be used to identify clients and assist the impaired institution in authorizing payments. A related proposal put forth by Duffie and Younger (2019) recommends a standby narrow payment-bank utility that provides emergency payment processing services to critical non-bank financial institutions during operational emergencies. At heart, the goal would be to develop operational redundancies for the broader financial system that would be activated only in emergency situations.

The two forms of policy responses, the emergency provision of liquidity and of operational support, are complements. An abundance in aggregate reserves and accessibility

⁷Although Fedwire can facilitate emergency payments for banks experiencing operational issues, only a set of prioritized payments can be processed in a timely manner.

⁸Sheltered Harbor is a not-for-profit industry-led initiative to have institutions regularly back up critical customer account data in a standardized format in case of an operational outage (<https://www.shelteredharbor.org/>)

to emergency liquidity can increase general resiliency to short-term cyber disruptions. For severe cyber incidents involving longer durations of recovery and for those involving key institutions of the network, an emergency payment system could be more efficient and effective at ensuring that markets function as usual, in parallel with the process of recovering an affected institution's operations.

To the extent that the payments proxy for financial transactions and that consumers and businesses would be reluctant to engage in those transactions with a bank impaired by a cyber attack, reserves and payment solutions may not have the same ameliorative effect. For example, if an impaired bank is a lender and cannot access books and records to authorize funds, payments may not be able to be made. While liquidity would not be the key source of amplification, it is possible that financial and real transactions would be hampered even if the payments issues were solved.

5 Conclusion

Increasing digitization is accompanied by increasing cyber risk. If cyber attacks are perpetrated for financial gain, they may occur randomly, or even be designed to cause only enough damage to achieve a lucrative ransom, but not so much damage that national authorities and law enforcement become engaged. In contrast, cyber attacks in pursuit of geopolitical goals are likely to occur in ways that are timed for maximum damage. In this paper, we show that the financial system is particularly vulnerable to cyber risk when uncertainty is high and prices are changing rapidly. This increase in vulnerability arises from the increase in payments volumes that accompany increased trading, as well as through the concentration of high dollar value payments among a relatively small set of systemically important banks. When considering policy responses, the optimal response to a malicious cyber attack may be very different, however, as the system must be resilient to the potentially higher amount of liquidity required in a situation with financial market volatility. Measures such as asset purchases may result in the increased reserves which can help to buffer these shocks.

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