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THE CASE OF CENTRAL COUNTERPARTIES

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Stress Testing Networks: The Case of Central Counterparties
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ABSTRACT

Stress tests applied to individual institutions are an important tool for evaluating financial resilience. However, financial systems are typically complex, heterogeneous and rapidly changing, raising questions about the adequacy of conventional tests. In this paper, we interpret the current stress test practice from a network perspective, highlighting central counterparties (CCPs) as an example of a critical network hub. Networks that include CCPs involve deep and broad interconnections, making stress testing a challenging task. We analyze supplementing both private and supervisory CCP stress tests with a high-frequency indicator constructed from a market-based estimate of the conditional capital shortfall (SRISK) of the CCP's clearing members. Applying our measure to two large CCPs, we analyze how they can transmit and amplify shocks across borders, conditional on the exhaustion of prefunded resources. Our results highlight how the network created by central clearing can act as an important transmission mechanism for shocks emanating from Europe.

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I. Introduction

Complex and diverse links among financial market participants across financial activities and borders are a defining characteristic of the modern financial system. Indeed, they are what make it a system, rather than merely a collection of individual firms and markets. Connections can be direct, indirect, or both. For example, firms are directly connected through mutual counterparty exposures and indirectly connected to other firms who are counterparties of their counterparties. Similarly, firms have indirect linkages through holdings of correlated portfolios of assets and through common funding and resolution mechanisms.

Interconnectedness creates both economic benefits and financial vulnerabilities. The process of financial intermediation can be simple, but to satisfy client needs, firms may innovate, creating new products, or connecting to specialized firms to obtain them. The rapid growth of securitization and derivatives markets before the crisis was a good example. The resulting elaborate division of labor among suppliers reduced the costs of intermediation and helped to diversify or share risks. Similarly, other services provide the processing required for completing financial transactions.

The diversity created by interconnections can add to financial system resilience. As then-Fed Chair Janet Yellen noted in 2013, the more complete is the network of interconnections, the more resilient it may be: "The principle behind this result is familiar and basic to economics: Diversification reduces risk and improves stability."

However, interconnections can also act as channels for transmitting and amplifying shocks. Liquidity or credit shocks in one part of the financial system may spread to other parts, resulting in runs and fire sales. In addition to being more complex, interconnected systems or networks tend to be more opaque. The combination can blind market participants to the nature and extent of exposures and can trigger individually rational but collectively destabilizing behavior, amplifying the effects of an initial shock. More concentrated, highly interconnected systems with a few key players can be particularly vulnerable to shocks unless these institutions are highly resilient. Even where direct linkages are sparse, common exposures can generate herding, amplifying shocks.

Two aspects of interconnectedness illustrate these benefits and costs. First, linkages in networks for payments, clearing, and settlement offer clear benefits for efficiency and risk management. Second, heterogeneous networks that operate across jurisdictions with different laws and regulatory frameworks can distort competition among market participants.

Analyzing and monitoring interconnectedness, and the benefits and vulnerabilities it creates, requires a systemwide, granular approach. Researchers suggest two broad methodologies for addressing this challenge. One relies on estimation of models from market price data and perhaps some details on quantities. Such a non-network approach relies on the validity of the model and its applicability to stress events. Examples include the development of so-called cross-sectional measures like CoVaR, the default insurance premium (DIP), marginal expected shortfall, and SRISK. The other approach starts with mapping the network and then uses various graph-theoretic tools to assess the strength of transmission mechanisms through both direct and indirect exposures.[1]

[1] See Kara, Tian and Yellen (2015) for a taxonomy of these two approaches.

Analysis of interconnectedness is critical for policy judgments. Equally important, researchers and policymakers need detailed, consistent, timely data on counterparty exposures (including derivatives transactions) to assess and monitor interconnectedness. Challenges remain in collecting granular data, in assuring the confidentiality and security of those data, and in developing methodologies to reconstruct the full network from partial information, when full data are unavailable. In addition, analysts necessarily customize network analysis to the special characteristics of each financial network, including its topology, the heterogeneity of its participants, and the speed with which it can become vulnerable.

Central counterparties (CCPs) are arguably the most interconnected of all financial institutions. Indeed, they have a host of counterparties, some of which also are very large and interconnected, and some of which are highly leveraged. It is relatively straightforward to map these connections, making them a natural object for applying network analysis. CCPs also conduct an enormous volume of transactions and may provide critical services for which there are no short-run substitutes. Hence, the study of these financial market utilities is essential for assessing and securing financial stability: What makes CCPs a source of systemic vulnerability? How might we determine the potential for these network hubs to transmit and amplify shocks? How can we mitigate the vulnerability?

Following this introduction, we start with a description of stress testing, including a discussion of why it is such a valuable tool for determining financial system resilience. We then move to a discussion of the topology of networks and the challenge of testing their fragility. Finally, we turn to CCPs, critical nodes in numerous, highly interconnected financial networks. After discussing the characteristics of CCPs, we suggest a metric for assessing the extent to which they would likely transmit and amplify shocks. Unlike most studies of CCP resilience that focus on the adequacy of pre-funded resources, we consider the impact on the financial system in the event that these resources run out.

Our customized CCP network risk measure starts with SRISK—an estimate of the capital shortfall following a large decline in the global equity market—of a CCP's clearing members (CMs). We analyze an index based on a weighted sum of each CM's SRISK as a measure of the degree to which the CCP adds to the fragility of the system. Not surprisingly, that contribution depends on the level of capital in the system. Applying a version of this index each to the Chicago Mercantile Exchange (CME) and to the London Clearing House (LCH) allows us to draw two conclusions. First, we confirm that they would likely come under stress simultaneously, as many of the CMs of the CME and LCH are the same. Second, our results reveal that the U.S.-domiciled CME currently has substantial exposure to European banks. As a result, an important source of fragility in these well-defined networks emanates from the relatively low capitalization (relative to the likely losses following a significant global shock) of European banks.

II. Preliminaries

"Supervisory stress testing has become a cornerstone of post-crisis prudential regulation. Stress testing, unlike traditional capital requirements, provides a forward-looking assessment of losses that would be suffered under adverse economic scenarios. The simultaneous testing of the largest firms lends a perspective on a large part of the banking system and facilitates identification of common exposures and risks." Federal Reserve Board Governor Daniel K. Tarullo, September 26, 2016.

Stress testing assesses the losses a financial institution would suffer under very adverse macroeconomic conditions. The practice has been around for decades. A risk manager might calculate the sensitivity of their firm's balance sheet to stress equivalent to that during a specific historical episode like the stock market crash of October 1987 or the fall 1998 collapse of Long Term Capital Management, simulating the impact on the value of the bank's assets. The bank's management could use the resulting report for both planning its capital levels, setting its risk tolerance and managing its risk.

As Schuermann (2014) describes, comprehensive stress testing encompassing all the financial risks of a bank only emerged during and after the financial crisis. In late 2008, the solvency of the largest U.S. intermediaries was in doubt. That uncertainty made their own managers cautious about taking risk and it made potential creditors, counterparties and customers wary of doing business with them. Those doubts contributed to the extreme fragility in many financial markets, leading to a virtual collapse of interbank lending.

In an effort to restore confidence, the Federal Reserve, the Office of the Comptroller of the Currency, and the Federal Deposit Insurance Corporation jointly conducted an extraordinary set of stress tests on 19 bank holding companies, publishing the results in May 2009.[2] The tests evaluated, on a common basis, the prospective capital needs of the 19 largest U.S. banks in light of the deep recession that was well under way. While observers questioned whether the tests were stringent enough—the adverse scenario quickly turned into the central forecast—the results were sufficiently credible to reassure the government, market participants, and the banks themselves that most of the institutions were in fact solvent. Together with the backstop provided by earlier guarantees of new senior bank debt[3], this new information fostered rapid improvement in financial conditions. And, armed with evidence of their wellbeing, most large banks were able to attract new private capital for the first time since the Lehman failure the previous September. This experience underscores how stress tests enhance the quality of public and private information thereby supporting market discipline and promoting high-quality supervision.[4]

Today, stress tests have a broad set of objectives. First, they can help with the notoriously difficult tasks of measuring the size of a capital buffer and calibrating the appropriate amount of self-insurance an institution should have. How risky are assets? What portion of capital is truly loss absorbing when a severely adverse shock hits? What happens to capital levels in the event of a severe recession that

[2] See Board of Governors of the Federal Reserve System (2009).
[3] See Federal Deposit Insurance Corporation (2013).
[4] For more on the history and uses of stress tests, see Cecchetti and Schoenholtz (2016). For a survey of their current widespread use, see Basel Committee on Banking Supervision (2017).

causes widespread distress? What are the consequences of adverse conditions for off-balance sheet exposure?

Second, risk management practices rely on evaluating potential losses under adverse conditions. What scenarios are appropriate for making such an evaluation? Are internal processes and information systems sufficient to monitor and mitigate risks that arise from the manner in which the institution conducts its various lines of business? Stress tests help guarantee that robust processes and information systems are in place.[5]

Third, are an institution's senior management and board of directors sufficiently attentive to the risks their enterprises face? Is there sufficient transparency—even internally—regarding the firm's assets, liabilities and off-balance sheet exposures? Does available data provide an accurate and comprehensive picture of risks the organization faces? Stress tests help managers, supervisors, market participants, and the public make informed decisions about the firm's resilience.

It is important to distinguish *micro*prudential from *macro*prudential tests. The former have been around from some time and measure losses that a public guarantor would suffer following the collapse of an *individual institution* that results from a firm-specific shock. The three objectives—assessing an institution's resilience, improving risk management practices, and informing critical parties both inside and outside the firm—apply to such tests.

By contrast, a macroprudential test is designed to evaluate a how a *system's* capital adequacy and liquidity conditions respond to an aggregate shock that hits all institutions simultaneously. In this second case, the concern is less with the solvency or survival of an individual bank or nonbank financial institution, but with the extent to which the shock affects the system as whole. While there is surely significant overlap between microprudential and macroprudential tests, the latter focuses on ensuring the system can still perform critical functions—such as clearing and settling payments or supplying credit to healthy borrowers. Unlike a microprudential test, it accounts for externalities and spillovers in the event that individual entities should fail.

The ultimate goal of a macroprudential test is to map the network of exposures, identifying weaknesses that may not be apparent to anyone lacking a complete view of the system. Such stress tests can be a guide to legislatures in calibrating regulation to make a system's resilience consistent with the society's preferences for the frequency with which systemic events require the use of public resources.[6]

Turning to a test's structure, we can evaluate any macroprudential test by looking at three attributes: transparency, flexibility and severity.[7] The mix of these characteristics determines the regime's effectiveness.

To understand the tradeoffs and pitfalls of the process, consider the case of Fannie Mae and Freddie Mac, the government-sponsored enterprises (GSEs) that serve as mortgage lenders and guarantors. As Frame et al. (2015) describe, unlike banks, the GSEs were subject to an annual government stress test *before* the financial crisis. Following a decade of development, the Office of Federal Housing Enterprise Oversight (OFHEO) began conducting tests in 2001. The GSEs always passed—until they collapsed at the

[5] See Counterparty Risk Management Policy Group (2008).
[6] See the discussion in Cecchetti and Tucker (2015).
[7] See Clark and Ryu (2015).

height of the crisis in September 2008. We can trace the ineffectiveness of these early stress tests to their mix of transparency, flexibility and severity. First, there was complete transparency: OFHEO published the models and scenarios in the Federal Register prior to initiating the tests. Second, there was no flexibility: from year to year, the parameters and the macroeconomic conditions were unchanged. Third, the stress applied was insufficiently severe: house prices *rose* for the first 10 quarters of the scenario, before falling only modestly over the full 8-year horizon.

Is any of these three dimensions (transparency, flexibility and severity) more critical than the other two? The answer is yes. First, if the scenarios are insufficiently dire, there is no point to the test. Second, flexibility is essential. Without it, the tests become a mechanical exercise instead of one that adapts to shifting economic environments, changing business models, new products, and adjustments in risk-taking behaviors. This relates to severity: What may have appeared adverse in one year could look mild the next. Third, while there is considerable room for transparency, there are limits. Because models change slowly, and banks can glean considerable information about the supervisor's models from experience with past tests, disclosure of these models is unlikely to be a problem. Premature disclosure of the scenarios is another matter: in contrast to the GSE tests, under the Fed's current Comprehensive Capital Analysis and Review (CCAR) tests, the scenarios change frequently and are disclosed only *after* the banks' portfolios are determined. The alternative invites gaming, allowing firms to manage to the test.[8]

It is also important that stress tests be frequent, comparable over time and coherent. If supervisory tests occur less than once per year, they may miss material changes in the health of system. Without comparability from one to the next, the results would be difficult to interpret. By coherence, we mean that any scenario has to have a reasonable degree of plausibility.[9] Specifically, the combination of changes in growth, unemployment, inflation, interest rates, property prices, risk spreads, and the like, needs to fit together. For example, we would not envision as reasonable a scenario in which a fall in unemployment accompanies a severe recession; or where a sizable increase in inflation comes along with a dramatic decline in nominal interest rates. Now, this leaves substantial latitude for financial variables and real variables to move in idiosyncratic, and never-before-experienced, ways; but overall, we would expect the scenarios to be *prima facie* plausible.

Before turning to specifics, it is worth noting a broad link between financial networks and different types of stress tests. When is the network whole equal to the sum of the parts and when is it not? To understand the difference, consider two possible approaches to implementing a stress test involving a group of institutions. In the first, each institution is completely isolated. That is, there is a ban on the sale of assets, and the issuance of liabilities or equity. Furthermore, assets and liabilities run off as they mature. Finally, no firm has information about circumstances at any of the others. In such a case, if every institution passes the stress test, meeting prudential standards, the system is safe as well.

Alternatively, imagine that firms are able to complete actions formulated prior to the presumed start of the stress test scenario. So long as plans are in place, firms can raise funds by selling assets, lines of business, and the like. These actions could very well amplify the effects of a shock, depressing important asset prices, sparking fire sales and aggravating insolvencies. An analysis of the system as a whole that

[8] See Cecchetti and Schoenholtz (2018a).
[9] See the discussion in Liang (2018).

takes account of these dynamic considerations could yield very different results than one that treats the parts independently and omits the spillovers.

This leads us to note two basic flaws in existing stress-testing technology. First, there is no obvious way to account for interconnectedness and feedback, either adverse or beneficial, when testing a group of institutions. Second, there is no straightforward way to determine the behavior and impact of institutions that are outside the scope of the test.

III. Conceptual Issues

Turning to a more detailed discussion of financial networks, we proceed in three steps. In the following section, we outline the basic tools of network analysis. Using our rudimentary characterization of financial networks, we then turn to stress testing. How can we move from the analysis of individual institutions to tests of networks? This leads us to the example of a network created by the combination of a central counterparty, its clearing members and their customers. Finally, we turn to a discussion of the need for high-frequency stress tests in finance. Given the speed with which institutions' (and individual traders') exposures change, how might we monitor stress in a network in something closer to real time?

A. Basics of network analysis

A financial *network* is a group of financial entities (the *nodes*) that conduct transactions with one another, as well as the set of *connections* among these nodes. Financial network connections always balance, with every long matched by a short. That is, for each transaction, there is a payer and a payee; for each obligation, there is a claimant and an obligor.[10] Nevertheless, the parties to a transaction have exposure to one another, so the risk flows in both directions.

The study of financial networks helps us understand how the connections among entities—both direct and indirect—can amplify or dampen shocks to the financial system. The tools of network analysis can help answer questions about what makes a financial network resilient or fragile. Is it simply an aggregation of the resilience of its nodes, or is it as brittle as its weakest node? More broadly, how do resilience and the resistance to contagion depend on a range of factors: [11]

- the well-being of the nodes?
- the number, type, scale, and completeness of the connections that form the network structure?
- the *distance* between the nodes (that is, on how direct or indirect their linkage is)?
- the information available about the nodes and their connections?
- the growth of the network?

As we will see, there is a sense in which financial networks are different from other sorts of networks, so assessing their resilience requires tools specifically designed for the task.

In theory, networks can be very simple. Scholars have analyzed a range of such basic networks with very simple topologies. One example is a *ring* in which each node lends to the clockwise-adjacent node and

[10] Private cryptocurrencies present an exception to this generalization, since there is no clear obligor for Bitcoin, Ethereum or the like.
[11] Classic references in the vast and growing literature on financial networks include Allen and Gale (2000); Elliott, Golub and Jackson (2014); and Acemoğlu, Ozdaglar and Tahbaz-Salehi (2015).

borrows from the counter-clockwise adjacent node—a pattern that arises in derivatives markets and creates the possibility for what is commonly known as multilateral netting or trade compression. Compared to a *complete* network in which all nodes are connected, a ring can be fragile: should one node become unable to meet its payment obligations, the shock can trigger a total network collapse unless at least one node in the ring is able to pay even if it is unable to collect from its borrower.[12]

Another simple example is a hub-and-spoke topology, where the direct connections all pass through the central node (the hub). In this case, a shock to one or more peripheral nodes that renders the central node unable to meet its obligations can cause a total collapse. That is, the failure of the central node (the hub) transmits the shock across the network (along the spokes). In contrast, a resilient center can prevent the transmission of the initial shock beyond those nodes that are directly affected. To insure the resilience of such a hub-and-spoke system, it is natural to focus attention on making the central node an effective shock absorber.

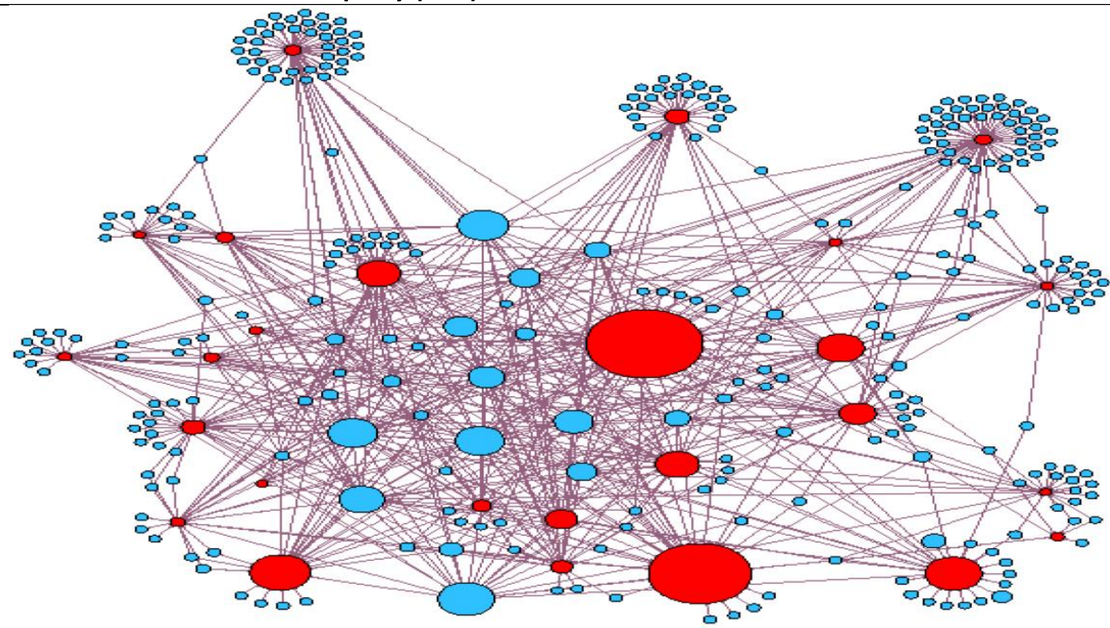
Even in the case of relatively simple networks, those limited by the number and type of connections among the nodes, the relationship between the topology and resilience can be complex. In some cases, increasing connectivity is a source of risk—helping to transmit or amplify shocks. Conversely, there can be instances in which linkages help to contain a shock by dissipating its impact across a wider group of entities in the network. Adding to the complexity of any analysis is that the relationship between increasing connectivity and resilience need not be monotonic. That is, increasing connections initially could increase diversification, reducing risk; but continuing to increase connections beyond a threshold could increase the transmission and amplification of shocks, augmenting risk. In relatively complex systems with considerable heterogeneity among the nodes, there can be nonlinear interactions and tipping points that affect amplification.[13]

In practice, financial networks are extraordinarily complex. The nodes may be numerous and heterogeneous in both size and structure. Figure 1, which maps the connections in 2017 across 15 jurisdictions among 26 central counterparties (CCPs) and their top 25 clearing members (CMs), highlights the complexity even in a reasonably well-defined network.[14] The size of each CCP node (red circle) is a proxy for the credit exposure to its CMs, while the size of each CM node (blue circle) reflects the scale of its resources posted at the network of CCPs. The figure reveals the concentration both of credit risk in a few CCPs and of pre-positioned resources in a somewhat larger number of CMs.

Analysts employ a range of metrics in assessing financial networks. Simple examples include the *degree distribution*—the number of connections for each node—and the scale of exposures for each node. In the case of financial networks, analysts often focus on measures of *centrality*, hypothesizing that central nodes (like that in the simple hub-and-spoke model) are critical for resilience. Some researchers have proposed innovative measures that are specifically suited to analyzing the resilience of financial networks. One example, labeled *node depth*, measures the amplification of losses arising through network connections.[15]

[12] See Allen and Gale (2000).
[13] See Covi, Gorpe and Kok (2018).
[14] See Basel Committee on Banking Supervision, Committee on Payments and Market Infrastructures, Financial Stability Board, and International Organization of Securities Commissions (2018).
[15] See Glasserman and Young (2016).

Figure 1. Global Central Counterparty (CCP) Network



Source: Figure 3 in Basel Committee on Banking Supervision, Committee on Payments and Market Infrastructures, Financial Stability Board, and International Organization of Securities Commissions (2018).

Complexity and the potential for rapid change make mapping most financial networks an extremely challenging task. Data limitations are endemic. As a result, supervisors, market participants and researchers are expending substantial effort to fashion tools that exploit partial data in an effort to gauge the structure and vulnerabilities of financial networks.[16] The general infrequency of crises further complicates the task of linking financial network analysis to financial stability. In practice, some types of systemic risk, such as cascading collapses (like the story of successive domino-like bankruptcies in the simple ring topology) surface even less frequently. More common are panics triggered by a broad loss of confidence—possibly arising from asymmetric information, common exposure, and the resulting illiquidity, insolvency, or both.

Perhaps unsurprisingly, in their broad review of the network literature, Glasserman and Young (2016) conclude that even in relatively straightforward networks—like the market for interbank lending—empirical work "has not yet produced a compelling link between traditional network measures and financial stability."[17] They attribute this analytical shortcoming to the lack of data describing financial networks and to their idiosyncratic features. Fortunately, their work lays out a useful path for empirical research by focusing on the importance of key nodes. Indeed, where there is only partial knowledge of the topology of the network—the usual case—Glasserman and Young place upper bounds on *node depth* as a proxy for the contribution of particular nodes to systemic risk. They also show that contagion is most likely when the nodes vary in size and a shock emanates from a highly leveraged and interconnected node.[18]

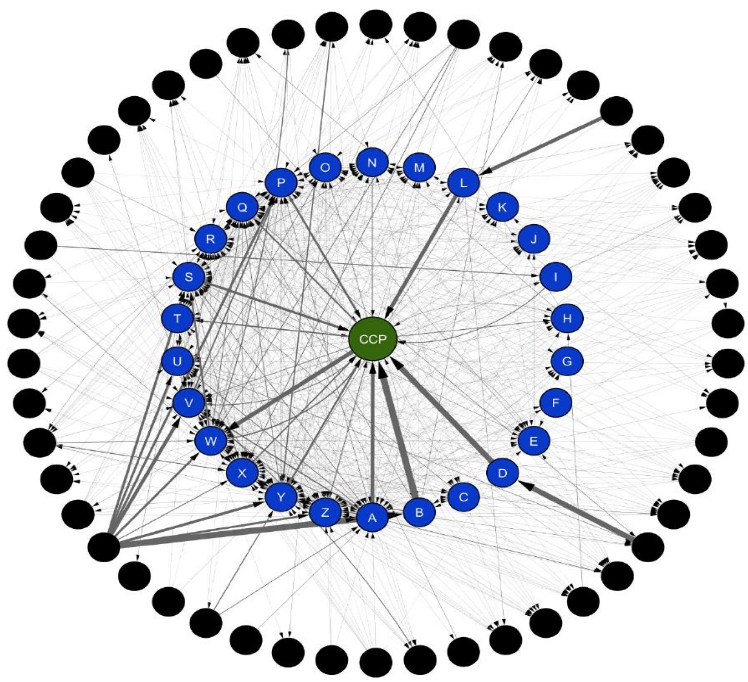
[16] See Anand et al (2018).
[17] See Glasserman and Young (2016).
[18] See Glasserman and Young (2014).

Of course, with empirical research on financial networks burgeoning, future observers may develop other, customized measures that are more fruitful for assessing the resilience of specific financial networks.[19] It already is useful to map financial networks—with especially close attention to highly leveraged, interconnected nodes—to help us identify potential avenues for risk transmission.

B. Network analysis and stress tests

Despite the challenges, taking a network perspective can alert us to important sources of vulnerability in a financial system, starting with a focus on the nodes. One obvious concern is the resilience of nodes serving critical functions that lack substitutability. When a key node is irreplaceable, its failure can lead to a collapse of the system. The most prominent instance of limited substitutability in the financial system is the payments, clearing and settlement functions that CCPs and other financial market utilities provide. Because of the importance of CCPs, and of the feasibility of mapping the networks where they serve as key hubs, section IV of this paper focuses on stress tests for CCPs.

Figure 2. Variation margin payment network after an asset price shock



Source: Figure 2 in Paddrik, Rajan and Young (2016).

At the same time, the central node of a financial network is not always the source of vulnerability. To see this, consider Figure 2, which maps the financial network of the credit-default swap market in 2015.[20] At the center of this hub-and-spoke system is a CCP. Its CMs (denoted by blue circles) are in the innermost ring around it. The outer ring is composed of the counterparties of the CMs. The arrows denote the direction and the size of the additional variation margin a particular node is obligated to post following an asset price shock. Not only does the mapping highlight the heterogeneity of the CMs, it reveals that the CMs' collective exposure to a single counterparty that is *not* a CM is larger than the

[19] See Covi, Gorpe and Kok (2018).

[20] See Paddrik, Rajan and Young (2016).

CCP's exposure to any individual CM. That is, by mapping the system we can see the network faces a vulnerability to stress that is outside of the direct CCP-CM system.

Network analysis can help illuminate other critical issues that are common objectives of stress tests. Virtually by definition, the fragility of a network is the result of an externality. As is clear in the case above, a weak node can trigger spillovers. Such weakness can reflect a number of factors, including inadequate resources (insolvency) or illiquidity, that make funding vulnerable in the presence of first-mover advantage. The prevalence of indirect connections in complex networks—well beyond anything in the simple hub-and-spoke system of Figure 2—makes it difficult to monitor and control exposure. Who knows the weaknesses of their counterparties' counterparties, much less their counterparties' counterparties' counterparty? Not to mention the speed at which their frailties change. One common theme that applies to the analysis of financial networks is that asymmetric information and uncertainty generate vulnerability, in which case transparency is an important remedy (as well as a means of promoting discipline).[21]

While firms and supervisors are well aware of the potential for spillovers or contagion from anywhere within a financial network, most stress tests focus precisely on key nodes as triggers, channels of transmission or amplifiers of shocks. As the network literature suggests, carefully defining the purpose of each stress test is a critical first step. Are we measuring the resilience of the system to liquidity disturbances, to insolvency at a key node, or to a generalized loss of capital and liquidity that fosters uncertainty and prompts runs? How should we account for fire sales and other second-round effects that amplify asset price declines, further depleting the system's capital?

In practice, the key nodes—the largest banks, insurers, asset managers, and clearing and settlements institutions—administer their own stress tests on a frequent, sometimes daily, basis. Firms typically base these tests on internal models and data. Banks may use self-imposed stress tests to assess the impact of both liquidity and solvency shocks, as well as of operational risks. Asset managers may assess the readiness of their funds to meet a sudden surge in redemptions. CCPs typically assess the availability of resources to cover one (or more) CM's inability to satisfy a variation margin call.

While supervisors may have access to the results of these high-frequency internal stress tests, their official tests occur at a far lower frequency, once a year at most. Supervisors typically impose the same test—involving the same adverse scenarios—across a class of entities, such as large, complex banks. In some cases, like the Fed's Comprehensive Capital Analysis and Review (CCAR), the supervisor uses its own suite of models to assess each institution's performance. By imposing a common set of scenarios and models, the supervisory tests are not only directly comparable across institutions, but they are likely to be more rigorous in assessing network effects.

As we hint in Section II, one way to interpret the adverse scenarios of supervisory bank stress tests—like the Fed's CCAR test—is as a large financial network where, following an episode of severe stress, the connections all freeze. Put differently, the specified declines of asset prices in each scenario reflect not only an initial shock, but are the end-result of multiple rounds of network amplification—driven by illiquidity, fire sales and insolvencies—that have made key markets dysfunctional. In this distressed

[21] Faruqui, Huang and Takáts (2018) discuss the risks associated with structures like the one in Figure 2.

state, the CCAR banks are no longer able to sell assets or to raise new equity funding.[22] In effect, each institution is completely isolated and information about its well-being is unavailable to others. In that state of the world, the write-downs arising from the asset price changes implied by each scenario determine both individual and collective capital adequacy. In this approach, if *every* institution passes the test—implying a sufficient pre-shock level of self-insurance in the form of equity finance—the system is as safe as the sum of its parts.[23]

From a systemwide perspective, the CCAR approach is a clear advance over the customized tests run by individual institutions' risk managers. Nevertheless, it would be desirable to go further and model the entire process from start to finish, including the destabilizing feedback mechanisms that amplified the initial asset price plunges. Specifically, in a dynamic general equilibrium model with heterogeneous firms and a set of initial shocks, the asset price declines that drive the CCAR and similar tests would emerge endogenously. However, constructing such a fully specified model remains beyond the capacity of technical experts inside and outside the official sector. In practice, stress scenarios take as given large asset price declines thought to be extreme but plausible. This makes the scenarios unavoidably subjective; however, it also allows supervisors to alter them in ways that focus attention on new and important risks.

Before continuing, we should note the possibility of *reverse* stress tests—something that is standard in some firms and that some authorities are considering implementing. The purpose of such a test is to gauge the size of a shock necessary to precipitate the failure of a key node or set of nodes. Combined with an estimate of the probability of such a shock, policymakers could determine whether the resilience of the system is consistent with social objectives. In the case of a bank, how large a decline in key asset prices would be sufficient to deplete the institution's capital?

C. High-frequency stress testing of financial networks

The low frequency of current supervisory stress tests is a concern. Because financial networks evolve rapidly, the exposures of key nodes change extremely quickly and point-in-time observations become obsolete very quickly. To monitor the system effectively, supervisors need higher-frequency tools and indicators. For this purpose, a number of organizations, like the U.S. Treasury's Office of Financial Research, use high-frequency financial market data to construct heatmaps and financial stress indexes that can alert supervisors to emerging risks. In theory, this type of information can guide the design of new supervisory stress tests, triggering updates of scenarios and tests that are more frequent when risks in the financial system are changing rapidly.

Over the past decade, researchers have taken up the challenge to construct real-time measures of institution and systemic stress using publicly available information. We highlight the NYU Stern Volatility Lab's weekly publication of SRISK, a forward-looking measure of each firm's estimated shortfall of capital (relative to a stated norm) in a bad state of the world (such as a 40-percent plunge over a six-

[22] We note that such ad hoc effects are part of most stress tests. A test might specify systemwide parameters that determine the severity of real estate losses or that limit a firm's share of funding coming from deposits during the stress period.

[23] In practice, supervisors base their stress test results on asset-specific models linking macroeconomic scenarios to price declines. However, typical model calibration, based as it is on experience, will tend to rely on a small sample of extreme outcomes needed to perform accurate tests. This means that accurate results may require shocks that are even larger than those present in the historical record.

month horizon in a broad aggregate of stock prices).[24] The notion is that a firm's contribution to systemic risk reflects the externalities (like fire sales and liquidity hoarding) that arise from its capital shortfall precisely when the system as a whole is short of capital.[25]

To be sure, SRISK has limitations. First, it is only available for listed firms, which means we cannot include those held privately or by a government. Second, comparison of SRISK measures across types of institutions (such as banks and insurers) and regions with different accounting standards (such as GAAP and IFRS) requires some caution. Third, market-based measures like SRISK tend to be pro-cyclical. Fourth, while SRISK's reference leverage ratios aim to exceed the minimum capital thresholds necessary to avoid runs in a crisis, their calibration is imprecise.[26]

That said, we see market measures like SRISK as among the most promising high-frequency tools to help guide supervisors in refining and modifying stress tests when, as is usual in finance, changes in the financial network occur too rapidly to examine in a comprehensive way. With that in mind, we now turn to a discussion of CCP stress testing from a network perspective.

IV. Central Counterparties (CCPs): Structure, Risks and Stress Testing

While clearinghouses have existed for centuries as part of the plumbing of the financial system, difficulties associated with bilateral over-the-counter derivatives markets in the run-up to and during the crisis led authorities to push for an increase in central clearing.[27] In 2009, the G20 leaders mandated central clearing of standardized OTC derivatives through CCPs.[28] Because of this commitment, central clearing grew dramatically over the past decade. In 2018, about three-fourths of OTC interest derivatives were cleared through central counterparties, up from less than one-fourth just a decade earlier.[29]

Central clearing has a number of benefits. First, by substituting the CCP as the buyer to every seller and the seller to every buyer, central clearing mutualizes and can—with appropriate margining, trade compression, position liquidation procedures, and reporting—reduce counterparty risk.[30] Second, it facilitates enforcement of *uniform* margining standards.[31] Third, through multilateral netting and trade compression, CCPs economize on the use of collateral. Fourth, should a CM default, central clearing also facilitates the orderly liquidation of that member's positions and provides for some sharing of the

[24] For a description and analysis of SRISK as a measure of resilience of the financial system, see Brownlees and Engle (2017).
[25] The idea of using market measures as a guide to financial resilience is not limited to SRISK. Sarin and Summers (2016), for example, use an array of indicators—including volatility, implied volatility, out-of-the-money put options, correlations, credit default swap spreads, price-earnings ratios, and preferred stock prices and yields—to assess the riskiness of the largest U.S. banks.
[26] We view the fact that they currently exceed regulatory requirements—8 percent in Asia and the United States and 5.5 percent in Europe— as a feature, rather than a flaw.
[27] See Gorton (1984) and Bernanke (2011) for discussions of the history of clearinghouses in the American financial system. The first U.S. clearinghouse—the New York Clearing House Association established in 1853—followed the model of the London Clearing House of 1773.
[28] See paragraph 13 of the G20 Leaders Statement: The Pittsburgh Summit (2009).**Error! Hyperlink reference not valid.**
[29] See Faruqui, Huang and Takáts (2018).
[30] See Tuckman (2015).
[31] See Duffie and Zhu (2011).

default costs. Finally, because of the centralization of information, the CCP improves trade reporting, making risk concentrations transparent, and allowing market participants and the CCP to impose a commensurate risk premium.

Central clearing involves significant economies of scale and scope, combined with network externalities.[32] As a result, CCPs tend to become extremely large: for example, LCH Clearnet (the largest CCP in Europe) has more than $330 *trillion* in gross notional contracts outstanding. While the shift from bilateral OTC derivatives trading to central clearing may reduce some aspects of systemic risk, it creates others. With central clearing, risk that was previously a web of complex network connections becomes credit and liquidity risk at the CCP. These risks surface if a CM defaults or if meeting a CCP's obligations requires significant transfers of securities for cash.

Experience shows that when a CCP fails, financial markets cease to function. In the past, the geographic spillover of these collapses, as in the case of the 1974 failure of the Paris commodities futures market, was limited by the size of the market or by the lack of cross-border financial integration. However, given the development of the global financial system since 1980, a failure could have a much broader and more prominent impact today.

The services that CCPs provide are inherently systemically important; central clearing creates *concentration* and *substitutability* risk. Because they are highly interconnected, CCPs have the potential to transmit shocks throughout the system. This makes it essential that a CCP be resilient and have sufficiently rigorous risk-management systems. Each CCP must confront two broad categories of risk, one arising from the default of a CM and the second related to non-default operational failures.

We have little to say about the second, except that cyber and other operational risks are among the biggest current threats to CCPs and to the financial system as a whole.[33] A significant cyber event could not only trigger a default at a CM, but the CCP itself could cease operating. As noted already, the services that CCPs provide are inherently systemically important. Nevertheless, in this context, we have more questions than answers: Are CCPs more vulnerable than other types of financial institutions? How do cyber shocks at CMs or counterparties affect CCP and system resilience and vice versa? Do CCPs absorb shocks, or amplify and transmit them? Does new technology help or hurt? How should CCPs and officials guard against and plan for recovery from such shocks? We leave these issues for future investigation, and turn to the risk associated with CM default.

a. The Default of a Clearing Member

Recall that a CCP has a *matched book*—for each short position there is an identical offsetting long position. What if one or more large counterparties to the CCP cannot perform? Such events do exist in the historical record. Bell and Holden (2018) describe two relatively recent cases: Lehman Brothers in 2008 and the default 10 years later of a Norwegian CM trading Nordic power spreads on a Sweden-based Nasdaq exchange.[34] In both cases, the CCPs involved proved resilient and were able to continue operating. However, in the recent Nasdaq episode, the exchange called on its remaining CMs to

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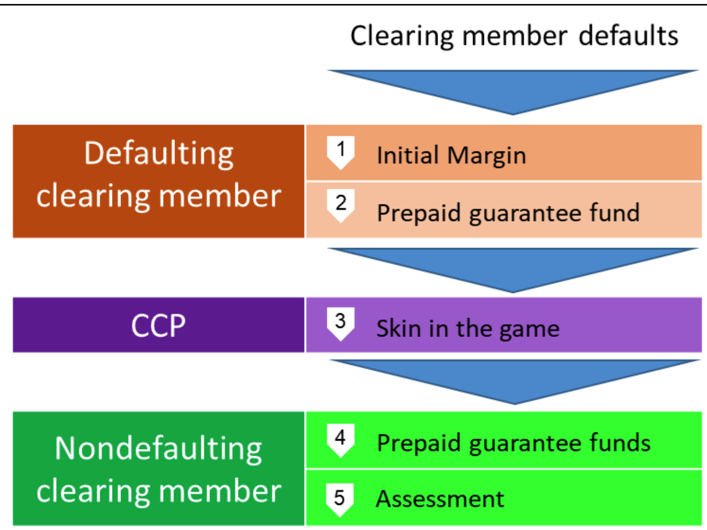
[32] See the discussion in Alexandrova-Kabadjova et al. (2018), especially Section 3.3.
[33] See Cecchetti and Schoenholtz (2018b).
[34] See Appendix 1 for details on the 2018 Nasdaq exchange incident.

replenish their pre-positioned guarantee funds rapidly, an action that could have transmitted and amplified distress in a financial system with a broad capital shortfall.

Before we get to the mechanics, it is worth noting that reforms to resolution regimes in the aftermath of the Lehman collapse should meaningfully reduce the likelihood of the default of a large CM. Under the new system, healthy operating subsidiaries in banking groups should be able to continue operating, meeting their obligations. Since these operating entities are typically the largest CMs, if this (still untested) system works, the odds of a large CM default should be slim.[35] However, the 2018 Nasdaq episode highlights that CM default remains a real possibility. Consequently, prudence requires preparing for one or more such defaults.

In the event of a CM default, the CCP has access to resources in a particular order known as a *waterfall*.[36] Figure 3 shows the stylized view of such a waterfall and Table 1 provides an estimate of the aggregate size of the tranches—across all contracts—for both the CME and LCH.

Figure 3. Typical CCP Default Waterfall



Source: Treasury Office of Financial Research, Figure 1.

The CCPs first line of defense is *margin* (sometimes referred to as a performance bond). To enter into a derivative contract, both parties need to supply *initial* margin. Each day, the CCP then posts gains and losses to the margin account of the two sides to the transaction. That is, whenever the price of the contract changes, the losers must pay the winners overnight (or sooner). To make these payments, the CCP may need to ask for resources from the parties to the trade. Depending on the CCP's rules, these *variation margin calls* can occur more than once per day.

What if a CM fails and its margin is insufficient to its obligations? Each member of the CCP—every institution that engages in transactions—is required to contribute to a guarantee fund. The failing firm's guarantee fund contribution is the second line of defense. Once the defaulting CM's own resources at the CCP—margin plus guarantee fund contribution—are exhausted, others contribute. This starts with

[35] Cecchetti and Schoenholtz (2018c) discuss the reforms to the resolution regimes for systemic intermediaries. For a detailed analysis of CCP resolution, see Duffie (2015).
[36] For a description of the usual waterfall, see Cecchetti and Schoenholtz (2017).

the CCP's own capital. Next, comes the guarantee fund contributions of other CMs. And, finally, the CCP has a loss-sharing arrangement among its CMs—ex post *assessments*—where everyone is required to contribute once all the pre-funded backstops are used up.[37]

For this to work, the CCP needs to ensure that it is in a position to make assessments should the resources in the first four layers of the waterfall—defaulting member resources (including margin and prepaid guarantee fund) plus own funds plus non-defaulting member prepaid guarantee funds—be insufficient to cover the losses created by the default. Will the non-defaulting CMs be able to meet a capital call or not? Clearly, the assessment acts as a transmission mechanism and amplifier of financial stress elsewhere in the system. We return to this shortly.[38]

Table 1: Margin and Default Resources
(end September 2018, Billions of U.S. dollars)

	CME	LCH
Gross Initial Margin Posted	$122.89	$150.17
CCP's Own Capital	0.25	0.08
Prepaid Guarantee Fund	7.33	10.73
Commitment/Further Assessment	11.19	10.73
Open Interest	NA	251,797.02
Gross Notional Outstanding	NA	332,500.00

Source: CPMI-IOSCO quarterly disclosures: https://www.cmegroup.com/clearing/cpmi-iosco-reporting.html, https://www.lch.com/resources/rules-and-regulations/ccp-disclosures, and https://www.lch.com/services/swapclear/volumes; and authors' calculations. Note that the CME does not disclose the value of either open interest or gross notional amount outstanding, while LCH reports both.

For two large CCPs, Table 1 shows the various components of the buffer that protects the integrity of their operations. In both cases, initial margin is by far the largest the piece. At the end of September 2018, for the CME and LCH initial margin was 11.0 and 13.7 times the potential assessment, respectively. We note that the top five clearing members, which likely include some of the most systemic nodes of the group, account for two-thirds of the initial margin posted at the CME but only one-quarter of the initial margin posted at LCH. That said, the CCP's buffers appear small relative to the size of their exposure. For LCH, initial margin is less than 6 basis points of open interest; while own capital, the prepaid guarantee fund and potential assessments sum to less than 1 basis point.[39]

A second source of risk facing the CCP is liquidity risk. Following a CM default, the CCP needs to make payments to settle contracts that it now guarantees. Making timely payments, requiring cash, could

[37] Based on Table 1 for LCH, the margin, pre-paid guarantee fund, and CCP's own contribution are 0.06%, 0.004% and 0.00003% of notional gross open interest, respectively. The ex post assessment can supplement these pre-positioned resources. We cannot calculate these ratios for CME, which does not report the value of open interest.
[38] Faruqui, Huang and Takáts (2018) provide a detailed discussion of how the waterfall functions.
[39] While open interest likely overstates CCP exposure (especially for short-maturity instruments), these ratios still strike us as small. The data are available at https://www.cmegroup.com/clearing/cpmi-iosco-reporting.html and https://www.lch.com/resources/rules-and-regulations/ccp-disclosures. See tab 6.1 for initial margin and tab 18.3 for the percentage posted by the five largest clearing members.

necessitate the sale of non-cash collateral. Keep in mind that the whole process starts with the default of what could be a relatively large financial institution. Under such circumstances, there is a very real possibility that market liquidity will become impaired. That means that the CCP may encounter difficulty selling the collateral, and that the attempt to do so could aggravate market conditions.

To guard against the possibility that a solvent CCP would become illiquid, some central banks offer liquidity backstops. In the United States, Title VIII of the Dodd-Frank Act authorizes the Federal Reserve to establish deposit accounts at the Fed for designated financial market utilities (DFMUs). At this writing, there are eight DFMUs. Furthermore, Dodd-Frank authorizes the Fed to lend to solvent DFMUs in times of market stress (what are termed "unusual and exigent circumstances"). Whether these arrangements are sufficient is unclear.[40]

b. CCP Stress Testing

Both CCPs and their supervisors conduct regular stress tests. As market conditions change, managers need to know whether their book will remain matched following a shock; and where stress points might be emerging. The Committee on Payment and Market Infrastructure (CPMI) and the Technical Committee of the International Organization of Securities Commissions (IOSCO) have a framework for supervisory stress testing of CCPs. It provides for governance arrangements and disclosure standards as well as protocols for development of stress scenarios and metrics for evaluation. Designed to be universally applicable, the CPMI-IOSCO standards are necessarily abstract.[41]

Authorities have translated these standards into action. For example, the European Securities Market Authority (ESMA) and the Commodity Futures Trading Commission (CFTC) have each conducted supervisory stress tests. The purpose of these was to assess the ability of the CCP to survive a shock with the resources it has on hand. That is, following adverse price movements and CM defaults, can the CCP meet its obligations without recourse to further assessments? Looking back at Figure 3, the stress tests examine whether the resources in the first four stages of the waterfall are sufficient so that there is no reason to go step five.

ESMA's first EU-wide stress test exercise assessed the resilience of 17 CCPs (including all authorized EU CCPs) for dates in the final quarter of 2014.[42] The test calculated the counterparty credit risk that EU CCPs would face if multiple CMs default in the face of simultaneous market price shocks. It did not consider liquidity and other risks. The goal was to determine whether extreme but plausible circumstances would produce losses that exceed prefunded or unfunded resources of the CCPs.

ESMA employed an array of scenarios: CM defaults, market price scenarios developed from history and models, and reverse stress tests. The default scenarios assume the default of each CCP's top-two CMs ranked by exposure. Furthermore, the test assumed cross-default: if a CM defaults, it does so in all CCPs in which it is a member. That is, the top two CMs in any CCP default across all CCPs. Combined with the

[40] To take one obvious case where matters remain unsettled, imagine a circumstance in which a U.S.-based CCP would require liquidity in a currency other than dollars. Without access to the appropriate central bank, it is unclear how such a problem could be resolved. Conversely, a CCP based outside the United States that needs to liquidate dollar collateral in a crisis may need access to a central bank that is able and willing to provide dollar funding against high-quality collateral.
[41] See Appendix 2 for details on the principles of CCP stress testing.
[42] See ESMA (2016).

worst-case market price scenarios, this creates an extremely severe test (and in ESMA's view, results in an implausibly high number of entities simultaneously defaulting at EU-wide and CCP levels). The results in these scenarios trigger CCP assessments for resources that were not prefunded, and still leave a small residual of uncovered losses (less than €100 million).

The CFTC stress test in 2016 assessed the ability of each of five CCPs to satisfy the resilience standard under 11 extreme but plausible scenarios depicting stressed market conditions.[43] The exercise focused solely on credit risk arising from scenarios in futures, options on futures, and cleared swaps. It included contracts based on financial products and contracts based on physical commodities. To incorporate interconnectedness, the tests focused on firms that serve as CMs at more than one CCP from a universe of the 15 largest CMs at each CCP. Reflecting the overlap in memberships among the give CCPs, the exercise included 23 CMs. CFTC staff analyzed both the house accounts and the customer accounts of these CMs at each clearinghouse. Because two of the CCPs have separate guaranty funds for some asset classes, the exercise covered eight different guaranty funds.

The CFTC methodology involves assuming a large move in prices, calculating the resulting variation margin requirement, checking that against the sum of initial margin, financial contributions of CCPs, and guaranty funds, and determining whether available resources were adequate *without resorting to further assessments*. The scenarios were extreme, representing the largest price moves of the past three decades, a 50% increase in the implied volatility of all options on the futures contracts, and a significant increase in cross-asset correlations in the exercise.

The tests revealed that, under a number of severely adverse scenarios, and across a wide range of products and instruments, all five CCPs had the financial resources to meet the standard in which the two top-ranked CMs default. Furthermore, under nearly two-thirds of the stress scenarios, clearinghouses could meet a standard in which all of the CMs in the exercise that incurred a loss defaulted. In addition, CM risk was diversified among the scenarios and across the CCPs. No single scenario accounted for more than 19% of the worst outcomes, and risk was not concentrated among a few firms. Furthermore, the scenarios did not cause CMs to incur losses at all CCPs.[44]

It is surely encouraging that authorities are performing periodic stress tests on CCPs. But, as is the case with bank supervisory stress tests like the Federal Reserve's Comprehensive Capital Analysis and Review (CCAR), they are very costly for both the financial institutions and the authorities. One reason is that they require vast amounts of granular, detailed and timely information.[45] Furthermore, they are quite time consuming, taking months to complete. And, they are infrequent compared to the rapid changes in market and institutional conditions that can affect the vulnerability of CCP networks.

[43] See CFTC (2016).
[44] Following this first round of CCP supervisory stress testing, both ESMA (2016, 2018a and 2018b) and the CFTC (2016, 2017a, 2017b, and 2017c) undertook tests that addressed liquidity (in addition to credit risk), publishing them in 2017 and 2018.
[45] Appendix 3 provides a discussion of data-related issues.

V. Complementing Supervisory Stress Tests using SRISK

In Section III of this chapter, we discuss the use of market information to construct a high-frequency measure of the contribution to systemic risk of any publicly traded financial institution. Here we apply a related method to gauge the vulnerability of the financial system to an assessment by a CCP on its CMs. That is, we focus on the impact on the financial system in the event that a CCP's pre-funded loss-absorbing resources are depleted, either partially or completely.

As we learned from the 2018 Nordic Nasdaq episode, CMs are subject to assessments not only in the final stage after the CCP has exhausted existing resources, but also to replenish a depleted pre-paid guarantee fund. In the Nasdaq case, assessments occurred within days of the loss. Looking back at Figure 3, this means that CMs are liable to a capital call at the fourth step of the waterfall as well as at the final step.[46]

Whenever a capital call occurs, the potential for further stress depends on the strength of the CMs. If the initial failure is the consequence of a large aggregate shock, rather than an idiosyncratic disturbance, it depletes capital levels throughout the system. In that circumstance, the assessment comes at the worst possible time, and can have an outsized impact.

We estimate systemic vulnerability arising from a CCP assessment as the weighted average of the SRISK of the CMs. Recall that SRISK is a market-based measure of the capital shortfall (relative to a benchmark) of a financial institution in the event of a large decline of global equity prices over a six-month period. For our purposes, we use the NYU Stern Volatility Lab's default definition of a large decline: namely, a 40-percent drop. A simple way to think about SRISK is that the higher an institution's leverage and the bigger its exposure to the aggregate market when market prices plunge (the higher its *conditional* beta), the more sensitive its capitalization is to a severe event. Furthermore, the bigger the weighted-average capital shortfall, the bigger the stress created for the financial system as a whole by a CCP call on its CMs' capital.

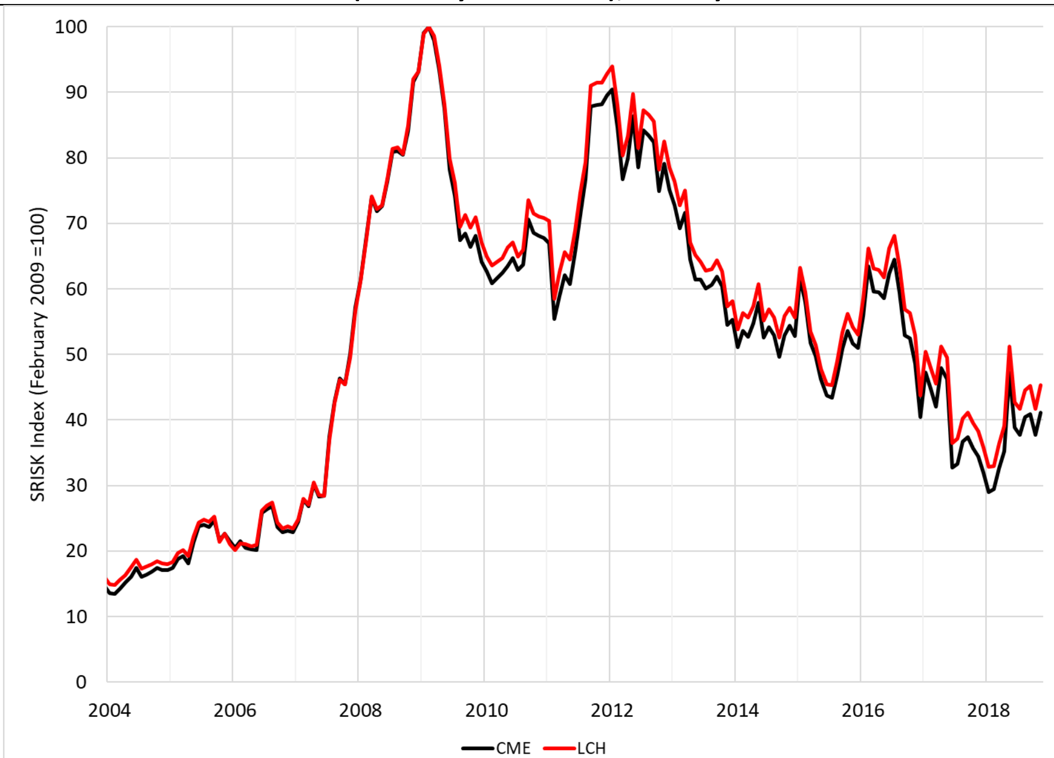
Ideally, we would measure the CCP's potential for transmission and amplification by weighting CM SRISK based on the size of their potential assessment. Unfortunately, that information is not publicly available.[47] In lieu of that, we use two types of information: measures of the gross notional derivatives exposure for a CM's parent and information on a CM's client margin posted at the CCP. The first data, available for 2017, come primarily from the Basel Committee on Banking Supervision's disclosure of the high-level indicators used to compute capital surcharges for global systemically important banks (G-SIBs).[48] The second is only available for the CME.[49] Gross notional derivatives exposure almost surely overstates the counterparty risk of a CCP.[50] The client margin weightings are likely closer to the ideal

[46] While there are obviously examples of the first of these, the second is extremely rare. In their discussion of the three known CCP failures, Faruqui, Huang and Takáts (2018) suggest that the closest historical example to the case in which a CCP drew on assessment powers of non-defaulting members was the failure of the Hong Kong Futures Guarantee Corporation in 1987.
[47] Perhaps surprisingly, CMs generally do not know each other's assessment obligations.
[48] See https://www.bis.org/bcbs/gsib/gsib_assessment_samples.htm. For CMs too small to be in the Basel Committee's sample, we took information from individual banks' annual Pillar III disclosures.
[49] We draw these from the Financial Industry Association's reporting of data from the CFTC. See https://fia.org/fcm-comparison-table.
[50] See Haynes et al (2018).

measures based on potential assessment, but they remain imperfect primarily because they exclude the CM's own exposure.

We construct an SRISK index for both the CME and LCH using weights computed from the gross notional derivatives exposures of their CMs. For the CME, we have information for 32 of the 65 CMs with independent parents.[51] LCH has 68 firms with independent parents; of these, we have data on 51. Importantly, 28 of the firms (or their subsidiaries) are CMs of both CCPs. This large overlap is unsurprising, as CMs frequently use these CCPs to clear different products: CME clears futures and swaps based on a variety of financial instruments and commodities, while LCH mainly clears interest rate swaps.

Figure 4. LCH and CME SRISK Index (February 2009 = 100), January 2004-November 2018



Note: The plot shows the weighted sum of SRISK of the publicly traded parent firms of CMs at the CME and LCH using weights based on 2017 gross notional derivatives exposure.
Sources: Authors' calculations based on data from the NYU Stern Volatility Lab, Basel Committee on Banking Supervision and various firm disclosures.

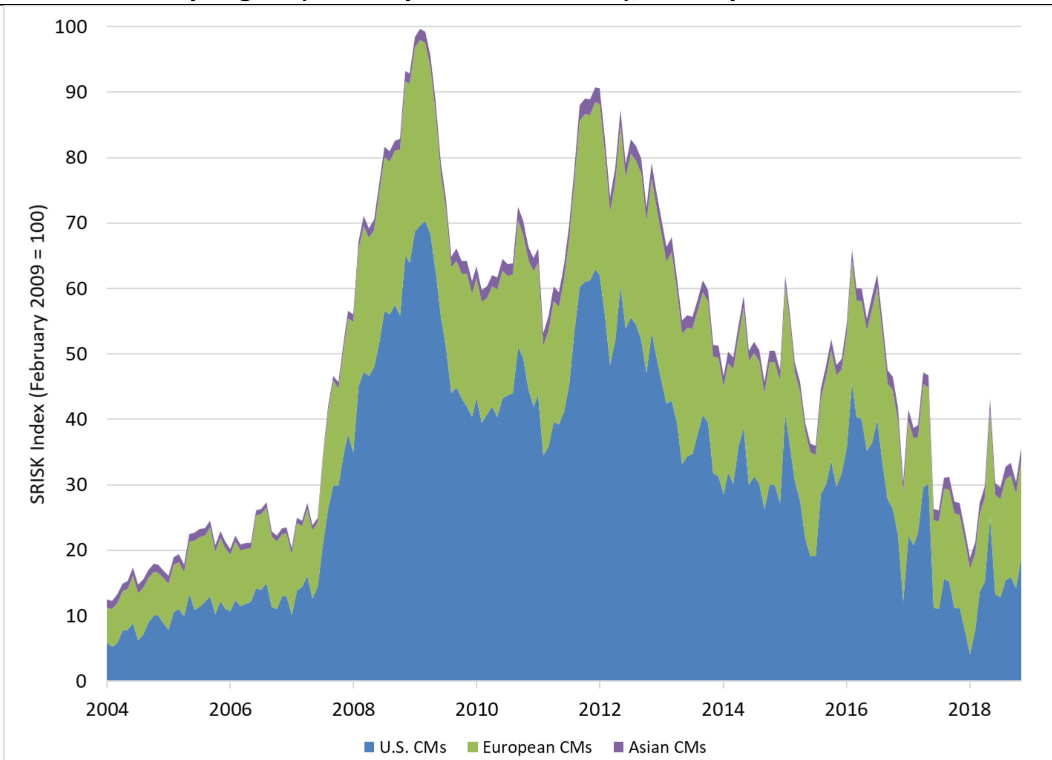
Figure 4 plots SRISK indexes for the CME and LCH using these weights.[52] In each case, the index is set to 100 at its peak (February 2009). We draw two conclusions from this set of calculations. First, for both

[51] While we know neither the individual shares nor the collective share of total activity at the CME accounted for by the 32 firms for which we have data, we do know that these firms account for more than 90 percent of posted customer margin.

[52] We base all of these calculations on the presumption that a group will not choose to allow a CM subsidiary to default if there are adequate resources at the group level. While such a default may be legally possible in some jurisdictions, we suspect that the reputational consequences would be sufficiently dire that a firm would only take this action if the alternative were holding company insolvency.

CCPs, the weighted SRISK index is less than half of what it was a decade ago. That improvement largely reflects the improved market capitalization of the CMs. Second, reflecting the large overlap in CMs, the SRISK indexes move closely together: the correlation between the two lines is 0.998. The immediate implication is that when the system is vulnerable to a CME call, it is also vulnerable to an LCH call (and vice versa), and that a capital call from one transmits stress to the other.

Figure 5. CME SRISK by Region (February 2009 Total = 100), January 2004-November 2018



Note: The index of client-margin-weighted shares of CME SRISK decomposed by world region. The fraction accounted for by Canadian clearing members is never more than 0.6 percent of the total, so it is included in the U.S. total.
Source: Authors' calculations based on data from the NYU Stern Volatility Lab and FIA (https://fia.org/fcm-comparison-table).

Turning to Figure 5, we disaggregate the SRISK index for the CME by region. Here we use weights based on posted client margin, which are probably a better proxy for the CCP's assessments, but are only available for the CME.[53] This exercise helps us to understand how a CCP can transmit and amplify shock across borders. The striking result here is the portion of CME's vulnerability emanating from Europe (the green shaded area), which ranges from 30 to 50 percent of the total, with the most recent reading near the high end of the range. While the CME surely remains exposed to domestic shocks, through capital assessments it can transmit shocks from defaulting European members to other CMs inside and outside the United States.

[53] The CME's CPMI-IOSCO disclosure reports that between 75 and 80 percent of margin is posted by customers of the CMs, rather than the CMs themselves (see tab 6.1 of CME Quantitative Disclosures, 2018). For the SRISK indexes that we construct, the change in weighting from gross notional outstanding to client margin makes very little difference as the correlation between the total in Figure 5 and the CME index (black line) in Figure 4 is 0.993.

Before turning to our overall conclusions, a word of caution is in order. We do not intend our CCP SRISK index as a tool for dynamic policy. If policymakers were to use heightened SRISK as a trigger for altering margin or collateral requirements, their response and the effect would be pro-cyclical. Modeling a dynamically optimal level of self-insurance for a CCP network across time is well beyond existing capabilities. Instead, we interpret the large historical variation in the CCP SRISK index as an indicator of the need for additional buffers at all times in the system. The fact that the default resources appear small relative to indicators of exposure (see Table 1) raises the question of whether the CCP's capacity for loss absorption—including its margin, capital and prepaid guarantee components—is adequate.

VI. Conclusion

While stress testing of banks has a decade-long history in a number of economies, testing of nonbanks is far less common. The empirical application of network analysis to financial systems also is relatively new, and remains limited to well-defined networks where data availability across jurisdictions significantly exceeds the usual norms.

In this paper, we highlighted the benefits of mapping financial networks to identify sources of vulnerability and of applying customized stress tests to these mapped networks to quantify those vulnerabilities and track them over time. We used CCPs as an example, both because regulators have made some progress in mapping these networks, and because CCPs now concentrate risk in ways that can transmit and amplify stress both domestically and across borders. As a result, they are arguably the most important nodes in modern financial networks.

We emphasize the importance of using high-frequency market-based indicators as tools for informing and framing less frequent, but comprehensive supervisory tests. As an example, we show how to use to SRISK, a measure of capital shortfall, to see how CCP assessments of their CMs can make the financial system more vulnerable to cross-border activity in derivatives markets.

Given the interest of financial regulators, and the increased effort to map and monitor key global financial networks, we expect rapid progress in the stress testing of networks that, like CCPs, are amendable to mapping. In the case of CCPs, regulators can utilize these tests to assess margin requirements and the adequacy of pre-positioned guarantee resources. They can further enhance the impact of their stress tests by making the process and results increasingly transparent to CCPs, CMs and their stakeholders. So long as CCP governance allows, such transparency would allow healthy CMs to impose greater market discipline on the CCPs with which they transact business.

We view such network-based, customized stress tests as a promising means to assess the vulnerability of the global financial system to shocks originating in key network nodes that lack short-run substitutes.

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Appendix 1: Background Information—Nasdaq clearing default of 2018

On September 10, 2018, the loss caused by the default of a single trader, Einar Aas, in a Nordic power spread derivatives contract cleared by Nasdaq Clearing consumed all of the trader's margin, the trader's own contribution to the guarantee fund, the entirety of the CCP's capital commitment (€7 million), and then wiped out more than two thirds of the €168-million clearing members' default fund of the Commodities Market segment of this Nasdaq CCP (see Nasdaq Clearing, 2018). The CCP called on its clearing members to replenish the default within days of the event.

What are the lessons from this event for the risk management and resilience of CCPs? The most important is: *set margins commensurate with risk.* Failure to do so can lead the CCP to call on the resources of its clearing members in a period of stress when doing so can transmit the shock broadly across the financial system. Another concern is governance: do the clearing members who contractually share in the losses faced by the CCP have the authority to impose discipline on the risk management of the CCP? In the absence of such discipline, they bear risk without meaningful control.

Guidance on how CCPs should set their margins to prevent the exhaustion of a defaulter's collateral is clear: Calculate initial margins referencing a time horizon long enough to capture the largest stress events; use conservative assumptions regarding market liquidity to allow for collateral liquidation without major loss; and limit offsets between products to those that would be robust in stressful conditions (CPMI-IOSCO (2017)).

Varma (2018) and Pirrong (2018a and 2018b) provide assessments of the event. As they describe, Nasdaq calculated Aas's initial margins on his Nordic and German futures positions as 99.2% of the biggest two-day market movements over the previous year, plus 25% of the biggest two-day movement that year. But Nasdaq incorrectly assumed that German and Nordic electricity prices would continue to move in parallel, so they gave Aas a correlation offset of 50% on the margin. In addition, Nasdaq used CME SPAN to calculate initial margin. SPAN handles dependence risk in an ad hoc way, using "Combined Commodity Evaluations" that group commodities, aggregating risk factors and sums them to yield the total risk for the portfolio. This approach can understate tail risk.

Moreover, despite the evident shrinkage in volume and (thus growing illiquidity) of the Nordic power market over the past decade, Nasdaq did not require Aas to pay any additional margin to compensate for the high cost of liquidating collateral from a portfolio that was large relative to the available market (Bell and Holden (2018)). Although a CCP is supposed to facilitate the orderly liquidation of positions, auctioning big defaulted positions in a period of stress is difficult because few market participants have the capital or the risk appetite to acquire them. Those who do will demand a big haircut, fueling fire sale dynamics.

Nasdaq described their post-default actions as follows (see Nasdaq Clearing, 2018):

> *"Within 48 hours after the default, the portfolio was closed out through an auction according to Nasdaq Clearing's close-out procedures. However, the close out resulted in a loss for Nasdaq Clearing that exceeded the defaulting member's collateral and default fund contribution. Therefore, on 14 September, Nasdaq temporarily contributed 20 mm EUR (200 mm SEK) to its Junior Capital fund, in addition to the EUR 7M that Nasdaq already had replenished in the Default Fund as Junior Capital.*

On 17 September, 8:40am the member Default Fund reached more than 90 percent committed funds for recapitalization from Nasdaq Clearing´s members. Later the same day, at 4pm in the afternoon, the member Default Fund was recapitalized by 100%, or 107 mm EUR.

In order to reduce the risk profile in the market situation following the default, Nasdaq Clearing has decided to increase margin levels: Confidence levels have been increased in order to shift risk of a particular portfolio from the mutualized default fund to the owner of the portfolio. We have increased margins on spread positions. We have commissioned Oliver Wyman, a Global Management Consulting firm, to perform a review of our risk management practices."

Appendix 2: Principles of CCP Stress Testing

As with banks, both CCPs and their supervisors conduct stress tests. CCPs conduct tests daily; as market conditions change, managers need to know whether their book continues to be matched and where stress points, especially for liquidity, might be emerging.

The CME has set out six principles to guide stress tests performed by the CCP (Chicago Mercantile Exchange, 2015). Unsurprisingly, they involve monitoring both the CCP and its CMs, and include basic ingredients that are critical to any stress-testing regime. For supervisory stress tests (SSTs), the Committee on Payments and Market Infrastructure and the Board of the International Organization of Securities Commissions (CPMI-IOSCO, 2018) have articulated a six-element framework that parallels the CME's approach. The purpose here is broader; namely "the framework is designed to support SSTs conducted for the purpose of evaluating broad, macro-level impacts across multiple CCPs."[54]

Three important questions emerge from this work.

First, what are the pros and cons of standalone CCP stress testing, given the interconnectedness of CCPs and their reliance on CM resources? The answer differs for CCP-run stress tests and supervisory stress tests (SSTs). For the former, standalone, daily stress testing is used as a high-frequency risk management tool. It would be virtually impossible to do comprehensive, macroprudential SSTs on a daily basis. Lower-frequency—but not infrequent—standalone tests are helpful for supervisors to assess CCPs' internal stress tests; to diagnose model error; to quantify spillovers; and to direct CCPs to take remedial action. Periodic macroprudential SSTs are used to assess systemwide resilience in the face of changing conditions in markets and among financial entities.

Second, to what extent should supervisory standardize scenarios across CCPs? There are tradeoffs between the benefits for comparability of a common framework and the assessment of specific risks. Different CCPs clear different products, so stress tests affecting interest rate swaps may be only indirectly relevant—say, as a result of sharing CMs in common—for a CCP that doesn't clear them. As the Bank of England notes, "Moving towards greater standardization may come at the expense of failing to fully reflect the specific risk framework, operational procedures, and rules under which each CCP operates. Similarly, a push for greater inclusion of CCP-specific risks can make the results more difficult to aggregate for a systemwide view."

Third, in what ways do stress tests incorporate critical liquidity risks? The question is whether CCPs are able to convert collateral into cash when needed. Doing so in a period of stress may result in adverse

[54] For general precepts, see Anderson et al (2018) and Bank of England (2018).

spillover elsewhere in the financial system, including to other CCPs. This is the "fire sale externality." As then-Federal Reserve Board Governor Jerome Powell argued in 2017:

> *"A stress test focused on cross-CCP liquidity risks could help to identify assumptions that are not mutually consistent; for example, if each CCP's plans involve liquidating Treasuries, is it realistic to believe that every CCP could do so simultaneously?"*[55]

Yet, liquidity stress testing is relatively new and complex, so it is understandable that regulators began by implementing CCP stress tests that focused exclusively on counterparty credit risk.

Appendix 3: Data Needs for CCP Stress Tests

A truly systemwide test entails mapping the full network of exposures of the CCPs, the CMs, the customers of the CMs, the customers' customers, and on and on. Taken to its limit, this requires exposure information for every legal entity in the world. The reason is that the resilience of a CCP depends critically on that of its CMs and on the CCP's exposures to each CM and (indirectly) to the CM's clients. Of course, such data are confidential, and are available only to supervisors and specific CMs, so outside parties (including other CMs) do not have access.

Publicly available data

Compared to a few years ago, there are now publicly available data that represent a major step forward in improving transparency. Beginning in 2016, under guidelines from CPMI-IOSCO (2015), CCPs began to make quarterly public disclosures conforming to the PFMI (CPMI-IOSCO, 2012). CCPs publish this information on their websites. The four key CCPs that clear U.S. dollar derivatives[56], as well as 30 of 32 major global CCPs, now engage in these disclosures. Included are the aggregate amount of resources available in the event of default, the quality of the assets held in margin accounts and guarantee fund accounts, the degree of concentration of default resources, and positions in derivatives trades.

In 2017, the Office of Financial Research curated and analyzed these published data from the four key CCPs active in U.S. derivatives as of mid-2016 (OFR, 2017).

While these four CCPs report significant resources to absorb potential defaults, and show the resources held in aggregate by asset class at each level of the CCP's waterfall, the aggregates do not reveal how the default of a specific CM would ripple through the default waterfall because the data do not divulge the margin posted by each CM.

Similarly, the aggregation of assets held as margin or as guarantee funds across house and client accounts may overstate liquid resources available to meet a specific variation margin requirement faced by a clearing member.

The data confirm expectations that the concentration of exposures among the top five and top 10 CMs is high at some CCPs, but it is not universally so (for example, the concentration at LCH appears to be

[55] See Powell (2017).

[56] They are: CME Clearing (CME), part of CME Group; ICE Clear Credit (ICE), which is part of the Intercontinental Exchange; LCH Clearnet Limited (LCH), which was formed following the merger of the London Clearing House and Clearnet SA; and Options Clearing Corporation (OCC).

significantly lower than at CME). Moreover, we would need to know the concentration at each of the top-ranked CMs to assess the adequacy for “Cover 1”, “Cover 2” or “Cover n” standards.

Finally, the data depict several stress measures, such as average and peak payment obligations of CMs to the CCP. Once again, however, these aggregate data mask information about the distribution of those obligations. They also show cash flows only in one direction: they do not report the average and peak payment obligations *from the CCP to its CMs*.

These disclosed data also suffer from other important shortcomings. The CPMI-IOSCO guidelines are insufficiently prescriptive, so different CCPs report data differently. That leads to gaps and inconsistencies across time and CCPs. As the information in Table 1 makes clear, LCH provides updates on the value of gross notional contracts outstanding and of open interest. CME does not. Furthermore, CCPs do not report compression trades that affect the size and analysis of gross notional exposures.

<u>Granular swap data require further standardization to assure quality</u>

Timely, high-quality information requires well-designed, well-understood and uniform standards. That is not yet the case for granular data on derivatives needed for frequent CCP stress testing. In the process of implementing central clearing requirements, regulators sought to promote post-trade transparency for both market participants and regulators through the establishment of swap data repositories (SDRs; TRs in Europe) and trade reporting requirements. In the United States, the CFTC greatly improved the quality of data by required the use of the Legal Entity Identifier (LEI) in swap reporting. There also has been broader progress. According to the CFTC, “in 2014, roughly half of all reports for the highly standardized credit default swaps (CDS) lacked complete price information, and approximately 15% of all CDS trades lacked a legal entity identifier, making it difficult to identify the counterparty. However, by early 2018, roughly 95% of all CDS trades had complete counterparty and price information.”[57]

Nevertheless, fully realizing the anticipated benefits of these data collections would require significant changes in practice. Most important, precise, harmonized standards across instruments, institutions and jurisdictions are still lacking. For example, swap data repository requirements are not yet harmonized between the SEC and CFTC; nor are they harmonized between the United States and the European Union. The sheer volume of granular data and their lack of comparability limits the ability to extract useful information.

A key lesson here is that details matter. Initial efforts left the decision to collect, and how to report, swap data up to the CCPs or their SDRs. As a result, each SDR reported data in its own, idiosyncratic way, with different data elements in different formats. The result, in the words of a senior official, was a “meteor storm.” [58]

Regulators understand the need to improve data quality. In July 2017, the CFTC announced that it was launching a new review of the swap data reporting regulations, and it subsequently announced a wholesale review of swaps regulations and reporting.[59]

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[57] See Giancarlo and Tuckman (2018).

[58] While CFTC leadership identified the problems in 2013, as noted by then-Commissioner O’Malia (2013), it took until 2017 to specify solutions

[59] See Commodity Futures Trading Commission (2017a and 2017b).