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UNDERSTANDING INTERCONNECTEDNESS RISKS

To Build A More Resilient Financial System

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FOREWORD

The discipline of risk management has become more complex and diverse than ever, driven in large part by new regulatory mandates, an explosion of technological and financial innovation and the growing interconnectedness of global markets. Today's risk managers are analyzing, measuring and quantifying the impacts of an expanding list of risk categories, including operational, systemic, technology, vendor, business continuity and physical risk. This evolution of risk management is essential because firms need to have a deeper understanding of all aspects of the risks they face as well as the intricate spider's web of interconnections they create.

In this new paradigm, risk managers can no longer view financial firms as stand-alone entities because, in reality, they are now a diverse set of interconnected components that distribute risk and are exposed to it, oftentimes in ways that are not transparent or expected. Furthermore, the openness and complexity of the financial ecosystem and the likelihood that breakdowns will occur mean that firms must do more than monitor and mitigate these risks – they also need to focus on building resiliency so they can detect potential systemic shocks before they strike or recover from them as quickly as possible.

These concepts underpin DTCC's approach to risk management because, as a designated Systemically Important Financial Market Utility (SIFMU) in the U.S. and a leading provider of critical post-trade services across asset classes globally, we are responsible for protecting the integrity of the global financial system and ensuring market stability. We have incorporated this thinking into the organization's risk management framework, beginning with creating a Systemic Risk Office and appointing a Chief Systemic Risk Officer to conduct industry outreach, map emerging risk trends and engage with regulators and clients to identify and report on internal and external sources of systemic risk. As part of this work, we have published several white papers on systemic risk and conduct a semi-annual risk survey, the DTCC Systemic Risk Barometer, to gain insight into industry attitudes and behaviors and to spark discussion on the most pressing risk issues.

Our latest white paper on interconnectedness risk builds on these efforts, synthesizing the research and work performed by academics, government bodies and industry participants and identifying implications for the future. It also includes our own experiences in addressing interconnectedness risk and offers practical guidelines for implementing some of these concepts.

As we have done in the past, we will use this white paper as a springboard to engage with clients and other key stakeholders globally to share ideas and insights, collect feedback and foster discussion on an area of risk that is top-of-mind with regulators and market participants. We look forward to your thoughts and comments and encourage you to share them with us in the months ahead.

Andrew Gray
DTCC Group Chief Risk Officer

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EXECUTIVE SUMMARY

The key findings of this paper can be summarized as follows:

- A wave of network-related studies have been undertaken in the wake of the 2008 financial crisis to better understand the role of interconnectedness in the transmission of risks. A major finding of these studies is that financial networks tend to be robust yet fragile, absorbing shocks up to a certain tipping point, beyond which they spread risks rather than contain them.
- While the importance of network structures in propagating financial shocks is generally recognized, it remains unclear under which circumstances interconnectedness promotes or impairs financial stability.
- Policymakers' initiatives to address interconnectedness risks focus mainly on increasing the resilience of the most interconnected – and most systemically important – financial institutions. Similar measures have been introduced to enhance the resilience of critical financial market infrastructures.
- Identifying and assessing interconnectedness risks promotes a broader and deeper understanding of the threats to an organization. The paper proposes a set of practical guidelines for practitioners who wish to adopt this approach as a way to manage risks more holistically across organizational silos.
- In line with this comprehensive and inclusive approach, DTCC is working closely with market participants on several initiatives that are designed to mitigate industrywide interconnectedness risks and proactively address related policy directives.

INTRODUCTION

The collapse of Lehman Brothers in September 2008 triggered the worst financial crisis since the Great Depression. The initial crisis, which originated in the U.S. subprime mortgage-backed securities and collateralized debt obligations markets, affected an ever-widening group of market participants around the world through a complex web of direct and indirect links. The contagion effects spread rapidly through the financial system, disrupting repo markets and creating severe funding and liquidity challenges in the U.S. and abroad. This led to the failure of numerous banks, as well as a sharp drop in global real GDP, and ultimately threatened global financial stability.

As a result, the recent global financial crisis has emphasized the importance of interconnectedness as a key dimension of systemic risk.

A better understanding of the risks related to financial interconnectedness is a leading objective of academics and policymakers worldwide. A growing body of research on the structure and behavior of financial networks supports this objective and suggests that financial interconnectedness plays a crucial role in the transmission of shocks.

The goal of this paper is threefold: (1) to share analytical insights more broadly as a topic of interest to market participants; (2) to highlight the policy implications of risks related to interconnectedness; and (3) to encourage the use of interconnectedness analysis as a way to increase financial institutions' resilience by addressing risks holistically.

To this end, the paper provides an introduction to the subject, followed by an overview of a selection of interconnectedness studies conducted thus far. It also highlights regulatory measures designed to address interconnectedness risks.

The paper also provides an overview of specific initiatives and transformational solutions that are being collaboratively developed to mitigate interconnectedness risks. It concludes with DTCC's perspective on interconnectedness issues and a list of practical guidelines that risk management professionals can use to analyze these threats.

> *"Examples of vulnerabilities include high levels of leverage, maturity transformation, interconnectedness, and complexity, all of which have the potential to magnify shocks to the financial system."*

– Excerpt of a speech delivered by Ben S. Bernanke on May 10, 2013, at the 49th Annual Conference on Bank Structure and Competition sponsored by the Federal Reserve Bank of Chicago.

1. WHAT IS FINANCIAL INTERCONNECTEDNESS AND WHY DOES IT MATTER?

KEY TAKEAWAYS

Financial interconnectedness is the network of credit exposures, trading links and other relationships and dependencies between financial agents.

Interconnectedness matters because it serves as a conduit for contagion. The impact of the failure of a large interconnected entity can spread rapidly and extensively across the financial system, to the point where it can cause worldwide financial instability.

Generally speaking, financial interconnectedness refers to relationships among economic agents that are created through financial transactions and supporting arrangements. For the purposes of this paper, the term *interconnectedness* refers more specifically to linkages between and across: (i) financial institutions (banks and non-banks); (ii) providers of financial market infrastructure services; and (iii) vendors and third parties supporting these entities.

Interconnectedness is a very broad concept. For example, banks that lend to and borrow from other banks become interconnected to each other through interbank credit exposures. Contractual obligations among financial institutions (such as ownership, loans, derivatives and many other types of contracts) create interconnectedness between them as well. When firms invest in the same asset, they also become interconnected as a result of having common exposures to a given asset.[1]

In a highly interconnected financial system, distress in one entity is likely to be transmitted to other entities. In some cases, these intra-financial and/or legal linkages help dampen shocks by distributing and dispersing their impact throughout the financial system. But in other cases, these interconnections have proven to propagate shocks beyond their original impact, amplifying them in the process. The global financial crisis that unfolded in the wake of the Lehman insolvency was a dramatic example of this phenomenon.

As a result, the failure of a large interconnected entity can ripple through the entire financial system and spill over into the real economy. This is why interconnectedness is one of the key factors of the framework for assessing systemic risk in the banking sector that has been developed by the International Monetary Fund (IMF), the Bank for International Settlements (BIS) and the Financial Stability Board (FSB).

Understanding the evolving landscape of the financial system – and whether additional links promote or impair stability – is an important aspect of analyzing systemic risk. In order to better understand how risks can be transmitted through the financial system from one interconnected entity to another, this paper will provide background information for a basic understanding of interconnectedness risk followed by a review of some of the key research in the field to date.

1 International Monetary Fund (2014). Research Bulletin Volume 15, No. 1.

2. TYPES OF FINANCIAL INTERCONNECTEDNESS

KEY TAKEAWAYS

Firms can be interconnected directly (e.g., through interbank loans) or indirectly (e.g., if they are exposed to common assets).

At the highest level, there are two distinct types of financial interconnectedness – direct and indirect:

Direct financial interconnectedness refers to direct linkages between entities through financial transactions, obligations, contracts and other arrangements or relationships that are explicitly documented or otherwise directly observable.

Indirect financial interconnectedness refers to channels through which distress of one entity can affect another entity, even in the absence of a direct linkage between the two. Distress between seemingly unrelated entities can spread in myriad ways, a few of which are highlighted below.

Direct and indirect financial interconnectedness are closely related to financial contagion and spillovers. Financial contagion is the process by which an adverse shock at one financial institution can have negative consequences for others. Shocks that spread through indirect interconnectedness can affect a wide range of institutions more or less simultaneously. As a result, market conditions may further deteriorate and affect an ever-widening series of firms, leading to a negative feedback loop that increases the initial shock and spreads deepening stresses throughout the system. This may trigger a default cascade.

The sections below identify and describe a few examples of direct and indirect financial interconnectedness.[2]

2.1 Direct financial interconnectedness

EXAMPLES OF DIRECT FINANCIAL INTERCONNECTEDNESS			
Credit Exposures Between Banks	Financial Market Infrastructure Relationships	Vendors and Other Third-Party Relationships	Other Financial Service Dependencies

Credit exposures between banks are among the most basic types of direct interconnectedness. If Bank A lends funds to Bank B, the two banks are directly connected and the interbank loan will show up as an asset on the balance sheet of Bank A and a liability on the balance sheet of Bank B. Bank A is exposed to Bank B and might suffer losses if Bank B were to become insolvent. Credit exposures can also result from holding securities issued by other institutions, securities financing transactions, derivatives trading and other activities beyond the interbank lending market. Finally, credit exposures can also arise in holding companies and other structures where legal entities are connected through ownership links to each other.

Financial market infrastructure relationships constitute another type of direct interconnectedness. In order to operate their businesses, banks, broker/dealers and other institutions need access to payment, clearance and settlement systems that collectively represent the financial markets' infrastructure. The arrangements used for securing this access – which can involve one or more intermediary service providers – constitute a network of direct interconnections. Additionally, certain financial market infrastructures have created various types of links between themselves.

2 Liu, Z., Quiet, S., & Roth, B. (2015). *Banking Sector Interconnectedness: What Is It, How Can We Measure It and Why Does It Matter?* Bank of England Quarterly Bulletin, 55(2), 130–139.

Vendors and other third-party relationships can also be a source of interconnectedness risk, as illustrated by the 2013 cyberattack against Target, one of the largest U.S. retail companies. Investigations into the security breach, which resulted in the theft of sensitive information of as many as 110 million customers, revealed that the attackers managed to gain a foothold in Target's network through weak security practices by a third-party vendor – a small Pennsylvania HVAC company that had been granted access to Target's network.

Other financial service dependencies represent additional types of direct interconnectedness, apart from credit exposures. For example, a financial institution may rely on another entity for access to derivatives markets for hedging purposes; for raising capital; or for providing custodial, guarantee or other financial services. Distress can spread through these types of direct interconnections if the failure of a financial service provider disrupts a firm's access to key services that it cannot immediately obtain from an alternative source.

2.2 Indirect financial interconnectedness

EXAMPLES OF INDIRECT FINANCIAL INTERCONNECTEDNESS				
Exposure to Common Assets	Mark-to-Market Losses	Margin Calls and Haircuts	Shadow Banking	Information Spillovers

Exposure to common assets. Financial institutions that hold common assets are indirectly interconnected. Concentrations of holdings in common assets have exposed financial institutions to increased price fluctuations and elevated risk, particularly during periods of market volatility or turmoil. Supply and demand dislocations, as well as pricing impact on assets, present additional vulnerabilities for financial institutions that can move quickly through the financial system in response to an initial market shock, actions of market participants and downstream reactions.[3]

Mark-to-market losses triggered by fire sales. Fire sales refer to situations where a firm tries to sell a large amount of assets in a short period of time. This can occur for a number of reasons – an institution may face distress due to capital constraints, a sudden withdrawal of funds or other liquidity or funding pressures. Similarly, when a bank defaults, its counterparties may sell securities received as collateral to cover losses they incurred as a result of the default. When a fire sale occurs, other firms that hold these or related assets will need to mark them to a lower price and report mark-to-market losses.

Margin calls and haircuts. When a fire sale drives down the value of collateral held by lenders, borrowers may become distressed if they do not have sufficient liquid assets to cover resulting margin calls. Additionally, haircuts may increase as a result of higher volatility, which can further spread distress.

Shadow banking. While the counterparty mix for large financial institutions still includes regulated banks, it has shifted to include more non-banks or shadow banks, such as money market funds, mutual funds, pension funds and hedge funds. Over the years, the shadow bank sector has been a steadily growing component of the global financial system. Some of these entities are not always subject to the same regulatory requirements and levels of transparency that apply to traditional financial institutions. While they may appear independent, they are often closely related to and interconnected with banks.[4]

Information spillovers. The distress or failure of one entity may be interpreted by the market as a negative signal about other entities. This may lead to a crisis of confidence, which in turn may reduce the appetite for bank debt and impair the provision of short-term wholesale funding.

3 Braverman, A., & Minca, A. (2014). *Networks of Common Asset Holdings: Aggregation and Measures of Vulnerability.*

4 Moghadam, R., & Viñals, J. (2010). *Understanding Financial Interconnectedness.* International Monetary Fund.

3. STUDIES ON INTERCONNECTEDNESS

KEY TAKEAWAYS

Financial networks tend to be robust yet fragile, absorbing shocks up to a critical tipping point, and spreading risk beyond this threshold.

The failure of a centrally located node tends to increase the likelihood and extent of contagion.

Some research suggests that networks with a moderate level of interconnectedness may be the most resilient ones.

Studies on interconnectedness can generally be classified into two broad categories:[5]

Network-based studies map the relationships between institutions and use those relationships as inputs to model and measure interconnectedness. Some network-based studies use simulations to assess the robustness of the system. Both direct and indirect forms of interconnectedness can be mapped to perform these studies.

Non-network-based studies, by contrast, use econometric techniques to analyze the variation between equity returns and other factors as a way to infer interconnectedness between entities or sectors. Default probability models, which try to understand the potential for systemic distress, are also related to this type of research.

Each of these types of studies has its benefits and drawbacks. Network-based studies that model direct forms of interconnectedness are generally easy to construct and interpret, but they have limited real-world applicability as they focus only on a narrow set of data. Networks that model indirect forms of interconnectedness are more comprehensive in scope, but they rely on underlying assumptions that are hard to verify. The main advantage of non-network-based studies is that they draw on real-world data. That said, their results and the underlying causes may be hard to interpret economically.

The remainder of this section will highlight research efforts that try to answer two related questions that have been the focus of many recent network-based studies:

What do financial networks look like? This question is addressed by studies that focus on the structure or topology of financial networks. These studies are empirical in that they describe the pattern of interconnectedness between financial institutions and infrastructures. They also help identify which nodes of a financial network are systemically important.

How resilient are financial networks to stress? This is a central question of studies that analyze how shocks spread through a network of interconnected entities. These studies try to determine which networks promote financial stability.

5 For a more detailed description, we refer to *Taxonomy of Studies on Interconnectedness*, by Gazi Kara, Mary Tian and Margaret Yellen, a FEDS Note that was published on July 31, 2015.

3.1 What do financial networks look like?

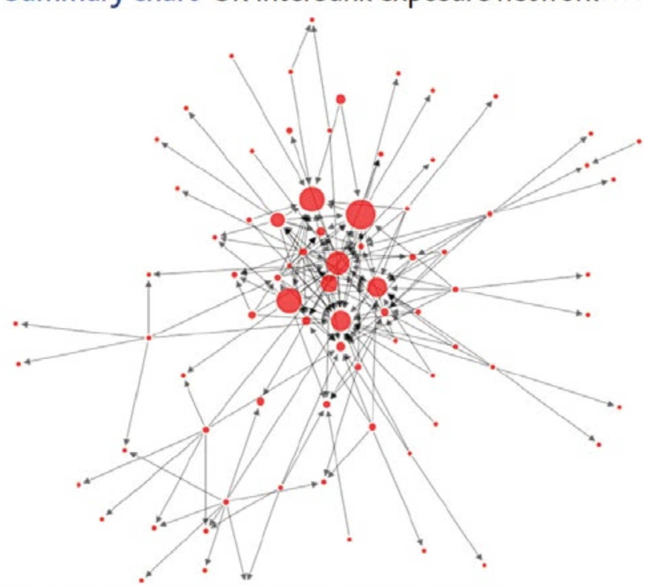
Network representations are particularly suitable for capturing interconnectedness in financial systems. They are able to visually show multiple characteristics, including the directional nature of links between entities (for example, borrowers vs. lenders or collateral providers vs. collateral takers). Additionally, networks also allow for weighted links, where the weights can represent interbank cash flows or other quantitative data.

In its most basic form, a network, or "graph," is a collection of points, or "nodes," connected together by lines, or "edges." The interpretation of nodes and edges depends on the context; in financial networks, the nodes are typically financial institutions and the edges can be anything from loans to trade flows.

Financial networks have very different structures, depending on what they depict. Rather than trying to provide an exhaustive overview, this section briefly highlights a few illustrative examples:

- **Networks that depict payment flows between financial institutions** are typically very dense, signifying that nodes in these networks have many interconnections between them.
- The structures of **trading networks** in markets that include a central counterparty (CCP) look very different from those that include bilateral trading only. By placing themselves between buyers and sellers, CCPs fundamentally transform the network structure of the original trade obligations into a far less complicated set of exposures.
- **Interbank exposure networks** typically show a highly connected set of core banks and a few connections to and among periphery banks, as illustrated in the example below. This type of network topology is referred to as a *core-periphery structure*, which is typical for real-world interbank networks:[6]

Summary chart UK interbank exposure network(a)(b)



Sources: Prudential Regulation Authority (PRA) and Bank calculations.

(a) Data as at end-2013. Exposures are net of collateral.
(b) Each node represents a bank and the size of the node is scaled by the total amount of exposures to and from that bank. Each arrow points from one bank to another bank that it has exposure to. The layout is designed so that for any two banks in the network, the greater the exposures between them, the more closely they are positioned.

6 Taken from Liu, Z., Quiet, S., & Roth, B. (2015). *Banking Sector Interconnectedness: What Is It, How Can We Measure It and Why Does It Matter?* Bank of England Quarterly Bulletin, 55(2), 130–139.

While financial networks can be very diverse, the most central node in a network is typically the most systemically important one. This means that the failure of the most central entity tends to have the largest impact on the system in its entirety. However, the centrality of a node does not reveal anything about its robustness per se. Therefore, it may be misleading to refer to the most central entity in a network as "the most vulnerable node." It is quite possible that the most central node in a network is actually the most robust one.

While these studies are useful to describe the characteristics of a financial network, they are unable to assess the robustness of the network itself. This is the focus of risk propagation studies.

3.2 How resilient are financial networks to stress?

Once the structure of a financial network is identified, the analysis focuses on how risk spreads from one node to another. Researchers use simulations and modeling techniques to gain a better understanding of how the characteristics of a financial system affect contagion and network stability.

In order to assess the resilience of a given network, two actions should be taken, each of which requires several decisions:

First, the network should be subjected to an initial shock, which requires a determination of what kind of shock is appropriate for analyzing the particular risk being assessed.

Shocks can be either *endogenous*, meaning they originate within the network itself (e.g., the default of a bank in a banking network) or *exogenous*, meaning they come from outside of the network (e.g., a major macroeconomic event).

Consideration should also be given to whether shocks are *idiosyncratic* (in which case they affect only one node initially), or *common* (in which case they impact multiple nodes simultaneously).

Second, the way in which that shock propagates through the network should be analyzed. The dissemination of a shock requires certain assumptions about how stresses are transmitted between interconnected nodes.

Stress can be transmitted *iteratively*, from one node to the next, or *simultaneously*, to several nodes at the same time.

Shock propagation can be *mechanical* (e.g., losses incurred by creditors of a defaulting bank) or *behavioral* (e.g., trading strategies based on certain heuristics) – or a combination of both.

Shocks can be spread along one or more of the following contagion channels:

- **Credit risk channel** – Contagion is driven by insolvencies, causing losses to creditors and holding companies (through cross-ownership structures), which in turn may cause additional insolvencies. In extreme cases, the impact can spread across multiple nodes and cause a *series of cascading defaults.*
- **Liquidity risk channel** – Contagion is driven by impaired funding liquidity and/or decreasing market liquidity, possibly resulting in *liquidity crunches or markets that seize up.*
- **Market risk channel** – Contagion is driven by market movements, causing trading losses, losses on investments and mark-to-market losses, which may ultimately lead to *market dislocations or crashes.*
- **Operational risk channel** – Contagion is typically driven by an initial failure, which may lead to subsequent issues through operational dependencies (e.g., in a payment system). In a worst-case scenario, this can lead to a *systemwide operational disruption or breakdown.*

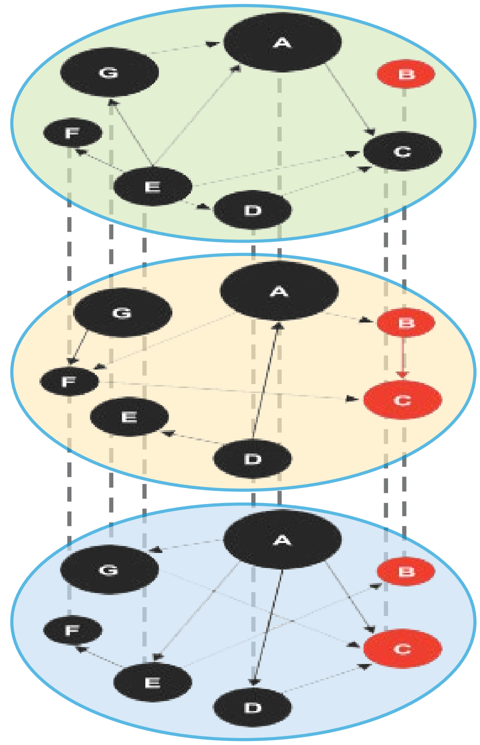
While theoretical studies typically analyze risk propagation channels individually, they interact with each other in the real world. This is a further complication that some researchers try to incorporate as they attempt to unravel the dynamics of fire sales, liquidity hoarding, crowded trades and other feedback loops.

Additionally, these phenomena often involve widespread uncertainty, loss of confidence, panics, herding behavior and other forms of irrationality that are particularly hard to model.

The combination of variables, assumptions and decisions described above produces an almost limitless number of shock propagation mechanisms. Each of those mechanisms can then be used to assess the resilience of an equally overwhelming number of networks. Unsurprisingly, the results of many of these studies are often ambiguous, if not inconclusive.

Modeling the financial system as a one-dimensional network is a useful first step, but it is an oversimplified representation of the real world. In order to overcome this limitation, network representations can also be extended to represent different types of links between nodes. This is an important feature, given that banks and other financial institutions engage in many different types of transactions with each other (e.g., interbank lending, repurchase agreements, and derivatives trading).

This multitude of possible link types can be captured by *multilayer or multiplex financial networks*, where different layers represent different types of transactions (see illustration to the right for a stylized representation). This comes closer to the more recent concept of thinking of the financial system as a "system of systems."



3.3 Research conclusions

The main conclusion of interconnectedness studies is that many financial networks tend to be robust yet fragile, meaning they absorb shocks up to a critical tipping point, beyond which they spread risk rather than contain it.

Risk contagion depends on three crucial factors: (i) the size of the initial shock; (ii) the position of distressed/failed nodes in the network; and (iii) the topology of the network itself. The relationship between these three factors is extremely complex – it can be nonlinear, non-monotonic and generally unpredictable, even in simplified theoretical models. This is especially true for the combined effect of multiple contagion channels.

For a given network, the risk of contagion generally increases with the size of the shock and the centrality of the affected nodes; all else being equal, the more central the location of a failing node, the greater the likelihood of contagion.

The effect of a network's topology on contagion is less straightforward. While the structure of a network definitely matters for risk propagation, it is unclear whether a higher degree of interconnectedness improves or weakens the resilience of a financial network.

A recent literature survey reports that researchers are finding "there is a trade-off between risk sharing via linkages to other banks and contagion risk due to too many linkages,"[7] suggesting that networks may have an optimal level of interconnectedness. The intuition behind these findings is that very sparse networks lack the interconnectedness required to optimally diversify shocks (so they can be channeled to a sufficiently large number of risk-absorbing nodes), while extremely dense networks are so interconnected that they tend to spread rather than diversify risk.

That said, studies on the relationship between a network's interconnectedness and its ability to withstand shocks also suggest that many other factors come into play, including the type of financial shocks, the maturity structure of banks' liabilities, existence of information problems and other financial frictions.[8] Researchers continue to study the impact of these and other factors as they try to gain a better insight into the impact of a network's topology on its resilience (see Appendix).

7 Too Interconnected to Fail: A Survey of the Interbank Networks Literature – SAFE Working Paper No. 91 by Anne-Caroline Hüser (May 2015).

8 Kara, G., Tian, M., & Yellen, M. (2015). Taxonomy of Studies on Interconnectedness. FEDS Notes.

4. POLICY IMPLICATIONS

KEY TAKEAWAYS

Regulators have made progress in understanding and addressing interconnectedness within the global financial system. Rather than curbing interconnectedness directly, they have chosen to emphasize measures designed to increase the resilience of highly interconnected – and systemically important – financial institutions.

While interconnectedness has many important advantages, both for the absorption of shocks – up to a critical threshold – and for improving operational efficiencies within the financial sector, there can be undeniable disadvantages as well. This fundamental insight has important implications for policymakers, who are understandably concerned about mitigating the potential systemic risks related to interconnectedness.

In order to address these risks, some regulatory measures have emerged that are intended to directly curb particular types of interconnectedness. However, such measures are hard to design because of the practical difficulties of determining which level of interconnectedness is undesirable in the first place. As a result, policy-makers have mainly focused on introducing rules aimed at increasing the resilience of the most interconnected – and most systemically important – financial institutions. Similar measures have been taken to enhance the resilience of critical market infrastructures.

As part of this effort, supervisors have established a series of indicators that are being monitored to assess the systemic importance of financial institutions. These include measurements of interconnectedness, in addition to other metrics that reflect an entity's systemic importance.

"[…] by its nature, interconnectedness demands a policy response that goes beyond the national level. International cooperation is essential to monitor and respond to vulnerabilities."

—Jaime Caruana, General Manager of the Bank for International Settlements, during a speech at the third Swiss National Bank – International Monetary Fund conference on the international monetary system, Zürich, May 8, 2012.[9]

9 The full speech is available at http://www.bis.org/speeches/sp120730.htm

4.1 Measuring and monitoring interconnectedness

Various types of metrics can be used to measure interconnectedness. Their appropriateness depends on several factors, including: the economic content of network versus non-network measures; how quickly measures reflect shocks to the financial system; and the frequency with which the data necessary to build the network can be obtained.

The Basel Committee on Banking Supervision (BCBS) outlined a methodology for assessing and identifying global systemically important banks (G-SIBs).[10] It is supported by an indicator-based approach that has five equally weighted broad categories of systemic importance: (i) size; (ii) interconnectedness; (iii) substitutability; (iv) global (cross-jurisdictional) activity; and (v) complexity.

Interconnectedness in the context of this methodology reflects the extent to which the failure of a bank to meet its payment obligations to other banks can cause distress at other institutions, given the network of contractual obligations that exists between them. Three equally weighted indicators measure interconnectedness: (i) intra-financial system assets; (ii) intra-financial system liabilities; and (iii) the total value of outstanding debt and equity securities issued by a bank.

Substitutability refers to the lack of readily available alternatives to a bank's infrastructure or other financial services. A bank is more systemically important if it provides important services that customers would have difficulty replacing if the bank failed.[11] As such, the concept of substitutability also captures specific types of direct financial interconnectedness. Three equally weighted indicators measure this effect: (i) a bank's payments activity; (ii) assets under custody at the bank; and (iii) the bank's total underwriting transactions in debt and equity markets.

It is important to note that these measures are not meant to reflect the probability that an institution will fail; instead, they are designed to measure the potential impact that a bank's failure could have on the global financial system and wider economy. As such, these are loss-given-default (LGD) measures, rather than probability of default (PD) measures.

Banks are required to report on these five indicators to national supervisors.[12] The indicators are then aggregated and used to calculate the systemic importance scores of banks in the sample. The advantage of the multiple indicator-based measurement approach is that it encompasses many dimensions of systemic importance, it's relatively simple and it's more robust than currently available model-based measurement approaches and methodologies that rely on only a small set of indicators or market variables.

Banks with a final score, including the use of judgment, above a cut-off point are identified as G-SIBs and are allocated to buckets that will be used to determine their higher loss absorbency (HLA) requirement. The additional loss absorbency requirements will range from 1% to 2.5% Common Equity Tier 1 (CET1) depending on a bank's systemic importance with an initially empty bucket of 3.5% CET1 as a means to discourage banks from becoming even more systemically important. The higher loss absorbency requirements will be introduced in parallel with the Basel III capital conservation and countercyclical buffers, i.e., they will begin to be phased in from January 1, 2016, with full implementation by January 1, 2019.

10 See http://www.bis.org/publ/bcbs255.pdf and http://www.bis.org/bcbs/publ/d296.pdf

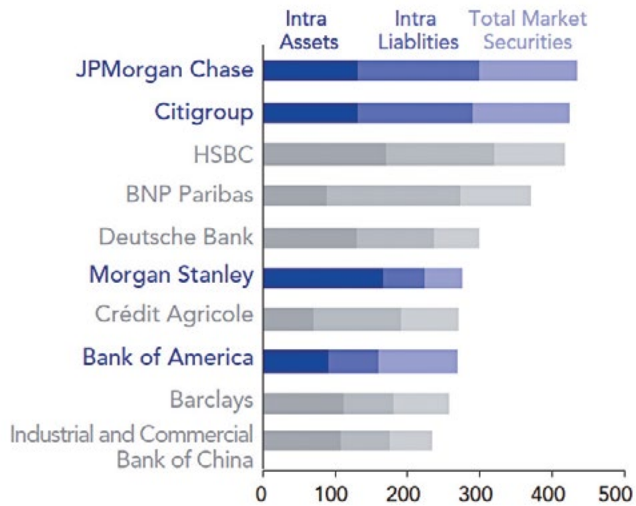
11 For example, the greater a bank's role in a particular business line, or as a service provider in underlying market infrastructure (e.g., payment systems), the larger the disruption will likely be following its failure, in terms of both service gaps and reduced flow of market and infrastructure liquidity. At the same time, the cost to the failed bank's customers in having to seek the same service from another institution is likely to be higher for a failed bank with relatively greater market share in providing the service.

12 In the United States, each U.S. bank holding company with over $50 billion in assets (and each U.S.-based organization that is designated as a global systemically important bank (G-SIB) by the Basel Committee on Banking Supervision (BCBS) that does not otherwise meet the consolidated assets threshold) is required to annually disclose its systemic risk indicators to the Federal Reserve by filing a Form Y-15, or Banking Organization Systemic Risk Report. The Y-15 reports are made publicly available to help ensure comparability when evaluating the systemic risk profile of large banking organizations.

A recently published report by the Office of Financial Research (OFR) lists the top 10 G-SIBs by interconnectedness:[13]

Top 10 G-SIBs by Interconnectedness (basis points)

U.S. banks rank relatively high on interconnectedness scores



Note: U.S. banks are in blue and non-U.S. banks are in gray.

Sources: Company G-SIB disclosures, Bank for International Settlements, OFR analysis

The OFR also estimates a *financial connectivity index* for U.S. bank holding companies, which measures the fraction of a firm's liabilities that are held by other financial institutions. Combining its financial connectivity index with measures of a bank's size and leverage, the OFR also calculates a *contagion index*, which is designed to provide an overall measure of the contagion risk that the bank poses for the financial system.

A recent OFR report[14] finds that highly leveraged banks are also the most interconnected. Based on recent data:

- seven of the eight U.S. G-SIBs had high financial connectivity index values; Bank of New York Mellon and State Street were high on both dimensions despite their relatively smaller sizes; and
- five of the U.S. banks had particularly high contagion index values: Citigroup, JPMorgan, Morgan Stanley, Bank of America and Goldman Sachs.

13 Glasserman, P., & Loudis, B. (2015). *A Comparison of U.S. and International Global Systemically Important Banks.* Office of Financial Research Brief Series 15-07.

14 Allahrakha, M., Glasserman, P., & Young, H. (2015). *Systemic Importance Indicators for 33 U.S. Bank Holding Companies: An Overview of Recent Data.* Office of Financial Research Brief Series, 15-01.

4.2 CPMI-IOSCO and interconnectedness

The Committee on Payments and Market Infrastructures (CPMI),[15] consisting of senior officials of its member central banks (including the European Central Bank, Federal Reserve Bank of New York and Bank of England, among others), has a mandate to promote the safety and efficiency of payment, clearing, settlement and related arrangements. Through the lens of this mandate, the CPMI has long been concerned with the impact of interconnectedness among financial market infrastructures (FMIs) on financial stability and global markets.

In June 2008, the CPMI published a report concluding that interdependencies among FMIs have significant implications for the global payment and settlement infrastructure, and that while tighter interdependencies can strengthen FMIs through cost and risk reduction, they also have the potential to rapidly spread disruptions across the global payment and settlement infrastructure.[16]

The CPMI collaborated with the Technical Committee of the International Organization of Securities Commissions (IOSCO)[17] to publish the *Principles for financial market infrastructures* (the "Principles") in 2012 in order to continue the efforts of both organizations to promote financial stability and further increase resiliency among the global payment and settlement infrastructure.

These 24 Principles build on the conclusions of the earlier CPMI report, recognizing that interconnectedness among FMIs may foster "knock-on" effects throughout the financial system in the event of a stress event, thereby impacting participants and markets across the FMIs.[18] Specific examples include:

- ***Principle 3: Framework for the comprehensive management of risks*** directs FMIs to regularly review the material risks they bear from and pose to other entities (such as other FMIs, settlement banks, liquidity providers, and service providers) as a result of interdependencies and develop appropriate risk management tools to address these risks.
- ***Principle 20: FMI Links*** directs FMIs to identify, monitor and manage sources of risk arising from the links it has established with other FMIs. An example of an FMI link is a connection established between central securities depositories (CSDs) for purposes of enabling participants of one CSD to access the services of and securities maintained in another CSD.

As members of IOSCO, national securities regulators should continue to develop and implement domestic securities regulations that are consistent with the Principles. Interconnectedness analysis will help further enhance confidence in FMIs and promote overall financial stability.

15 Effective September 1, 2014, the Committee on Payment and Settlement Systems (CPSS) was renamed the Committee on Payments and Market Infrastructures (CPMI). Refer to https://www.bis.org/cpmi for further details.

16 Refer to the CPSS report *The interdependencies of payment and settlement systems*, June 2008, at http://www.bis.org/cpmi/publ/d84.htm

17 IOSCO is an international organization that comprises the world's securities regulators and is recognized as the global standard setter for the securities sector. Refer to http://www.iosco.org for further details.

18 Refer to CPMI-IOSCO, *Principles for financial market infrastructures*, April 2012, at https://www.bis.org/cpmi/publ/d101.htm

4.3 Basel III

The Basel III framework that was developed by the Basel Committee on Banking Supervision[19] includes a section that specifically focuses on measures designed to address systemic risk and interconnectedness. These include:

- capital incentives for banks to use central counterparties for over-the-counter derivatives;
- higher capital requirements for trading and derivative activities, as well as complex securitizations and off-balance sheet exposures (e.g., structured investment vehicles);
- higher capital requirements for inter-financial sector exposures; and
- introduction of liquidity requirements that penalize excessive reliance on short term, interbank funding to support longer-dated assets.

4.4 FFIEC guidance related to interconnectedness risks

The Federal Financial Institutions Examination Council (FFIEC) is a formal interagency body that is empowered, among other things, to make recommendations to promote uniformity in the supervision of financial institutions.

As part of its mandate, the FFIEC maintains a series of booklets that provide guidance to both examiners and financial institutions on a variety of risk management topics. Collectively, these booklets constitute the *FFIEC Information Technology Examination Handbook.*

The FFIEC acknowledges the increased interconnectedness that has resulted from financial institutions' growing reliance on vendors, partners and other third parties for a variety of technology solutions and services. Two FFIEC booklets specifically address this type of interconnectedness:

1) The *Outsourcing Technology Services* Booklet

This booklet provides guidance related to a financial institution's process to establish, manage, and monitor IT outsourcing relationships. It addresses an institution's responsibility to manage the risks associated with these outsourced IT services and outlines how these risks may be realized in a different manner than if the functions had been performed internally. Many of the general principles of managing outsourcing relationships discussed in this booklet can and should be applied to managing the outsourcing of software development (which is described in more detail in the FFIEC's *Development and Acquisition* Booklet).

2) The *Supervision of Technology Service Providers* Booklet

This booklet covers the supervision of third-party *Technology Service Providers* (TSPs) that enter into a contractual arrangement with a regulated financial institution. It highlights financial institutions' undiminished responsibilities to monitor these third parties and ensure that they comply with applicable laws and regulations, to the same extent as if the institution were to perform the outsourced activities itself. It also explains how regulators expect financial institutions to establish a comprehensive process to govern their TSP relationships. This process should include risk assessment, selection of service providers, contract review and monitoring of service providers.

In further recognition of the importance of interconnectedness, the other booklets that are part of the FFIEC Information Technology Examination Handbook contain explicit guidance for both financial institutions and the service providers they engage.

19 *Basel III: A global regulatory framework for more resilient banks and banking systems*, December 2010 (rev June 2011) – http://www.bis.org/publ/bcbs189.pdf

4.5 Recovery and resolution plans

Another aspect of policymakers' efforts to address interconnectedness risks is the requirement for both systemically important financial institutions and FMIs to develop and maintain recovery and resolution plans. These plans are designed to demonstrate a firm's ability to recover from a severe idiosyncratic or systemic stress scenario, as well as its ability to be resolved in a rapid and orderly manner in the event of material financial distress or failure, while continuing to provide critical operations to its customers or users, in the case of an FMI. As part of the planning process, firms are required to identify and document both internal interconnectedness (e.g., dependencies on other subsidiaries of the designated company for the provision of their critical operations) and external interconnectedness (e.g., dependencies on third parties or FMIs). Through this analysis, the firms identify potential impediments to recovery or an orderly resolution, and develop plans to remediate or mitigate the identified potential impediments.

The importance of this analysis was echoed in the August 2014 feedback of the Board of Governors of the Federal Reserve System (FRB) and the Board of Directors of the Federal Deposit Insurance Corporation (FDIC) provided to the 11 firms that filed their second resolution plans in 2013. Among the plans' shortcomings noted by the FRB and FDIC was the need to reduce complexity within the firms' legal entity structures in order to improve firm resolvability.[20]

Further emphasis on this objective was offered by Martin J. Gruenberg, Chairman of the FDIC, during a May 12, 2015 progress report on the resolution of systemically important financial institutions presented to the Peterson Institute for International Economics in Washington, D.C. One aspect of the presentation focused specifically on how recovery and resolution plans are designed to address the issue of interconnectedness:[21]

> "The actions the firms are being required to take focus in particular on reducing the interconnectedness between legal entities within the firms.
>
> In order to understand why reducing this internal interconnectedness is being stressed, it is important to recognize how the largest, most complex financial firms are organized and what would happen if one were to fail. These firms are extremely complex with hundreds, if not thousands, of legal entities, which operate on a business line – not legal-entity – basis. While business lines stretch across multiple legal entities, foreign and domestic, failure occurs on a legal-entity basis. The inability to resolve one legal entity without causing knock-on effects that may propel the failure of other legal entities within the firm makes the orderly resolution of one of these firms extremely problematic.
>
> To improve resolvability, firms must show how their legal entities can be separated from their parent company and their affiliates, that the default or failure of one entity will not trigger the default or failure of other entities, and that critical operations will continue to function in resolution. [...] Ensuring that firms can disentangle their business lines and services into separate legal entities so that critical operations can be maintained during resolution will better enable firms to be split apart and liquidated in resolution."

20 Refer to the FRB and FDIC Joint Press Release, at http://www.federalreserve.gov/newsevents/press/bcreg/20140805a.htm

21 Refer to the speech transcript, at https://www.fdic.gov/news/news/speeches/spmay1215.html

4.6 Additional policy initiatives designed to address interconnectedness risks

Certain measures have been designed to directly control and limit interconnectedness by imposing direct restrictions on the scope of businesses conducted by large banks. These restrictions aim to safeguard core banking activities from contagion that might originate in riskier areas – while simplifying the banks' organizational structures in the process. Direct measures that limit banks' activities include:

- **the Volcker Rule in the United States**, which is designed to prohibit deposit-funded banks from engaging in speculative trading and investments;
- **two European proposals (Vickers and Liikanen)** which aim to ring-fence deposit-funded banks from their investment banking affiliates and, in one case, prohibit them from maintaining business relationships outside a pre-specified geographic perimeter; and
- **the European Market Infrastructure Regulation (EMIR)**, which is designed to provide a regulatory framework to address central clearing, transaction reporting and segregation for over-the-counter (OTC) derivatives.

As mentioned earlier, one of the challenges of designing direct measures is the uncertainty surrounding the level of interconnectedness that is deemed undesirable. That is why policymakers also use a more indirect approach to mitigating interconnectedness risk by: (i) identifying which entities are systemically important; and (ii) trying to ensure that these critical network nodes are as robust and resilient as possible.

The IMF has produced a detailed report that provides guidance for risk managers to identify all interconnectedness touch points and develop an approach to assess and evaluate their interconnectedness exposure.[22]

22 *Addressing Interconnectedness: Concepts and Prudential Tools* – IMF Working Paper prepared by Nicolas Arregui, Mohamed Norat, Antonio Pancorbo, and Jodi Scarlata (https://www.imf.org/external/pubs/ft/wp/2013/wp13199.pdf)

5. IMPLICATIONS FOR RISK MANAGEMENT PRACTITIONERS

KEY TAKEAWAYS

While additional research may help deepen our insight into certain risk dynamics, risk management practitioners may benefit most from incorporating an interconnectedness lens into everyday activities. This can meaningfully contribute to enhancing systemic resilience, both for individual organizations and for the financial industry as a whole.

While network theory provides better insights into the dynamics of risk contagion, its practical application for risk experts outside of the academic and regulatory community is not always immediately obvious.

As network research continues to advance, integrating interconnectedness analysis into everyday risk management practices can contribute to financial stability in a meaningful way for at least four reasons:

- **First, it promotes holistic thinking about risks facing the financial industry.** This comprehensive mindset is more crucial than ever in order to recognize emerging threats in an ever-changing world that is increasingly dynamic, global and complex – a world that grows more fragmented and interconnected at the same time.
- **Second, it clarifies the boundaries between actionable and inherent risks.** Focusing on interconnectedness helps organizations distinguish more clearly between risks they can mitigate versus risks they cannot control or otherwise influence. Different organizations will draw different boundaries, depending on whether they are market participants, financial infrastructures or regulatory authorities.
- **Third, it fosters an equally comprehensive mindset in thinking about risk mitigants.** Thinking in silos leads to developing isolated and fragmented mitigants that cannot stand the test of time. Industrywide risks require long-term, industrywide solutions rather than temporary patches.
- **Fourth, it sharpens risk managers' focus on key strengths and opportunities, both internally and externally.** In addition to helping organizations home in on their own areas of expertise, focusing on interconnectedness also enables them to recognize core competencies outside of their own walls.

Janet Yellen, chair of the FRB, focused on interconnectedness during a January 4, 2013 speech titled *Interconnectedness and Systemic Risk: Lessons from the Financial Crisis and Policy Implications* at the American Economist Association/American Finance Association Joint Luncheon in San Diego, California. A component of this speech focused specifically on the benefits and risks related to interconnectedness:[23]

> "So, what have we learned from this brief tour through recent research on interconnectedness and systemic risk? We have seen how interconnectedness can be a source of strength for financial institutions, allowing them to diversify risk while providing liquidity and investment opportunities to savers that would not be available otherwise. But more-numerous and more-complex linkages also appear to make it more difficult for institutions to address certain types of externalities, such as those arising from incomplete information or a lack of coordination among market participants. These externalities may do little harm or may even be irrelevant in normal times, but they can be devastating during a crisis."

The next section provides a few tangible examples of how DTCC has started to collaboratively develop solutions alongside market stakeholders in order to address a variety of industrywide challenges related to interconnectedness.

23 Federal Reserve, *Interconnectedness and Systemic Risk: Lessons from the Financial Crisis and Policy Implications*, January 4, 2013 (http://www.federalreserve.gov/newsevents/speech/yellen20130104a.htm)

6. INITIATIVES TO ADDRESS INTERCONNECTEDNESS RISK

KEY TAKEAWAYS

DTCC is involved in several internal and external initiatives aimed at addressing concerns related to financial interconnectedness.

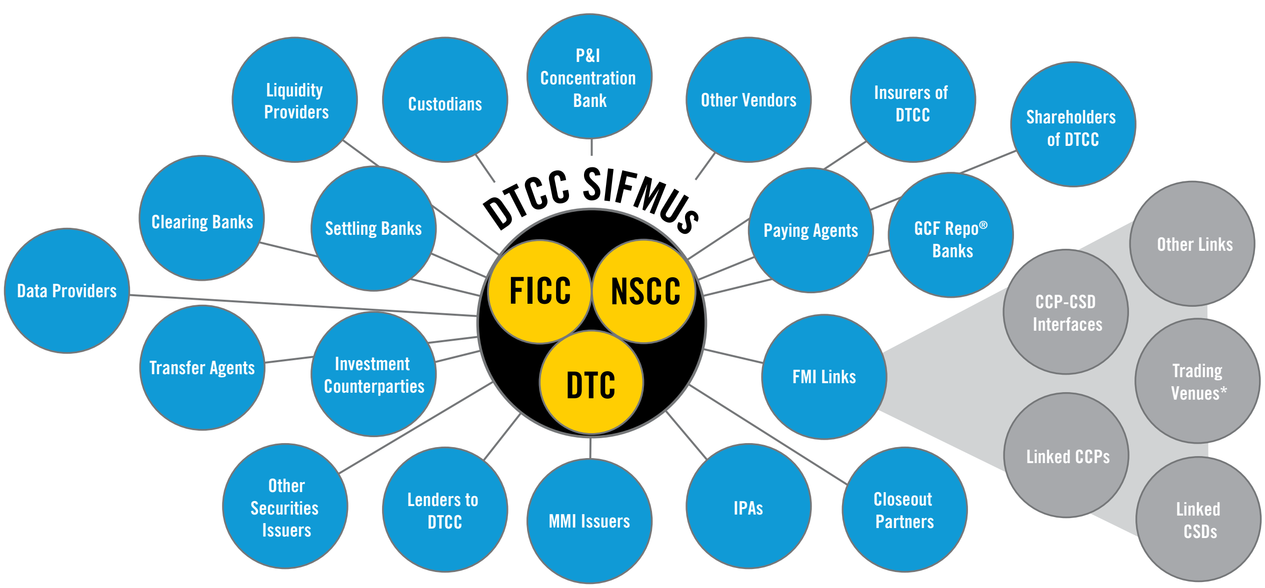
Internal efforts focus primarily on enhancing DTCC's resilience in the face of interconnectedness risk, while external initiatives are designed to help mitigate industrywide systemic risks.

6.1 Addressing DTCC's interconnectedness risks

In recognition of DTCC's pivotal role in protecting financial markets and promoting financial stability, the company expanded its risk management structure by creating a Systemic Risk Office, a team specifically dedicated to identifying, monitoring and containing potential systemic threats. This decision was made in the wake of the recent financial crisis, several years before three DTCC subsidiaries were officially designated as Systemically Important Financial Market Utilities, or SIFMUs.[24] DTCC's continued focus on systemic threats as an integral part of its overall risk management strategy aligns with the financial industry's emphasis on these threats.

In 2012, the Systemic Risk Council was created, a cross-functional advisory group containing senior executives from key areas within DTCC. In addition to serving as a forum to raise and discuss emerging systemic threats, the Council provides advice on the prioritization of initiatives to address such risks.

In 2013, DTCC started a multi-year, cross-functional effort to address the risk that an interconnected entity becomes unavailable or fails to operate as expected. To launch this program, the Systemic Risk Office created a comprehensive inventory of the different types of interconnections for each DTCC SIFMU, as illustrated below:



*Definition of "Trading Venues" to be confirmed once the SEC's proposed rule *Standards for Covered Clearing Agencies* is finalized

24 On July 18, 2012, the Financial Stability Oversight Council (FSOC) designated eight financial market utilities as systemically important under Title VIII of the Dodd-Frank Wall Street Reform and Consumer Protection Act, including The Depository Trust Company (DTC), Fixed Income Clearing Corporation (FICC) and National Securities Clearing Corporation (NSCC).

The risks associated with these connections are not all equally critical, which is one of the elements that affects how DTCC prioritizes these risks. Other elements include DTCC's potential for risk mitigation, which depends on structural factors within the securities industry (e.g., a limited number of providers for certain core market functions), as well as the nature of the connections themselves.

Some connections represent relationships that a DTCC SIFMU establishes directly and that it can elect to change or discontinue (e.g., investment counterparties or liquidity providers); other connections, by contrast, represent relationships established by clients or other stakeholders with third parties at their own discretion (e.g., settling banks or issuing and paying agents). This is a key distinction, as it largely affects DTCC's level of control – and opportunities for risk mitigation – with respect to the associated connections.

DTCC uses the following approach to address its interconnectedness risks:

- **Review rules and procedures** related to the failure of an interconnected entity
- **Map and rank** interconnected entities
- **Develop actions to mitigate** interconnectedness risks

The ultimate goal of this program is to limit, to the extent feasible, the potential impact of disruptions caused by the failure – operational or otherwise – of an interconnected entity to function as expected.

6.2 Creating and assigning globally accepted legal entity identifiers

The recent financial crisis underscored the need for increased market transparency, as the identification of interconnected trade counterparties across multiple markets, products and jurisdictions proved challenging for regulatory authorities. This hindered the regulators' capability to manage systemic risk and understand exposures of key market participants at a global level.

Recognizing this gap, regulatory authorities, working with the private sector, have developed the framework of a Global Legal Entity Identifier (LEI) System (GLEIS) that has begun, through the issuance of unique LEIs, unambiguously identifying entities engaged in financial transactions.[25]

DTCC's Global Markets Entity Identifier (GMEI) utility[26] is a legal entity identifier solution offered in collaboration with SWIFT, which went live in August 2012. It is designed to meet global requirements across all asset classes by creating and applying a single, universal and perpetual standard identifier to any organization or firm involved in a financial transaction globally. To date, close to 400,000 LEIs have been issued globally, with the GMEI utility having issued approximately half of those.

The GMEI utility has been endorsed at a global level by the Regulatory Oversight Committee (ROC), a global group of regulators established by the Group of 20 (G20) and the Financial Stability Board (FSB) to oversee development of the GLEIS. This means that GMEIs are recognized as LEIs by all of the 65 regulators that are members of the ROC. The GMEI utility operates as one of 26 pre-Local Operating Units, sponsored by a ROC member regulator and endorsed by the full ROC, within the GLEIS.[27]

Legal entities from all jurisdictions involved in financial transactions can use the GMEI utility to register for LEIs. The GMEI utility validates the accuracy of the associated reference data supplied by the registrant and creates and assigns globally accepted LEIs in a standard format. The system then stores all the information in a public database, which is free for all to use and redistribute.

25 The Global Legal Entity Identifier Foundation (GLEIF) was created to act in the public and private interest as the operational arm of the GLEIS. The GLEIF website is gleif.org.

26 The GMEI utility website is gmeiutility.org.

27 On July 20, 2015, the U.S. Commodity Futures Trading Commission (CFTC) announced that it has issued an order extending for one year the designation of the GMEI utility as the provider of LEIs pursuant to the CFTC's swap data recordkeeping and reporting rules. The GMEI utility's initial designation for a two-year term was made by a CFTC order on July 23, 2012, and was extended for one year on July 22, 2014. Refer to the CFTC press release on July 20, 2015, at http://www.cftc.gov/PressRoom/PressReleases/pr7199-15

The GMEI utility enables large global organizations with many legal entity subsidiaries and affiliates to meet current and future regulatory requirements around the globe, and provides organizations with the ability to register and maintain the reference data for all their entities in a single location. The resulting database of LEIs provides regulators with greater risk aggregation capabilities for analyzing positions and transactions on a global basis.

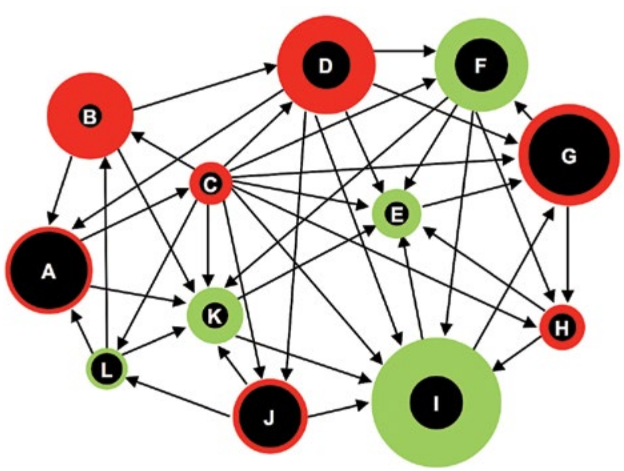
As the GLEIS has become fully operational, more regulatory authorities have mandated the use of LEIs in recordkeeping and reporting, starting with OTC derivatives but now expanding across jurisdictions and asset classes. Regulators with LEI mandates include Australian Securities and Investments Commission, Commodity and Futures Trading Commission, European Securities and Markets Authority, Hong Kong Monetary Authority, Monetary Authority of Singapore and Ontario Securities Commission and other provincial regulators in Canada. In Europe, broader rules including MiFID II and MiFIR will expand LEI requirements across asset classes, and in the U.S., the SEC has included an LEI mandate across asset classes in its proposed rule on Investment Company Reporting Modernization. As LEI mandates continue to be implemented across more jurisdictions and asset classes, the importance of LEIs as a critical tool for enhancing market transparency and managing global systemic risk will continue to grow.

6.3 Using network diagrams to enhance systemic risk monitoring of derivatives exposures

DTCC's Trade Information Warehouse (TIW) operates and maintains the centralized electronic database for virtually all credit default swaps (CDS) contracts outstanding in the global marketplace. This database increases market transparency by enabling regulators and market participants to view the market's overall risk exposure to OTC credit derivatives instruments.

Academics and other researchers also use information included in TIW's database to study interconnectedness and contagion risk in CDS markets worldwide.[28]

In order to make this data even more useful for managing risk, DTCC has constructed a proof of concept in cooperation with Markit that visualizes the effect of price shocks and other scenarios on CDS market participants. By way of example, the stylized diagram on the next page illustrates the impact of a given price move on a simplified universe of 12 fictional CDS market participants:



Each node in the diagram represents a CDS market participant (labeled "A" though "L"). The arrows between the nodes represent directional Profit & Loss (P&L) cash flows that would result from the scenario that is being analyzed.

- **The size of each node** is commensurate with the size of a firm's overall position.
- **The position of each node** is closer to the center for those nodes that are most affected by the market moves included in the scenario (and vice versa).
- **The color of the ring around each node** is green (for firms that realize an aggregate profit) or red (for firms that incur an aggregate loss).
- **The thickness of the colored ring around each node** is proportional to the size of the firm's aggregate profit or loss.

28 One example, among several others, is *Assessing Contagion Risks From the CDS Market*, a 2013 paper by the European Systemic Risk Board.

Once finalized, this proof of concept could serve as a valuable tool to dynamically and easily model the potential impact of various scenarios. Central banks and other regulatory entities could use the results of these modeling exercises to better understand the structure and dynamics of CDS markets and to identify early warning signs of systemic risk buildup in a quasi-real-time environment. As such, this tool should help mitigate systemic risk by further enhancing global derivatives market transparency, which was one of the goals articulated by the Group of 20 (G20) in 2009.

At the same time, it should be noted that the policy response that was drafted following the G20 commitments was prepared along regional or national lines. While this approach increased market transparency at the local level, it fell short of achieving the same goal on a global scale. In order to turn trade repository data into actionable intelligence that can be used to monitor systemic risk in the global derivatives market, the following key obstacles must be addressed:[29]

- **The emergence of regional trade reporting regimes** with unique reporting requirements for each local jurisdiction has resulted in fragmented and inconsistent data being housed across multiple trade repositories. This approach has left regulators unable to aggregate information across markets, thus limiting their ability to fully monitor systemic risk.
- **Lack of global data standards** or common data vocabulary across repositories has left trade repositories unable to share and aggregate data on a global scale. Agreement on the specific data requirements for systemic risk identification is required from regulators to establish a globally consistent set of data and reporting standards. Incremental progress has been made through the adoption of Legal Entity Identifiers (LEIs), as well as the work performed by the CPMI-IOSCO Harmonization Working Group to establish a common data vocabulary across repositories.
- **Legal barriers that limit data sharing amongst regulators** must be removed so that data can be aggregated and used by appropriate regulatory authorities across jurisdictions. Further coordination and dialogue are required across the global regulatory landscape to either remove the legal restrictions to data exchange or develop acceptable workarounds to take advantage of this increased data transparency.

Development of a uniform consistent approach across all jurisdictions, coupled with the establishment of a proper governance model and increased regulatory coordination, is required to break down these structural barriers and allow the G20 commitments to reach their full potential for systemic risk monitoring.

29 For additional information, see DTCC's January 2015 White Paper *G20's Global Derivatives Transparency Mandate* and *Three Steps to Realizing the G-20 Transparency Goals* by Larry Thompson (The Hill, July 30, 2015).

6.4 Participating in joint industry exercises

Exercises are particularly helpful tools to assess and enhance an organization's ability to respond to incidents or crises. While these kinds of exercises are very useful for companies to perform internally, they are far more powerful when conducted as a joint industry effort across interconnected entities. In addition to allowing players to practice the execution of their procedures and protocols, joint industry exercises enable participants to assess how their policies and procedures interact with those of others in the face of simulated events.

Joint industry exercises are crucial in helping build sectorwide resilience and protecting market stability. As such, DTCC supports and participates in various industrywide exercises that are designed to assess and enhance the financial industry's preparedness in the face of a number of systemic threats.

Recent examples include the following exercises:

- Over the past four years, DTCC has participated in the Quantum Dawn series of industrywide exercises (it actually sponsored the first exercise in 2011). The second Quantum Dawn exercise, which was held in 2013 and led by the Securities Industry and Financial Market Association (SIFMA), included more than 500 participants from over 50 different entities.

  The objective of the Quantum Dawn exercises is to test the resilience of the financial industry to a series of cyberattacks aimed at disrupting trading in the U.S. equities markets. Participants in the exercise execute the protocols, procedures and processes included in their cyber crisis response plans to address a series of simulated cyberattacks. Every player's actions and inactions are executed in a virtual equities market environment, where they affect the other players in the game.

  The first two Quantum Dawn exercises used infrastructure outages to determine at what point the markets would cease to operate. The 2015 version (Quantum Dawn 3), also led by SIFMA, simulated the degradation of critical infrastructure by affecting the timeliness (availability) and/or accuracy (integrity) of the clearance and settlement process for equities, and required participants to coordinate their actions in order to address this degradation.

- Recognizing the importance of building and testing processes for collaboratively responding to cybersecurity incidents, government agencies, financial sector companies and the U.S. Department of Treasury constructed the Hamilton Series, a set of three simulation exercises:

  > *Hamilton Alliance*, a cybersecurity tabletop exercise involving 85 participants from 24 organizations, focused on defending against a simulated malware attack against major U.S. equity exchanges, resulting in disruptions to core trading systems.

  > *Hamilton Vault*, a discussion-based exercise that brought together 90 individuals representing 24 firms, tested public and private sector response to a significant cyber incident impacting U.S. depository institutions.

  > *Hamilton Revive*, a facilitated discussion between approximately 90 individuals from 33 public- and private-sector organizations, focused on the processes for recovering from a major cyberattack resulting in the forced closure of banks and exchanges.

- DTCC also participated in the 2014 Pandemic Accord Full Scale Exercise in New York City, which was designed to test the business recovery and continuity plans and policies of both private organizations in the financial services industry and the public sector in the face of a pandemic influenza event. The Pandemic Accord Exercises were the second set of exercises in a two-year exercise series that sought to increase readiness for a pandemic event.[30]

30 http://www.sifma.org/services/bcp/fema-pandemic-exercise-series

6.5 Developing recovery and resolution plans

Given the numerous interconnections between DTCC's SIFMUs and other entities in the global marketplace, DTCC's recovery and resolution planning efforts have also included a member outreach component with two main objectives.

First, DTCC has supported its members' efforts to improve their own plans and enhance sections that describe how members in distress can continue to maintain access to FMIs. Specifically, DTCC has assisted in providing greater detail on the types of interaction distressed members would have with each DTCC SIFMU, and how distressed members could continue to maintain access to SIFMU services in a wide range of adverse circumstances, including a member's resolution.

The second objective is to increase transparency regarding DTCC's recovery and resolution efforts to create plans for circumstances where its SIFMUs would become distressed. To that end, DTCC has undertaken active outreach with members, and recently issued its June 2015 white paper, *CCP Resiliency and Resources*, which articulates DTCC's strategy for continuing to provide critical services to the industry in times of distress.

Providing this level of transparency for both sets of scenarios described above enhances financial institutions' capability to model various stress events, and prepare in advance to mitigate potential interconnectedness risks due to either the failure of a systemically important financial institution or an FMI.

CONCLUSION

Although there are many different methodologies and approaches available to assist practitioners and other stakeholders in their efforts to analyze the multiple forms of financial interconnectedness that exist in the global financial marketplace, some of these approaches either are still in nascent stages or may not be easily implemented in short order.

For those with an interest in identifying, quantifying and visualizing interconnectedness risks in the securities industry, the box below offers a list of tangible steps that may be taken today to lay the foundation for such analysis:

PRACTICAL GUIDELINES FOR ANALYZING INTERCONNECTEDNESS RISKS

1. **MAKE A COMPREHENSIVE INVENTORY OF EXTERNAL ENTITIES ON WHICH YOU RELY.** Most financial institutions rely on adequate funding and liquidity, credit, access to markets and market infrastructures, as well as the provision of reliable and timely data – among many other processes. External entities that provide or support these services represent external interconnections to your firm. Given that insolvencies occur at a legal entity level, intra-group dependencies between distinct legal entities should also be represented as external interconnections.

2. **DETERMINE WHICH INTERCONNECTIONS ARE CRITICAL TO YOUR BUSINESS.** Use the following criteria to assess the level of criticality of your interconnections:
   - **Severity** – how severely might an impaired or failed interconnection impact your firm, its clients, shareholders, regulators or other stakeholders?
   - **Time sensitivity** – how long would it take for a failed interconnection to have a considerable impact?
   - **Substitutability** – how easily and quickly could you switch to a suitable replacement?

3. **QUANTIFY YOUR CRITICAL INTERCONNECTIONS IF PRACTICAL.** Quantifying interconnections can be useful as a straightforward and objective way to aggregate, rank and assess the related risks. It may also help prioritize risks and monitor their evolution over time. That said, operational interconnections with providers of data and other financial services may be harder to quantify than those with borrowers/lenders, trade counterparties and funding providers. Therefore, interconnections should be quantified as appropriate depending on the circumstances and the effort involved in doing so.

4. **ASSESS IN DETAIL HOW AN IMPAIRED INTERCONNECTION COULD AFFECT SPECIFIC AREAS.** Depending on the circumstances, the failure of an interconnected entity may cause a credit or trading loss, but it may also cause a loss of revenue, affect funding or have a different type of impact altogether. In assessing the effect of an impaired or failing interconnection, it may be more appropriate to take into account peak volumes and associated risks, rather than average values.

5. **IDENTIFY HIGHLY INTERCONNECTED ENTITIES AND ASSESS THE POTENTIAL IMPACT OF THEIR FAILURE ON YOUR BUSINESS IN ITS ENTIRETY.** While the analysis described above is valuable in its own right, its real power lies in the aggregation of risks across areas that may be simultaneously affected by a single failure. The failure of a highly interconnected entity may have a combined effect – for instance, by simultaneously causing credit losses while affecting your firm's funding, as well as your access to other financial services. While each of these impacts may be manageable individually, their combined effect may not be.

6. **MANAGE EXPOSURES TO INTERCONNECTED ENTITIES HOLISTICALLY.** Given the potential combined effect of the failure of a highly interconnected entity, it is important to manage the associated risks holistically. Among other things, that means that concentration risk should be managed not only by assessing the relative exposures to funding, trading, credit and other counterparties in isolation, but also in its entirety across these various areas. Stress tests and scenario analyses can be very valuable in this respect, provided they explicitly incorporate these forms of interconnectedness.

7. **COOPERATE ACROSS DEPARTMENTS.** Organize cross-functional risk reviews and discussions to make interconnectedness awareness an integral part of your organization's risk management culture. Interconnectedness analysis should complement other disciplines, not replace them.

8. **TAKE A GRADUAL APPROACH.** As is the case for other risk management disciplines, interconnectedness analysis is an iterative process – start small and expand gradually. Periodically assess in which areas you may need to become more sophisticated.

We hope that this paper helps promote the industrywide adoption and integration of the fundamental insights related to interconnectedness. We view this as a practical and productive contribution to our key goal of further enhancing the resilience of the financial system.

We actively encourage our Members and other industry stakeholders to share their thoughts and participate in the ongoing dialogue we are looking to foster.

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APPENDIX – A Survey of the Literature on Interbank Networks

The body of this paper briefly mentions empirical studies of the structure and topology of real interbank networks. This appendix provides an overview of two other types of interconnectedness research:

- **Section 1** reviews theoretical studies on the **effect of network characteristics on contagion.**
- **Section 2** reviews the research that focuses on the **process of network formation.**

This overview is drawn from a recent comprehensive survey of the literature on interbank networks published by the Sustainable Architecture for Finance in Europe (SAFE) research center, a cooperation of the Center for Financial Studies and Goethe University Frankfurt.[31]

Section 1 – The effect of network structure on contagion

This section reviews the theoretical literature on the effect of network characteristics on the process of contagion. Studies covered in this section analyze network dynamics that are generated by subjecting an exogenously given and static network structure to a shock. Some of the research in this area focuses exclusively on direct or indirect linkages; other studies explicitly take both types of connectedness into account.

STUDIES FOCUSED ON DIRECT LINKS

Pioneering theoretical research by Allen and Gale (2000) demonstrates that the spread of contagion depends crucially on the network topology, i.e., the pattern of interconnectedness between banks determines the number and magnitude of defaults. Their work suggests that a highly connected interbank network enhances the resilience of the system to the insolvency of an individual bank. However, subsequent research has qualified this insight significantly and has established that there is a trade-off between risk sharing via linkages to other banks and contagion risk due to too many linkages.

While the existence of the trade-off is not disputed, there is no consensus on whether a complete network dampens or fuels contagion. Some studies argue that intermediate levels of connectivity are better – for example, because the effect of connectivity on contagion is non-monotonic. Recent research argues that a complete network is more resilient to small shocks whereas less connected networks are better able to prevent contagion due to large shocks. The lack of consensus hinges on the fact that these studies have been conducted on widely different network structures and under different assumptions about the size and type of shocks.

The intuition behind these results is that increased connectivity and risk sharing may lower the probability of contagious default, but conditional on a failure, more connections also allow contagion to spread further. This is a variant of the robust-yet-fragile tendency of financial networks.

More recent research has also moved beyond a network's density (or connectivity) as the only factor affecting its resilience and has analyzed the impact of other characteristics of financial networks, such as the size of interbank exposures, leverage, the degree of concentration of the system and balance sheet characteristics.

Given the robust-yet-fragile tendency of financial networks, research into network resilience focuses on two main questions: (i) What affects a network's tipping point if its nodes are subject to random shocks? and (ii) What is the impact of a targeted shock to a key node in the network?

In response to the first question, a study that simulated the effect of random adverse haircut shocks on a network of banks that hold both unsecured interbank liabilities and repo liabilities found that the most robust networks have an intermediate level of connectivity, characterized by nodes that have 7.5 connections on average. Other

31 *Too Interconnected to Fail: A Survey of the Interbank Networks Literature* – SAFE Working Paper No. 91 by Anne-Caroline Hüser (May 2015).

research similarly found that the average degree of the nodes in a network matters more for determining its tipping point than a series of other characteristics.

In order to assess the impact of concentration, simulations were run for networks where the links between banks were distributed roughly uniformly and for so-called fat-tailed (geometric) networks, where some banks are much more highly connected than the typical bank. The results show that contagion in fat-tailed networks is both less severe and less likely, confirming earlier findings that they tend to be more robust to random shocks than other types of networks.

In response to the second question, the fragility of the system depends on the location in the network of the institution that was initially affected. Intuitively, the failure of core banks is more damaging than the failure of a periphery bank.

A targeted shock to the most interconnected interbank lender is more likely to trigger contagion than a shock to a random node. While this is true for different types of networks, it makes only a small difference for the less concentrated network, while it makes contagion a virtual certainty for a very wide range of average degrees in the fat-tailed networks. These results reflect earlier findings that fat-tailed networks are vulnerable to targeted attacks on key nodes. This outcome is intuitive, given that the key node in a fat-tailed network is significantly more connected than the key node in less concentrated networks.

Other studies find that the likelihood of contagion increases with the overall size of interbank liabilities, as well as the size of the originating node and its leverage.

STUDIES FOCUSED ON INDIRECT LINKS

Another part of the literature studies the effect of network structures and nodes' characteristics on contagion through indirect linkages in financial networks, which include cross-holdings of shares, common asset holdings (e.g., overlapping portfolios) and linked portfolio returns. Diversification, integration and bank leverage appear to be important network characteristics in this context.

Firms that are connected through cross-holdings of each other's shares constitute a network that may be subject to contagion and amplification of relatively small and entity-specific shocks. If a firm fails, losses will affect its counterparties via cross-holdings that can propagate through the network. The likelihood and the severity of the contagion effects depend on two factors: the degree of integration, which refers to the level of exposures firms have to each other, and diversification, which refers to how spread out cross-holdings are.

Financial contagion due to overlapping portfolios is related to the phenomenon of fire sale dynamics, where the forced liquidation of an asset causes the asset's price to drop and cause losses to other entities that hold the affected asset, ultimately leading to a series of cascading failures. In a network of banks that have overlapping portfolios, contagion can occur depending on the diversification of the portfolios and the banks' leverage. The overall stability of the network decreases as leverage increases.

STUDIES FOCUSED ON THE INTERACTION BETWEEN DIRECT AND INDIRECT LINKS

Most empirical financial network simulation studies find little potential for direct interbank exposures to cause contagion. However, in reality banks have many more types of direct and indirect links. The literature reviewed in this section focuses on interbank networks that include both direct and indirect links. The combination of both of these types of links describes not only how shocks are propagated, but also how they can be amplified. The amplification mechanism in these models is mainly driven by fire sales. They combine counterparty risk resulting from direct exposures with liquidity risk resulting from the indirect exposures that are propagated through the fire sales channel.

The propagation of losses through fire sales can be modeled using an interbank network that combines direct linkages with indirect linkages via overlapping asset portfolios of banks. The failure or distress of one bank can cause an initial shock to the system. Asset sales by the impacted institution will depress the assets' market price (assuming the market's demand is less than perfectly elastic). The lower asset prices will then be reflected through mark-to-market adjustments and induce a further round of endogenously generated asset sales, depressing prices further and inducing subsequent sales. This creates a negative feedback loop where contagion can considerably amplify the impact of relatively small initial shocks.

Research that models this interaction finds that liquidity risk increases contagion for any level of network connectivity. When markets are illiquid, the more concentrated networks become particularly fragile. This is intuitive, given that the failure of a large bank in a concentrated network requires a significant part of the banking system to be liquidated, which can quickly drive down market valuations for the remaining banks, exacerbating asset price contagion relative to less concentrated networks.

Similar research that explores the impact of a mark-to-market regime explicitly incorporates the impact of a crisis of confidence, where a bank's perceived ability to pay declines. It finds that a lack of confidence can act as a significant channel of contagion, even in the absence of fire sales, and that it is more likely than direct contagion to lead to systemic instability.

A network of cross-exposures between banks helps explain how a surprise liquidity shock, which can lead to an isolated fire sale, can be absorbed as long as it stays under a critical threshold. However, if the shock reaches this threshold, banks start hoarding liquidity as a precautionary measure and buyers turn into sellers, thus exacerbating the fire sales.

Extending the analysis to models that include the interactions between domestic banks, overseas banks and firms can be useful to describe how financial distress, amplified by fire sales, can ultimately lead to a credit crunch that affects the real economy.

Recent research that combines counterparty risk with overlapping portfolio risk shows that the combined effect of risk transmission through direct and indirect channels strongly amplifies contagion, resulting in much larger cascading failures than would be observed otherwise.

An avenue for further research is to have more realistic network structures on which to analyze contagion. Since empirical studies now provide an increasing number of stylized facts on the interbank network topology, research needs to move beyond deriving results on random networks or on overly simplified structures. Again, conducting analyses on more realistic network structures is required to make a convincing case.

A question that remains is how banks strategically trade off risk sharing and contagion risk. This topic has recently been studied as part of the literature on network formation, which is covered in the next section.

Section 2 – Network formation

The relevance of static network models is limited, as they fail to incorporate the dynamic process by which financial institutions enter into obligations with each other in the first place. Three main ways to address this shortcoming by modeling link formation are emerging in the literature:

- **Random or probabilistic link formation.** In these models, banks create links with each other, based on either a stochastic process or on a conditional process called preferential attachment, where firms are more likely to create links with trusted or profitable counterparts.

  Research in this area finds that trust is a key driver in the formation of interbank relations, leading to the formation of a core-periphery structure with a few large banks acting as intermediaries between many smaller banks. These results are consistent with empirical studies of interbank network structures.

- **Strategic link formation.** In these models, banks assess the costs and benefits of linking with each other. Prominent in strategic network formation are rollover decisions by banks, often modeled using mathematical game techniques. Creditors strategically decide to roll over a loan after receiving a signal about the solvency or performance of the borrower.

  Key to this approach is an explicit modeling of the costs and benefits associated with creating links. Different payoff structures and initial states can lead to a great variety of network structures. Research using this approach has shown that banks may become reluctant to refinance as a result of increased uncertainty, even when underlying fundamentals are solid. It has also shown the importance of bank homogeneity in assessing the stability of a network. Core-periphery networks that are unstable for homogeneous banks can become stable structures if they consist of a range of big and small banks.

- **Endogenous link formation.** In these models, which combine network modeling and economic modeling techniques, banks typically behave as optimizing agents. Two approaches can be found in the literature. In the first approach, banks decide on the amount of interbank lending and/or borrowing by optimizing their (heterogeneous) balance sheets. In the second approach, the overall amount of borrowing and lending is fixed and banks must select their optimal counterparty.

These models have been used to simulate contagion through interbank links (direct contagion channel) and fire sale externalities (indirect contagion channel). Additionally, some models have included liquidity hoarding by risk-averse banks. The use of this approach to analyze the impact of the financial network structure on financial stability has shown that core-periphery networks are more stable than purely random networks in times of distress.

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