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Unintended Consequences of Regulating Central Clearing*

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Abstract

Recent U.S. and European regulations promote centrally clearing derivatives to reduce complexity and systemic risk in the financial system. We argue that more clearing does not guarantee less systemic risk. We identify conditions under which the core clears less intensively than the periphery, which increases systemic risk by substituting multilateral netting for bilateral netting and making contagion less likely to start in the core but more likely to spread from the core. We study confidential derivatives regulatory data and find evidence of such clearing patterns. We further explore the implications of complexity and centrality within the financial system for stability.

Keywords: Central Clearing, Systemic Risk, Interbank Networks, Central Counterparty (CCP), Over-the-Counter Trading (OTC).

JEL Classifications: G20, E50, L14

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1 Introduction

The 2008-09 financial crisis originated in malfunctioning derivatives markets, particularly credit default swaps (CDS), which were unable to absorb the wave of potential defaults propagated through a vast and complex network of derivative exposures among financial counterparties. This experience motivated the Dodd-Frank Wall Street Reform and Consumer Protection Act, aimed at curbing systemic risk. A key element of these reforms was to increase oversight of the over-the-counter (OTC) derivatives market and encourage more (central) clearing through Central Counterparties (CCPs). The intention was for all institutions to clear all exposures with a single agent (the CCP), dissolving the complex web of excess exposures and eliminating implied fragilities. But which banks, and to what extent, have adopted clearing after these reforms? Understanding the anatomy of clearing is crucial, as regulatory success depends on the extent and patterns of clearing across banks.

We use a novel and confidential dataset on derivative exposures by counterparty for the largest banks in the U.S., which we call *core* banks, to document how their clearing patterns and exposures have evolved.¹ This data is reported in bank holding companies' (BHCs) FR Y-14Q filings, a quarterly regulatory collection that supports the Federal Reserve supervisory stress tests. We combine this data with public data available for BHCs in the U.S. (Consolidated Financial Statements for BHCs FR Y-9C) to put these changes at the core in the context of changes in aggregate clearing patterns.²

To interpret the documented changes in clearing patterns, we start by extending a simple model of contagion in interbank networks with banks' choices of whether to clear some or all of their exposures centrally. We use this simple model as a laboratory that serves two purposes: first, to guide us on what to measure in the data and, second, to shed light on whether those measures constitute signs of improved stability after regulation.

Our simple model assumes the clearing decisions are based on reduced-form costs and benefits that stand for a wide range of items related to regulation, such as risk weights based on clearing, the mandate to clear standardized incentives, clearinghouse membership terms, bank-level transparency, and the need for flexibility. We do not take a stand in this paper on how recent regulation affects the costs and benefits of clearing. In ?, we do and present a model in which banks choose their derivative contract counterparts (the extensive margin) and the amount of those contracts (the intensive margin). In that paper, the explicit cost of clearing is given by its higher transparency (which has costs in terms of funding opportunities), and the explicit benefit is a lower regulatory risk-weighted capital requirement for collateral. In this paper, we do not

¹Using this confidential data, we construct consistent time series for the largest 6 banks in the U.S., which represent almost the majority of derivative activities among U.S. banks.

²The public data is used, for example, by the Office of the Comptroller of the Currency (OCC) in its Quarterly Report on Bank Trading and Derivatives Activities. See <https://www.occ.treas.gov/topics/capital-markets/financial-markets/derivatives/index-derivatives.html>.

focus on how different regulatory measures map into the direct costs of clearing but instead on how regulation maps into the endogenous structure of financial exposures and the implications on systemic risk.

We focus on endogenous bank defaults triggered by endogenous failure of interbank payments, not by exogenous shocks to non-interbank assets. To this end, we focus on the best and the worst *balance sheet contagion* as in Eisenberg and Noe (2001). Self-fulfilling failures are possible only in the presence of exposure cycles; hence, regulation's effectiveness hinges on clearing exposure cycles. To illustrate how contagion gets triggered on cycles, imagine three banks, A , B , and C , interconnected through derivative exposures. A owes B , B owes C , and C owes A , say all in equal amounts. If A cannot pay B , then B cannot pay C , and subsequently C cannot pay A , leading back to A 's inability to pay B . This cycle creates the potential for a self-fulfilling collapse within the derivative network. However, if all three exposures in this network were cleared, *bilateral netting with the CCP* would eliminate all exposures among banks, implementing the outcome of full multilateral netting. The rationale behind the implemented regulations was eliminating unnecessary exposures, which pairs of banks may not fully internalize.

Multilateral netting through clearing is meant to target cycles that originate contagion. *But contagion has two pillars: origination and cascades.* Once a cyclic failure is triggered on a cycle, contagion is originated, which can now cascade outwards from the cycle across the network, via direct and indirect exposures to the cycle. The cascade features standard domino effects, possibly reaching systemic levels. Successful regulation to mitigate systemic risk must consider both pillars, origination and cascades, not only origination. First, the cyclical nature of exposures must be addressed by reducing the complexity of the network of OTC exposures. This is to mitigate the origination of contagion. Second, unless all cycles can be completely eliminated, direct and indirect exposures to cycles must be moderated. This is to mitigate the cascading domino effects that spread outwards from the originating cycles. Eliminating all cycles is an impractical (and even implausible) goal without restrictive mandated clearing of all derivatives, which can also prove inefficient if reducing the flexibility of banks' insurance needs. Regulations should heighten the focus on mitigating not only origination but also cascading of contagion.

We highlight that clearing incentives may affect banks asymmetrically, affecting origination and cascading differently. This reaction to regulations may make regulatory efforts irrelevant in addressing the origination pillar but also may create unintended consequences on the cascades pillar. For example, if A owes 3 to D , and D owes 2 to A , bilateral netting would reduce the exposure to $3 - 2 = 1$. If clearing incentives are asymmetric, and say 2 is cleared, but 3 is not, now D 's exposure to A is 3 instead of 1, and D gets *more* exposed to the cycle between A , B , and C . Therefore, contagion spreads *more*, conditional on its self-fulfilling origination. This adverse effect on the second pillar is the consequence of what we call *de-coupled clearing* between cycles and the rest. Decoupling refers to the observation that if exposures between two groups

of banks are cleared at different rates, the bilaterally netted exposure of one group to the other can, in fact, increase.

These insights from our simple setting lead us to empirically assess whether regulation eliminated cycles (origination) and reduced bilateral exposures (cascading). Financial networks are known to exhibit core-periphery structures. By its nature, a core-periphery network houses cycles inside the core. So, we look for the anatomy of cycles inside the core to assess the regulation of the origination pillar. We look at the exposures between the core and the periphery to assess the regulation of the cascades pillar.

First, we evaluate how aggregate clearing patterns have evolved. We find that cleared exposures have remained stable among core banks since 2015 (the period most affected by changes in regulations) and have doubled, on average, for peripheral banks, reaching levels comparable to core banks. Our data also shows that while core banks accounted for over 95% of cleared derivatives in 2019, their share decreased to less than 80% by the end of 2022. This evidence suggests an asymmetric adoption of clearing within the system, with less intensity among core banks than periphery banks. As the peripheral banks are known to trade sparsely with each other, the patterns suggest that the regulation does indeed cause an unintended adverse consequence in the cascades pillar through de-coupling.³

Second, to assess the effects of regulation on the origination pillar, we use confidential data to show that cycles inside the core persist. Although aggregated data shows increases in clearing even by core banks, core-to-core exposures remain elevated and cyclic. This shows that the origination pillar is only partially addressed. We compute the likelihood of coordination failures originating within the core. Despite the fact that this probability has steadily declined, although not down to zero, we show it may surge dramatically and rapidly, as it did in the lead-up to the 2008 financial crisis. In other words, the risk of cyclic failure and contagion origination is not static and can escalate rapidly, hence its existence is in itself a potential concern for future stability.

Finally, we propose measures of financial network complexity. We find that the number and properties of cycles have remained relatively constant over time. This suggests a persistent vulnerability to contagion origination inside the core. Additionally, we observe significant heterogeneity across the six banks in their contribution to cycles. Some banks participate in most cycles, acting as “failure conductors” due to their systemic relevance. Others are less involved in cycles but are net debtors to most others, making them “failure sources.” This finding highlights the need for bank supervisors to monitor not only the number and structure of cycles but also

³An alternative interpretation is that core banks bilateral exposures consisted mostly of standard derivatives, which post-reform are centrally cleared and net out. Our evidence suggests this is not the case. For example, in our empirical section, we describe that centrally cleared contracts increase more for core banks than for other banks and that the fraction of aggregate centrally cleared contracts increases more (relatively) for banks outside the core than for core banks.

the individual role of banks within those cycles.

In summary, the evidence we present indicates that contagion origination probability seems to be mitigated by recent pro-clearing regulations but not eliminated. The persistent cycles in the core retain the origination risk despite some mitigation, while contagion cascades have been exacerbated. The periphery becomes more exposed to CCPs, CCPs become more exposed to the core, and the core retains origination risk. Even though the aggregate amount of clearing increases, systemic risk possibly increases as well, not necessarily in its origination probability but in its reach and extent. The patterns of clearing matter just as much as the amount of clearing. Our results call for renewed attention to regulation to also consider bilateral netting and the cascade potential of the network, not only multilateral netting and origination probability in the network, and to identify the individual role of banks within the core.

Related Literature

Recent regulatory efforts in the U.S. and Europe aimed at reducing the influence of OTC derivative markets by incentivizing the use of CCPs have sparked a renewed wave of research on the financial stability implications of this shift.⁴ ? study clearing in the context of multiple asset classes and multiple CCPs. They argue that exposures can increase if only one asset class is cleared since exposures of another asset cannot be netted. We instead highlight a different type of decoupling of gross exposures from the same asset class but asymmetrically across counterparties. In this sense, the cascades pillar we have discussed complements ?. Even though they also discuss the trade-off between bilateral netting without the CCP and multilateral netting with the CCP, they do not provide a theory of how and under what conditions cycles can trigger contagion. Relatedly, Cont and Kokholm (2014) emphasize that while CCPs may mitigate counterparty risk, they might also reduce netting benefits across asset classes. Duffie et al. (2015) examine how CCPs, given heterogeneous margin requirements, affect overall collateral demand in the system, highlighting potential distributional consequences across intermediaries. We abstract from this heterogeneity in this paper but make it central in ?.

Several studies, such as Duffie (2015), ?, ?, Bignon and Vuillemy (2019), Paddrik and Young (2021), and Kuong and Maurin (2024), delve into CCP resolution protocols and their potential systemic consequences in times of distress. We abstract from this important issue and focus instead on the likelihood of self-fulfilling crises given a well-functioning CCP.

In the wake of the financial crisis, a wealth of literature emerged exploring the functioning and fragility of OTC markets. This research was partly spurred by a search-theoretic approach applied to asset markets, as seen in Duffie et al. (2005) and Lagos and Rocheteau (2009). Afonso and Lagos (2015), for example, studied the federal funds market using a search model to analyze how two banks engage in bilateral bargaining. Building on this tradition, Atkeson et al.

⁴An excellent survey of this literature is ?. This interest extends to legal scholarship, with recent works like McBride (2010) and Allen (2012) actively exploring the effects of CCPs and their regulation.

(2015) introduced entry and exit into OTC derivative markets to study the resulting network characteristics. More recently, Hugonnier et al. (2019) examined the role of heterogeneity and search/bargaining frictions in OTC markets and their implications for market fragility. Our primary focus in this paper is not on the intricacies of OTC market operations but rather on their coexistence with CCPs to affect the probability and extent of contagion.

More generally, our paper contributes to the growing body of literature highlighting and examining the unintended consequences of government regulations and interventions in financial networks, such as Erol and Ordóñez (2017) on capital regulations and Anderson et al. (2019) on public liquidity provision.

Besides our focus on regulation and clearing, our core theory of systemic risk, while related to Caballero and Simsek (2013), presents distinct features. Notably, their model exhibits iterative *domino* contagion within a single cycle, with multiplicity arising from the feedback loop between prices and contagion. The price acts as an endogenous *popcorn* effect. See Erol and Vohra (2022) for a detailed discussion of popcorn and domino theories of contagion.⁵ Our modality of contagion is a novel “dome” effect, where the dome-like architecture distributes and balances weight against minor “tremors,” until a sudden and complete collapse occurs under a significant “earthquake.”

Here, we document the asymmetric reactions of core and periphery banks to regulations and the consequences of such asymmetric reactions, not the specific reasons behind the asymmetric reactions. Spatt (2017) provides a rich discussion of a plethora of direct costs and benefits of Dodd-Frank reforms, which can guide the behavior of individual banks.

Section 2 details the model and conditions for contagion, illustrating cyclic behavior and asymmetric responses between core and periphery banks. Section 3 presents data on the evolution of multiplicity and exposure cycles among U.S. core banks and connects regulations promoting CCP usage to the model framework. Section 4 describes the anatomy of cycles within the core by proposing and exploring different notions of network complexity and bank centrality using our confidential data. Section 5 concludes.

2 Model

In this section, we propose a variant of Eisenberg and Noe (2001) and ? with central clearing. We first focus on highlighting the conditions for coordination failures that generate self-fulfilling systemic risk (origination pillar). We then discuss the conditions for clearing to reduce the likelihood of contagion and focus on the role of asymmetric reactions between core and periphery banks (cascading pillar). We illustrate these forces with simple examples.

⁵Additionally, complexity in Caballero and Simsek (2013) reflects price informativeness about the details of a given cycle of exposures, whereas, in our work, complexity reflects intertwined cycles as multiple sources of systemic risk.

2.1 Setting

Environment. The financial system consists of a finite set of banks, B indexed by i , and a CCP denoted c . We refer to any bank or the CCP as an institution and denote $I \equiv B \cup \{c\}$ the set of institutions.

Each i holds assets A_i and liabilities L_i . Asset values are subject to shocks α_i , resulting in a post-shock value of $\tilde{A}_i = \alpha_i A_i$. These shocks are jointly drawn from a distribution F with support in $\times_i [\alpha_i, \infty)$. The CCP holds no independent assets or liabilities.

Banks are related to each other by an initial network of debt obligations. The debt of i to j is D_{ij}^{**} . The *exposure* of i to j is the asset of i that corresponds to the debt of j , $E_{ij}^{**} \equiv D_{ji}^{**}$. The CCP has no initial debt or exposure.

Clearing Exposures. Clearing an exposure of i to j by an amount e_{ij} , where $0 \leq e_{ij} \leq E_{ij}^{**}$, reduces the exposure of i to j to $E_{ij}^* = E_{ij}^{**} - e_{ij}$.

The cleared exposure e_{ij} is replaced by exposures to and from the CCP, increasing i 's exposure to c and c 's exposure to j by e_{ij} . After all clearing, the exposure of i to and from the CCP is given by $E_{ic}^* = \sum_j e_{ij}$ and $E_{ci}^* = \sum_j e_{ji}$.

The resulting exposures and corresponding debts, denoted E_{ij}^* and $D_{ij}^* = E_{ji}^*$ for all $i, j \in I$, are termed cleared exposures and cleared debts.

Bilateral Netting. All cleared exposures undergo bilateral netting, resulting in the bilaterally netted exposure of $i \in I$ to $j \in I$, defined as $E_{ij} \equiv \langle E_{ij}^* - E_{ji}^* \rangle$, where $\langle \cdot \rangle = \max(0, \cdot)$. The corresponding bilaterally netted debt is given by $D_{ij} = E_{ji}$.

The bilaterally netted exposures and debts constitute the interbank assets and liabilities. The total debt of $i \in I$ is $D_i = \sum_{j \in I} D_{ij}$, and the total exposure of i is $E_i = \sum_{j \in I} E_{ij}$.

Defaults and Contagion. Shocks materialize after bilateral netting, potentially leading to a shortfall in realized interbank payments relative to obligations. Let \tilde{E}_{ij} denote the interbank assets recovered by i from j , and $\tilde{E}_i = \sum_{j \in I} \tilde{E}_{ij}$ the total recovered interbank assets of i . Institution i defaults if:

$$\tilde{A}_i + \tilde{E}_i - L_i - D_i < 0. \quad (1)$$

Upon default, institution i is liquidated at a cost, reducing asset value to $\lambda \tilde{A}_i$ ($\lambda < 1$). Assuming external debt L_i is senior to interbank debt D_i , and interbank payments are pro-rata, j 's recovery from i upon i 's default is:

$$\tilde{E}_{ji} = \frac{D_{ij}}{D_i} \langle \lambda \tilde{A}_i + \tilde{E}_i - L_i \rangle. \quad (2)$$

These rules also apply to the CCP, with the convention that $A_c = L_c = 0$.

2.2 Contagion Outcomes and Coordination Failures

Going forward, bold symbols denote vectors or matrices of the corresponding variables. Given a system of independent and interbank assets and liabilities $(\mathbf{A}, \mathbf{L}, \mathbf{E})$, a contagion outcome under α is the collection of recovered interbank assets $\tilde{\mathbf{E}}$ satisfying equations (1) and (2) for all institutions.

Multiple contagion outcomes typically exist for a given α , forming a lattice structure with best and worst cases. To assess self-fulfilling systemic failures, we focus on the maximum gap between these extremes. The worst outcome is termed a *coordination failure* if all banks default and settle zero payments, while no bank defaults in the best outcome.

To identify shocks α enabling a coordination failure, define for each bank i :

$$\begin{aligned}\phi_i &\equiv A_i^{-1} \min \{L_i + D_i, \lambda^{-1} L_i\} \\ \phi'_i &\equiv A_i^{-1} (L_i + D_i - E_i).\end{aligned}\tag{3}$$

Proposition 1. *A coordination failure occurs under α if and only if $\phi' \leq \alpha < \phi$.*

When $\alpha_i < \phi_i$, bank i defaults in the absence of interbank payments. Due to the liquidation loss, this default results in no assets being distributed to other banks. Conversely, when $\alpha_i \geq \phi'_i$, bank i remains solvent if it recovers all interbank assets. Considering these conditions for all banks, we conclude that no bank defaults in the best outcome if and only if $\alpha \geq \phi'$. In contrast, all banks default and make zero payments in the worst outcome if and only if $\alpha < \phi$. Therefore, α enables a coordination failure if and only if $\phi' \leq \alpha < \phi$. This region is termed the coordination failure region, and the probability of a coordination failure is defined as:

$$\Phi \equiv F(\phi' \leq \alpha < \phi).$$

For example, in the case of aggregate shocks where $\alpha_i = \alpha$ for all $i \in B$, the coordination failure region simplifies to $\alpha \in [\phi', \phi)$, where $\phi' \equiv \max_i \phi'_i$ and $\phi \equiv \min_i \phi_i$, as depicted in Figure 1. The probability of coordination failure becomes $\Phi = \langle F(\phi) - F(\phi') \rangle$.

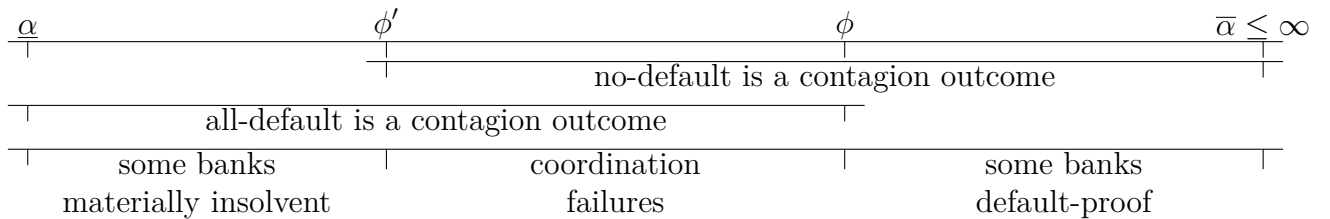


Figure 1: Coordination failure region

Proposition 2. *If $\Phi > 0$, then each bank belongs to a cycle-rooted directed tree of exposures.*

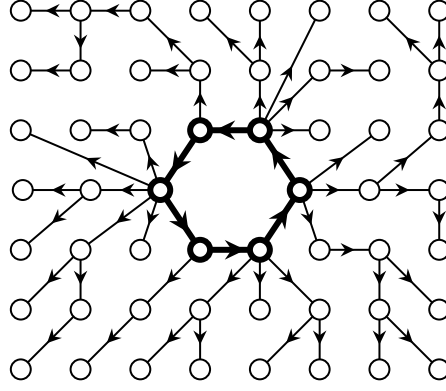


Figure 2: A cycle-rooted tree subgraph. Arrows indicate the direction of payments, which is the reverse direction of exposures.

Coordination failures arise only when the network topology allows for the transmission of distress among all banks. Figure 2 illustrates such a topology, where each bank holds exposures to other institutions. A bank without exposures is immune to interbank losses, its default becomes independent of other banks, and coordination failure is precluded.

The requirement for all banks to have exposure for a coordination failure to occur stems from our strict definition, where all banks must default. If we relax this definition to consider the default of specific banks, only those banks need exposure to the selected banks.

Applying basic graph theory, we find that the existence of coordination failures necessitates a cycle of exposures. Additionally, all banks must either participate in a cycle or be indirectly exposed to a cycle. This underscores the mechanism of coordination failures: a self-fulfilling failure of payments along a cycle that propagates through the network.

This observation is particularly pertinent to the financial system, where many networks exhibit a core-periphery structure resembling the topology conducive to coordination failures.

Systemic risk. High debt ($L_i + D_i$) and low assets (A_i) inherently increase a bank's fragility, making both ϕ'_i and ϕ_i measures of fragility.

Clearing, while affecting individual debt and exposure levels, leaves the net interbank position ($D_i - E_i$) unchanged. This is due to clearing merely shifting counterparties from banks to the CCP without altering the overall financial position. Consequently, the lower bound ϕ'_i , determined by external assets and equity, remains unaffected by clearing. We term ϕ'_i the independent fragility of bank i , as when $\alpha_i < \phi'_i$, i defaults even with full interbank asset recovery. Conversely, ϕ_i is termed interdependent fragility, as when $\phi'_i < \alpha_i < \phi_i$, i 's default depends on its interbank asset recovery.

In our empirical analysis, we report both ϕ' and ϕ . Focusing on interdependent and self-fulfilling failures, we simplify the theoretical analysis by assuming $\phi' < \underline{\alpha}$ for the initial debt obligations and the shock distribution. This means that no bank defaults if other banks do not. Hence, all systemic failures are coordination failures. To further emphasize coordination failures,

we assume that on the path of play, the coordination failure materializes whenever $\alpha < \phi$, and no bank defaults otherwise.

2.2.1 Example

Consider three banks $B = \{1, 2, 3\}$. Each bank has assets $A_i = 4$ and liabilities $L_i = 3$. The exposures are by $D_{12}^{**} = D_{23}^{**} = D_{31}^{**} = 3$ and $D_{21}^{**} = D_{32}^{**} = D_{13}^{**} = 1$. Assume that the shock is aggregate $\alpha_i = \alpha$ for all i . All banks are symmetric, so we can drop the indices.

Figure 3 displays the network of exposures (left panel) and the bilaterally netted exposures (right panel), with arrows indicating debt direction.

The liability of each bank is 3. The total exposure of each bank is $3 + 1 = 4$, and the total debt of each bank is $3 + 1 = 4$. So regardless of clearing, $\phi' = \frac{3+4-4}{4}$. Assuming $\alpha = \frac{3}{4}$, no-default is always an outcome, as $4\alpha > 3$ ensures sufficient funds to cover both interbank and senior debt if a bank receives all its interbank exposures. We now analyze how ϕ responds to clearing.

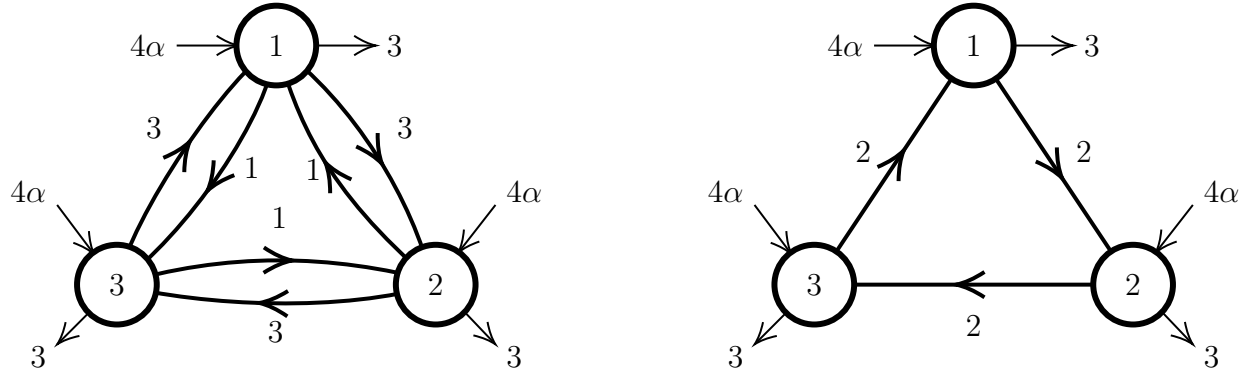


Figure 3: The system before and after bilateral netting

Absent clearing, each bank's bilaterally netted exposure is 2. In the no-default outcome, each bank receives $\alpha A + E = 4\alpha + 2 > D + L = 5$, as shown in Figure 4 (left panel).

Conversely, without receiving $E = 2$, a bank cannot fulfill its debt if $4\alpha < 5$, leading to liquidation when others default and $\alpha < \frac{5}{4}$. With low liquidation values ($\lambda < \frac{3}{5}$), liquidated assets only cover senior debt ($L = 3$), leaving nothing for interbank debt (D), resulting in full default as shown in Figure 4 (right panel).

In this example, $\phi = \frac{L+D}{A} = \frac{5}{4}$, and the probability of coordination failure is $\Phi = F(\frac{5}{4})$. The condition $\lambda < \frac{3}{5}$ ensures that interbank default leads to systemic failure.

In summary, full default occurs when (i) aggregate shocks are sufficiently adverse compared to total liabilities ($\alpha < \frac{5}{4}$), (ii) default triggers costly liquidation ($\lambda < \frac{3}{5}$), and (iii) there exists a cycle of exposures (as seen in Figure 3).

Role of Clearing in Coordination Failures. Complete clearing of all exposures prevents coordination failures. However, complete clearing is often impractical. We illustrate the effects

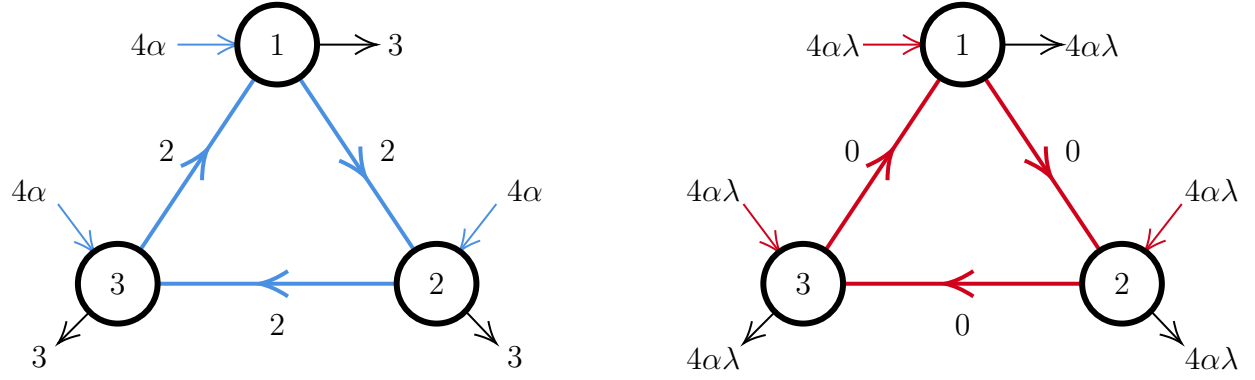


Figure 4: Example of a coordination failure under conditions $3 < 4\alpha < 3 + 2$ and $4\alpha\lambda < 3$. Left panel: all pays given $3 < 4\alpha$. Right panel: no one pays given $4\alpha < 5$ and $4\alpha\lambda < 3$.

of partial clearing using our example.

Suppose banks clear their large exposures (3) but not their small ones (1). This results in *pro-cyclic clearing*, where the subsequent bilaterally netted exposures decrease in volume in the original (i.e. absent clearing) direction of bilaterally netted exposures, as shown in Figure 5 (left panel). In this scenario, a bank cannot pay its interbank debt if $4\alpha < 4$, leading to coordination failure when $\alpha < 1$. Formally, $\phi = 1$, and the probability of coordination failure decreases from $F(\frac{5}{4})$ to $F(1)$.

Alternatively, if banks clear their small exposures (1) but not their large ones (3), we have *counter-cyclic clearing*, where subsequent bilaterally netted exposures increase in volume in the original direction, as shown in Figure 5 (right panel). Here, a bank cannot pay its interbank debt if $4\alpha < 6$, leading to a coordination failure when $\alpha < \frac{6}{4}$. Formally, $\phi = \frac{6}{4}$, and the probability of coordination failure increases from $F(\frac{5}{4})$ to $F(\frac{6}{4})$.

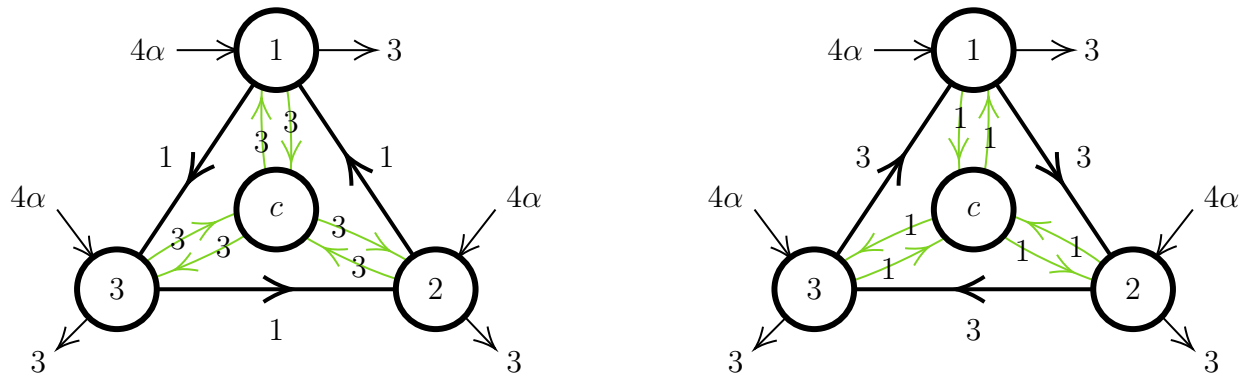


Figure 5: Partial clearing. Left panel: system after pro-cyclic clearing. Exposure 3s are cleared and netted out through bilateral netting with the CCP. The coordination failure conditions become $3 < 4\alpha < 3 + 1$ and $4\alpha\lambda < 3$, reducing Φ . Right panel: system after counter-cyclic clearing. The exposure 1s are cleared and netted out through bilateral netting with the CCP. The coordination failure conditions become $3 < 4\alpha < 3 + 3$ and $4\alpha\lambda < 3$, increasing Φ .

Remark: The impact of clearing on coordination failures and contagion depends on details beyond the amount of clearing. As we have illustrated, clearing that increases bilaterally netted exposures along the direction of the cycle exacerbates coordination failures.

To generalize this insight, consider a cycle with clockwise debt D and counter-clockwise debt $D' < D$. The original bilaterally netted exposures absent clearing are $D - D'$ clockwise.

Counter-cyclic clearing is clearing an exposure $d' \leq D'$ against the original bilaterally netted exposure. Counter-cyclic clearing increases exposures along the cycle, changing $D - D' > 0$ to $D - (D' - d') > D - D'$. Counter-cyclic clearing exacerbates coordination failures.

Pro-cyclic clearing is clearing an exposure $d \leq D$ in the direction of the original bilaterally netted exposure. Pro-cyclic clearing can either decrease the bilaterally netted exposure to $(D - d) - D' > 0$ or reverse the cycle's direction with bilaterally netted debt $D' - (D - d)$ counter-clockwise. However, if $D \geq d > 2(D - D')$, the resulting bilaterally netted exposure $D' - (D - d)$ exceeds the original $D - D'$, increasing exposures along the cycle.

Thus, for pro-cyclic clearing to be beneficial, the cleared amount must not be too large. This poses a risk when exposures are close to each other and bilaterally netted amounts are small relative to original un-netted amounts: $D \geq 2(D - D')$.

2.2.2 Endogenous Clearing and Equilibrium

Here, we expand our setting in Section 2.1 and describe how a bank's clearing decision is determined. Each bank i consists of a unit measure of bankers indexed $u \in i$. We also denote $b(u) = i$. Each banker u makes and manages contracts with a mass of bankers m_u from other banks. The contracts are undertaken on behalf of banks. For $v \in m_u$, the contract is an independent random variable $(\kappa_{uv}, \kappa_{vu})$ describing the payment κ_{uv} that b_u is promised and the payment κ_{vu} that b_v is promised. These contracts underlie the exposures of banks:

$$E_{ij}^{**} = \int_{u \in i} \int_{v \in m_u \cap j} \kappa_{uv} dv du.$$

Each banker is promised compensation as a function of the net gains from the contracts that u manages. This is

$$\pi_u = \pi \left(\int_{v \in m_u} (\Gamma_{b(v)} \kappa_{uv} - \kappa_{vu}) dv \right),$$

where $\Gamma_j = \frac{\bar{D}_j}{D_j}$ is the recovery rate of exposed banks from bank j .⁶

If i defaults, there is nothing left to pay bankers. So u 's settled compensation is $\tilde{\pi}_u = \mathbb{1}[\Gamma_i > 0] \times \pi_u(\Gamma_{-i})$.⁷ The vector of recovery rates $\mathbf{\Gamma} = ((\Gamma_j)_{j \in B}, \Gamma_c)$ is an aggregate variable.

⁶The compensation can be defined more generally. It can include a wage. It can depend or not depend on recovery rates.

⁷There is pro-rata distribution within the bank when total compensation cannot be provided. This is, each

Contracting and clearing are done at the banker level. Infinitesimal bankers have no effect on $\mathbf{\Gamma}$. In making contracting and clearing decisions, u maximizes its utility from $\tilde{\pi}_u$ given the equilibrium $\mathbf{\Gamma}$. Γ_j can be seen as the stochastic price of stability of j akin to Walrasian prices.⁸

Our focus is clearing and we fix the contracts. Clearing is endogenous. Net exposed banker in a pair decides. This is, if $\mathbb{E}[\kappa_{uv} - \kappa_{vu}] > 0$, u is said to be exposed to v . In this case, u decides whether to clear the contract or not and bears the net cost of clearing κ_{uv} . This cost can be positive or negative, and it is defined in utils for simplicity.

The net cost κ_{uv} can have several components. For example, if the CCP entails lower counterparty risk than v 's bank, u is incentivized to clear the contract. This cost or benefit is reflected in changing $\Gamma_{b(v)\kappa_{uv}}$ into $\Gamma_{c\kappa_{uv}}$ in π_u . Other costs are regulatory costs, collateral costs, transparency, funding costs, CCP membership, margin calls, contract standardization costs, and benefits like reduced risk-weights in capital requirements.⁹ We are agnostic on the precise determinants of costs. In general, costs take the form $c_{uv}(\mathbf{\Gamma})$ given that the contracts are fixed. The cost is the sole determinant of clearing since $\tilde{\pi}_u$ does not depend on u 's decision on clearing. Then the cleared amount out of the exposure of i to j , E_{ij}^{**} is

$$e_{ij}(\mathbf{\Gamma}) = \int_{u \in i} \int_{v \in m_u \cap j} \kappa_{uv} \mathbb{1}[\mathbb{E}[\kappa_{uv} - \kappa_{vu}] > 0 \wedge \mathbb{E}[c_{uv}(\mathbf{\Gamma})] < 0] dv du$$

Then the resulting exposure network after bilateral netting, $\mathbf{E}(\mathbf{\Gamma})$, and the distribution of the shock α determine $\mathbf{\Gamma}$ via the contagion dynamics described before, $\mathbf{\Gamma} = \Psi(\mathbf{E}(\mathbf{\Gamma}), \alpha)$. This is the “market-clearing” condition. A similar condition arises also when contracts are endogenous.

As we have shown in the previous section, more clearing does not necessarily reduce the probability of coordination failures. Moreover $\mathbf{E}(\mathbf{\Gamma})$ is not even necessarily continuous in $\mathbf{\Gamma}$, for example when c_{uv} is homogenous across pairs. The existence of equilibrium is not guaranteed. We leave identifying general conditions that yield existence to future work.

We consider constant costs $c_{uv}(\mathbf{\Gamma}) \equiv \delta_{uv}$. This is natural in the context of coordination failures. All defaults are perfectly correlated and so the relative stability gain of clearing is

$$u \in i \text{ gets } \tilde{\pi}_u = \pi_u \min \left\{ 1, \frac{\max\{0, \bar{A}_i - L_i + \bar{E}_i - D_i\}}{\int_i \pi_{u'} du'} \right\}.$$

⁸For example, if all bankers in a bank were completely identical, then it would be as if there is a representative banker and the bank takes Γ_{-i} as given. In this sense, banks are “stability-takers” in the model.

⁹There are opportunity costs of collateral due to margin requirements. The CCP and the OTC counterparties have different requirements regarding collateral. This would be proxied by $\mathbb{E}[\Gamma_{i/c\kappa_{vu}}]$ and $\mathbb{E}[\Gamma_{b(v)/c\kappa_{vu}}]$.

There are regulatory costs. Cleared derivatives are subject to lower risk weights in capital requirements. Then, keeping a contract OTC can create shadow costs on the banker through restrictions placed on trades by the bank's risk division whose objective is to ensure regulatory compliance at the bank level. This cost could be proportional to $\mathbb{E}[\kappa_{uv} - \kappa_{vu}]$ as the reduction in exposures via clearing. This cost also depends on the size of the bank as systemically important banks have higher capital adequacy ratio.

There are transparency costs depending on the type and size of the contract. Clearing generally improves transparency. But banks prefer to protect the privacy of their positions for several reasons. The large trades of large banks can suffer from more inference by the market. This cost would depend on the size of the contract $\mathbb{E}[\kappa_{uv} + \kappa_{vu}]$ as well as the size of the bank.

$$\Gamma_c - \Gamma_{b(v)} = 0.$$

Theorem 3. *A (general) equilibrium exists. In it, for any u and $v \in m_u$, the contract $(\kappa_{uv}, \kappa_{vu})$ is cleared if and only if $\mathbb{E}[\kappa_{uv} - \kappa_{vu}] > 0$ and $\delta_{uv} < 0$.*

Our empirical analysis shows that large banks' clearing is less elastic to regulatory changes that influence costs. This is possible because reduced risk weights do not incentivize banks with high equity that are not bound by capital requirements. These banks may have a larger need for flexibility as they trade in many different asset classes and have exotic derivative contracts that CCPs may refuse to clear. They may also be subject to more scrutiny by the market and prefer to protect privacy. These indicate positive δ for large banks.

2.3 Core-Periphery

Financial networks often exhibit a core-periphery structure characterized by a small group of densely connected core banks linked to sparsely connected periphery banks with minimal or no connections among the periphery banks themselves. We assume that the initial system of debt obligations has a core-periphery structure, denoting K the core and P the periphery. Notably, most cycles in core-periphery structures involve the core due to sparse connections within the periphery. We make this point starker for clarity and assume that there are no exposures between periphery banks and there are no cycles involving the periphery banks. Also note that the core-periphery structure surprisingly aligns with the topological conditions for coordination failures outlined in Proposition 1 and illustrated in Figure 2.

The benchmark case is the absence of clearing, with coordination probability denoted Φ^* . This corresponds to a regulatory environment where all clearing costs are positive. We now analyze changes in systemic risk under different cost scenarios, reflecting the impact of regulations on clearing incentives and, consequently, systemic risk.

Theorem 4. *(Asymmetric clearing) If the core does not clear, coordination failure probability increases. This is, $\Phi \geq \Phi^*$ if $\delta_{uv} > 0$ for all $u \in i \in K$.*

We illustrate the implications of this result by simplifying costs further. We assume that relative clearing costs depend on the types of banks only instead of the bankers: δ_{KK} (core-core), δ_{KP} (core-periphery), and δ_{PK} (periphery-core). Note that δ_{PP} is irrelevant due to the absence of periphery-periphery exposures. We also disregard asymmetric clearing costs within the core for clarity. Asymmetry within the core would introduce pro-cyclic or counter-cyclic clearing, which we discussed earlier.

Proposition 5. *Relative to no-clearing benchmark Φ^* , the endogenous coordination failure probability Φ satisfies the following:*

- *Core clearing:* If $\delta_{KK} < 0$, then $\Phi = 0 \leq \Phi^*$.
- *Coupled clearing:* If $\delta_{KK} > 0$, and $\delta_{PK}\delta_{KP} > 0$, then $\Phi \leq \Phi^*$.
- *Decoupled clearing:* If $\delta_{KK} > 0$, and $\delta_{PK}\delta_{KP} < 0$, then $\Phi \geq \Phi^*$.

Under core clearing, all exposures within the core are cleared, eliminating cycles within the core. Since cycles are in the core and coordination failures can be triggered only with cycles, systemic risk is eliminated at its source.

Under coupled clearing, exposure between the core and the periphery are either both cleared or both not cleared. The latter is the benchmark case. The former is the clearing of exposures between the core and the periphery. This facilitates multilateral netting, reducing core-periphery exposures and mitigating the propagation of cyclic failures originating in the core.

Under decoupled clearing, one-directional clearing decreases bilateral netting between the core and the periphery and increases exposures while leaving core cycles intact. Consequently, cyclic failures that start at the core propagate more either through the CCP or directly to the periphery.

This analysis highlights the crucial role of multilateral netting in mitigating systemic risk. When clearing is limited to only one direction between the core and periphery, the system fails to achieve multilateral netting but reduces bilateral netting, leading to an increased susceptibility to coordination failures.

When clearing costs inside the core are heterogeneous, the details of the cycles inside the core determine whether clearing is pro-cyclical or counter-cyclical. This can amplify or attenuate the effects in Proposition 5.

2.3.1 Example

The example in Section 2.2.1 highlighted the importance of clearing direction within core banks for the likelihood of coordination failures. While we imposed specific clearing patterns in that example, patterns could be rationalized by specific heterogeneously structured costs along the cycle.

Now, we illustrate coupled and decoupled clearing. Consider a financial system with three core banks $K = \{1, 2, 3\}$ and three periphery banks $P = \{4, 5, 6\}$. Shocks are aggregate, $\alpha_i = \alpha$ for all i . Core banks have assets $A_i = 4$, liabilities $L_i = 3$, and cyclic exposures within the core: $D_{12}^{**} = D_{23}^{**} = D_{31}^{**} = 2$, with $D_{ij}^{**} = 0$ otherwise. This core cycle can trigger a coordination failure if the shock α is sufficiently low. We assume large liquidation costs, $\lambda < \frac{3}{7}$.

Periphery banks have assets $A_i = 2$, senior liabilities $L_i = 3$, and no exposures among themselves. Exposures between the core and periphery are bidirectional, as illustrated in Figure 6 (left panel).

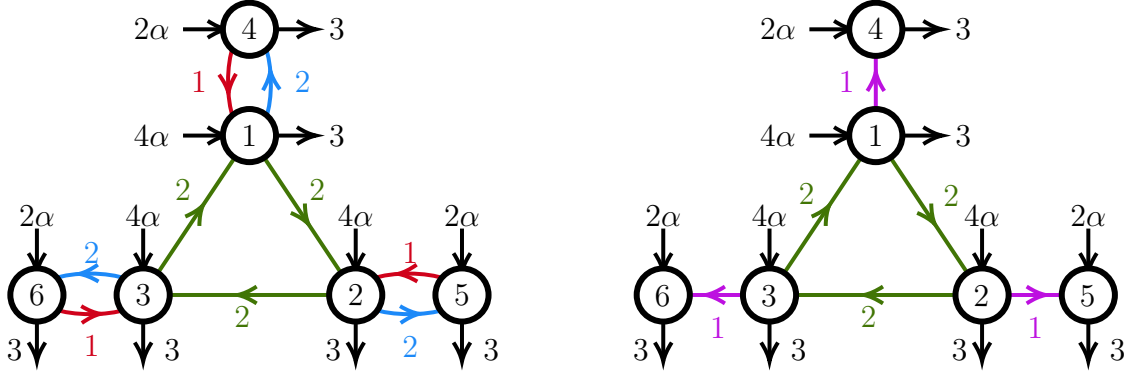


Figure 6: No clearing and bilateral netting. Arrows indicate the direction of payment flows.

Without clearing, after bilateral netting, each core bank owes 2 to its core creditor along the cycle and 1 to its periphery counterparty, resulting in total interbank debt $D_K = 3$. Periphery banks, due to netting, owe nothing ($D_P = 0$). This post-netting system is shown in Figure 6 (right panel). Without clearing, we compute $\phi_K = \frac{3+3}{4} = \frac{3}{2}$ and $\phi_P = \frac{3+0}{2} = \frac{3}{2}$, leading to a coordination failure probability of $F(\frac{3}{2})$.

We now consider endogenous clearing scenarios based on Proposition 5. Assuming $\delta_{KK} > 0$, we study the divergence in the incentives of the core and the periphery to clear.

If $\delta_{PK} < 0$ and $\delta_{KP} < 0$, core-periphery exposures are cleared and clearing is coupled. The resulting system is shown in Figure 7. In this example, ϕ_K and ϕ_P remain unchanged after clearing, and thus $\Phi = F(\frac{3}{2})$.

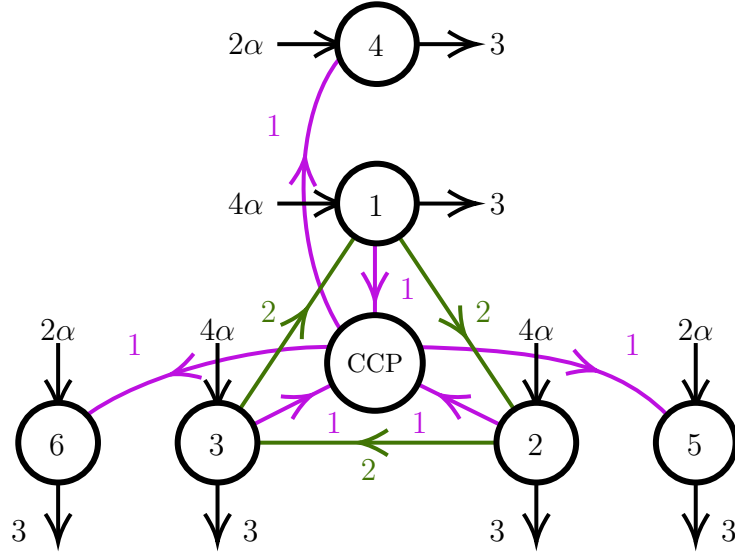


Figure 7: $\delta_{KK} > 0$ and $\delta_{PK}, \delta_{KP} < 0$

Consider the case of decoupled clearing where $\delta_{PK} < 0 < \delta_{KP}$. Here, periphery banks clear their exposures to the core, while core banks do not clear their exposures to the periphery. This implies that periphery banks prefer to be paid by the CCP instead of the core, while core banks

prefer to be paid by the periphery rather than the CCP.

The resulting system is shown in Figure 8. After clearing, a core bank's exposure to its periphery counterparty is 1, but it now owes 2 to the CCP instead of the periphery bank. The periphery, in turn, is exposed to the CCP by 2.

Decoupling eliminates bilateral netting between the core and periphery, increasing the total debt of both core banks (from $D_K = 3$ to $D_K = 4$) and periphery banks (from $D_P = 0$ to $D_P = 1$). This impacts the likelihood of coordination failure, with the new interdependent fragility levels being $\phi_K = \frac{3+4}{4} = \frac{7}{4}$ and $\phi_P = \frac{3+1}{2} = 2$. The probability of coordination failure increases from $F(\frac{3}{2})$ without clearing to $F(\frac{7}{4})$ with decoupled clearing.

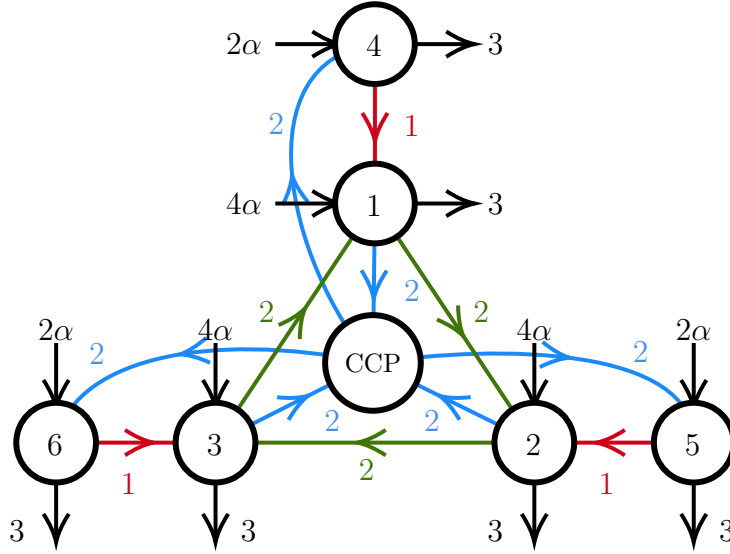


Figure 8: Decoupling under $\delta_{KK} > 0$ and $\delta_{PK} < 0 < \delta_{KP}$

Finally, consider the reverse decoupled clearing scenario where $\delta_{PK} > 0 > \delta_{KP}$. Here, core banks clear their exposures to the periphery, while periphery banks do not clear their exposures to the core.

This scenario is depicted in Figure 9. After clearing, a periphery bank's exposure to its core counterparty increases to 2, and it now owes 1 to the CCP instead of the core bank. The core, in turn, is exposed to the CCP by 1.

As in the previous decoupling case, bilateral netting between the core and periphery is eliminated, and the total debt of both core and periphery banks increases. This leads to the same increase in the likelihood of coordination failure, from $F(\frac{3}{2})$ without clearing to $F(\frac{7}{4})$ with decoupled clearing.

The similarity in outcomes between the two decoupling scenarios emphasizes that the direction of clearing in a decoupled system does not fundamentally alter the increase in systemic risk caused by the loss of bilateral netting benefits. Both scenarios highlight the importance of aligned and balanced clearing to achieve multilateral netting and effectively mitigate coordina-

tion failures.

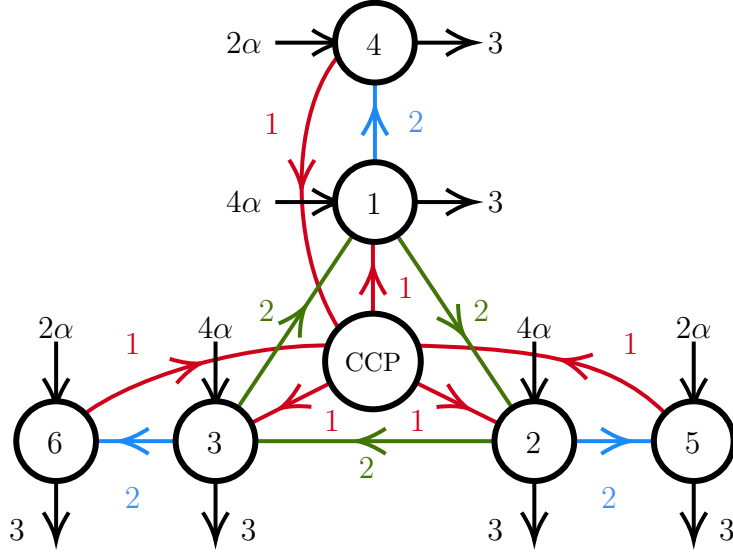


Figure 9: Decoupling under $\delta_{KK} > 0$ and $\delta_{PK} > 0 > \delta_{KP}$

Decoupled clearing, while aiming to achieve multilateral netting through CCPs, can be detrimental to bilateral netting. When applied between the core and periphery asymmetrically, it fails to provide any benefits in terms of multilateral netting. Conversely, clearing within the core has the potential to eliminate coordination failures altogether.

Therefore, understanding who clears what and in which direction is crucial for assessing the impact of clearing on coordination failures. The choice of clearing strategy should be carefully considered, as it can either mitigate or exacerbate systemic risk.

It is important to note that eliminating coordination failures does not guarantee the elimination of system-wide failures. Systemic failures can still occur due to solvency issues, even in the absence of cycles. However, the presence of cycles introduces an additional layer of vulnerability through contagion, making the system more susceptible to cascading defaults.

3 Empirical Evidence

In this section, we outline the regulatory reforms, present the relevant data, and discuss the key empirical findings, connecting them to the predictions of our model.

3.1 Clearing, Reforms, and Incentives

The 2008 financial crisis led to a series of regulatory reforms aimed at enhancing the resilience of the financial sector. These reforms encompassed changes in capital and liquidity requirements, with a particular focus on reducing counterparty credit risk through increased central clearing. This emphasis on central clearing was implemented through two key regulatory mechanisms:

1. **Restrictions:** Standardized over-the-counter (OTC) derivatives are mandated to be cleared through central counterparties (CCPs).¹⁰
2. **Incentives:** Non-cleared derivatives are subject to higher capital (higher risk-weights) and collateral requirements.¹¹

The initial proposal for reform was made in 2009 when G-20 leaders agreed that all standardized OTC derivative contracts should be traded on exchanges or electronic trading platforms, where appropriate, and cleared through central counterparties (see FSB (2010)). Most of the final rules were implemented between 2012 and 2015.^{12,13} For most of the analysis, and consistent with our reading of the changes in the financial system, we focus on the period that starts in 2015.Q1 as the post-reform period.

Our model is sufficiently versatile to reflect changes in the regulatory environment through adjustments in the relative clearing costs $\{\delta_{KK}, \delta_{KP}, \delta_{PK}\}$. These costs encapsulate the full range of regulatory changes, so we do not attempt to measure them directly. Instead, we assume values for these costs that are consistent with the observed reactions of the network and then use these inferred costs, along with the observed network behavior, to make predictions about systemic risk. In the following sections, we present the data we utilize and the predictions derived from our analysis.

3.2 Data Sources

In order to analyze systemic risk in the financial network, the connection across the most important players, and the role of central counterparties, we work primarily with two data sources: (1) the Consolidated Financial Statements for Holding Companies (FR Y-9C) and (2) the Capital Assessments and Stress Testing Data (FR Y-14Q - Schedule L “Trading and Counterparty”).¹⁴ Both data sets are available at a quarterly frequency.¹⁵

¹⁰A centrally cleared derivative contract is defined as “an exposure associated with an outstanding derivative contract that an institution or an institution that is a clearing member has entered into with a central counterparty (CCP), that is, a transaction that a CCP has accepted” (see www.federalreserve.gov/reportforms/forms/FR_Y-9C20191231_i.pdf, link last accessed 05/24/2024). In our framework, these are the cleared exposures. Any other derivative contract is called OTC.

¹¹Derivatives cleared through a CCP incur not only the capital charge due to the trade exposure but also a default fund capital charge (on average small).

¹²We provide an extended account of the changes in regulation that affected OTC derivatives in the Appendix. See also the Financial Stability Board (FSB) progress reports published since 2010 and Ghamami and Glasserman (2017).

¹³The original proposal also included collateral costs for OTC derivatives via margin requirements but those reforms were postponed several times and implemented only recently.

¹⁴We provide here a general description of the data but both sources and the variables we use are presented in more detail in the Appendix.

¹⁵The FR Y-14Q Schedule L started to be reported at the quarterly frequency after 2014.Q2.

The FR Y-9C is (for the most part) public and collects financial data (balance sheet, income statement, and several other schedules, including institution-level values of off-balance sheet items) at the BHC level on a consolidated basis. Only bank holding companies (“banks”) with more than \$3 billion in assets are required to report. We make use primarily of two non-confidential schedules from the FR Y-9C report: schedule HC-R (“Regulatory Capital”) and schedule HC-L (“Derivatives and Off-Balance Items”). Using the schedule HC-R, we can obtain estimates of derivative activity by whether the contract is centrally cleared or traded over-the-counter using credit equivalents and notional values.¹⁶ The distinction between over-the-counter derivatives and centrally cleared derivatives has been available since 2015. Using credit equivalents, it is possible to look at the distribution of contracts across the risk-weight distribution. Using notional value, it is possible to provide information on the type of contract (e.g., interest rate, foreign exchange and gold, credit, equity).¹⁷ Schedule HC-L provides additional information on notional amounts, gross positive fair value (GPFV), and gross negative fair value (GNFV) by derivative type (e.g., interest rate contracts, foreign exchange contracts, equity derivative contracts, commodity and other contracts, and credit derivatives). The GPFV corresponds to the total of all contracts with positive value (i.e., derivative receivables) to the bank and represents a key measure of credit exposure (i.e., these are the contracts on which a bank would lose value if the counterparty of a contract defaulted). The GNFV represents a measure of the exposure the bank poses to its counterparties.

Our second data source, the FR Y-14Q, is confidential and used to support supervisory stress testing models and for continuous monitoring by the Federal Reserve. We gained access to the “Trading and Counterparty” schedule (schedule L).¹⁸ Schedule L includes key information on counterparty risk, and it is submitted by banks with significant derivative activity and allows us to construct a consistent time series for 6 reporting banks (some other banks start reporting after 2019 and not in a consistent frequency).¹⁹ These are the largest banks in the U.S. when sorted by assets: J.P. Morgan Chase, Bank of America, Wells Fargo, Citibank, Morgan Stanley, and Goldman Sachs. We call the group of six banks for which we construct the full picture

¹⁶Credit equivalent adds current credit exposure (sometimes referred to as the replacement cost) plus the potential future exposure over the remaining life of the derivative contract. The current credit exposure is (1) the fair value of the contract, when the fair value is positive, and (2) zero, when the fair value is negative or zero. A bilateral netting agreement between the reporting bank and a counterparty may be taken into consideration.

¹⁷The report also has information on some broad maturity buckets (one year or less, one to five years, and over five years).

¹⁸Banks that comply with the following requirements submit these regulatory forms: (1) have aggregate trading assets and liabilities of \$50 billion or more, or aggregate trading assets and liabilities equal to 10 percent or more of total consolidated assets, and (2) are not “large and noncomplex firms” under the Board’s capital plan rule. A large and noncomplex firm is a BHC with total consolidated assets of at least \$50 billion but less than \$250 billion, total consolidated nonbank assets of less than \$75 billion, and is not a U.S. globally systemically important bank (GSIB).

¹⁹This is not an important restriction since derivative activity is highly concentrated. The banks included in this sample account for 85.7 percent of all reported derivative contracts (by notional value) in 2022.Q4.

of counterparty exposure in our sample “core” banks. We think of core banks as large and interconnected banks that pose systemic risks.

Of particular importance, the L schedule in FR Y-14Q provides detailed information at the counterparty level. This schedule contains 18 sub-schedules and provides unique information about the derivative profile by the counterparty as well as aggregated across all counterparties of each reporting bank. We use sub-schedules L1.a, L1.b, L1.c, L1.d, and L1.e for our analysis. Sub-schedule L1.e is particularly important as it provides information at the aggregate level distinguishing between exposures where the counterparty is a CCP or is not.^{20,21} Possible counterparties include (but are not limited to) other BHCs, other financial institutions (e.g., insurance companies, hedge funds, nonbank financial institutions), sovereigns, non-financial corporations, and central counterparties. Designated CCP exposures include both cleared over-the-counter (OTC) derivatives and exchange-traded derivatives. All counterparties have a unique identifier, and reporting banks provide the name and type of the counterparty, which allows us to track relationships over time, with information on the industry code (six-digit NAICS code), the country of domicile of the counterparty, an internal rating, and (when available) the external rating of the counterparty.²² We focus primarily on the network of U.S. counterparties. We document the changes in exposures using Gross Credit Exposure (Gross CE). Gross CE is pre-collateral exposure after bilateral counterparty netting. Sometimes referred to as the replacement cost or current credit exposure, Gross CE is the fair value of a derivative contract when that fair value is positive. Gross CE is zero when the fair value is negative or zero.²³ Importantly, Gross CE aligns relatively well with the credit equivalent measure that we use from the FR Y-9C.

Combining these two key sources, we provide a comprehensive picture of derivative activity for most banks in the U.S. and describe the network of exposures for the most relevant players (i.e., those that we defined as core banks). The FR Y-9C provides an almost complete picture of derivative activity across banks in the US but, as opposed to the FR Y-14Q where we observe counterparty level exposure, it only provides information at the bank level (i.e., not granular exposures). The FR Y-14Q allows the presentation of evidence at the counterparty level for the

²⁰Required reporting of all CCPs started in 2015. Sub-schedules L1.a-d, which provide information at different levels of disaggregation, provide a significant share of the aggregate exposure. We discuss this further below and the appendix.

²¹In 2020.Q1 there are significant reporting changes because sub-schedules L1.c and L1.d stop being reported, making the use of L1.e for the exposure to CCPs crucial. Figure A.3 presents a comparison between the aggregate levels reported in sub-schedule L1e and the aggregate values computed from sub-schedules L1a-d.

²²The reporting requirements by type of counterparty changes over time as the data requirements evolved during the last decade.

²³Another available measure of exposure in this schedule that can be traced over time is Net Credit Exposure (Net CE). Net CE corresponds to Gross CE less the value of collateral posted by the counterparty to secure those trades. Only collateral that was actually exchanged is incorporated in the Net CE reporting. This measure, however, is subject to assumptions about the value of collateral and how that value is reported. In addition, it is not fully consistent with how exposures are accounted for in our model. For these reasons, most of our analysis is based on Gross CE, but we also discuss how our empirical results are affected by different measures of exposure below and in the appendix.

banks that account for more than 80% of derivative activity. As our theory suggests, the core is where cycles reside and the systemic risk originates. We also focus on the links between the core and periphery and central counterparties.

Table A.2 in the appendix provides a set of summary statistics on banks in the core (i.e., the banks reporting in FR Y-14Q) as well as comparison with banks not in the core but that report in FR Y-9C.²⁴ We note that, on average, banks in the core are significantly larger and have lower equity-to-asset ratios than banks outside the core. They also account for the lion's share of the activity in derivative markets, accounting for over 80% of the total value of derivative exposures both when measured using credit equivalents and notional amounts. The average ratio of the value of derivative contracts over assets is 14.5% and 0.56% for banks in the core and banks outside the core, respectively, when the value of derivative contracts is measured using credit equivalents. This table also shows that using the ratio of notional values to assets as a measure of derivative activity leads to a similar picture (i.e., exposure is significantly larger for core banks than for other banks). Consistent across the two groups, we observe that interest rate, foreign exchange rate, and equity derivatives make for the bulk of activity. The share of centrally cleared contracts for core banks is 34.3% and 54.3% when using credit equivalents and notional value, respectively. We discuss the evolution of the fraction of centrally cleared contracts in the following subsection.

3.3 Aggregate Patterns

The regulatory changes that we described above led to an increase in aggregate central clearing activity.²⁵ This, however, did not translate into a significant increase in the fraction of centrally cleared derivatives for core banks. More specifically, using the notation from our model, let $E_{bc,t}$ denote the total exposure to central counterparties (total derivatives that are centrally cleared) and $\sum_{j \neq c} E_{bj,t}$ denote total derivatives that are not centrally cleared (i.e., transacted over-the-counter with counterparties other than central counterparties c). We compute the share of derivatives that are centrally cleared $s_{b,t}^c$ for bank b in period t , as follows:

$$s_{b,t}^c = \frac{E_{bc,t}}{E_{bc,t} + \sum_{j \neq c} E_{bj,t}}. \quad (4)$$

We measure $E_{bj,t}$ using credit equivalents (FR Y-9C) and aggregating Gross CE across all counterparties (FR Y-14Q). With the bank level estimates at hand, we then compute the asset-weighted average within bank group (core and non-core) $\bar{s}_t^{c,K} = \sum_{b \in K} s_{b,t}^c \omega_{b,t}^K$ where K denotes

²⁴See Table A.1 in the appendix for a definition of variables used.

²⁵Between 2015.Q4 and 2022.Q4 the notional value of centrally cleared contracts has increased by approximately 10% for U.S. banks. See Figure A.1 in the appendix for the time series of aggregate notional amounts and credit equivalents of derivative contracts that are centrally cleared.

the set of core banks and $\omega_{b,t}^K$ is the share of assets in core banks that correspond to bank $b \in K$ in period t .²⁶ We also compute $\bar{s}_t^{c,P}$ for banks not in the core (where P as in the model denotes peripheral banks). Figure 10 presents $\bar{s}_t^{c,K}$ and $\bar{s}_t^{c,P}$ using data from FR Y-9C. Data on $E_{bc,t}$ and $\sum_{j \neq c} E_{bj,t}$ from the FR Y-9C is available only since 2015, which we identify with the post-reform period.²⁷ Figure 10 shows that $\bar{s}_t^{c,K}$ (i.e., the average share of the credit equivalent that is centrally cleared) has remained relatively constant for core banks since 2015 (i.e., banks that report consistently counterparty risk in the FR Y-14Q). We observe an increase from 33% to 38% between 2015 to 2018, followed by a decline to 36.6% at the end of 2021. There seems to be a significant increase for other banks ($\bar{s}_t^{c,P}$) for which the share of total exposure to CCPs increases from 19% in 2015 to 28% at the end of 2022 but these banks represent only a small fraction of derivative activity.

Figure 10 suggests that during the post-reform period there is still significant activity that is traded OTC among core banks and that the incentives to centrally clear were stronger for banks outside the largest six (i.e., core banks). That is, at the aggregate level, the dynamics in the banking sector appear to be consistent with decoupled clearing (see Proposition 5). In that sense, regulations induced an increase in central clearing, but the increase is mostly explained by banks outside the core, which hints at regulations being somewhat ineffective at reducing cycles that involve the largest banks in the system. With the counterparty data at hand, we will describe the evolution of these cycles and show that this is, in fact, the case in the next section. An alternative interpretation of the increase in aggregate central clearing accompanied by relative constant shares of central clearing among core banks is that, prior to the change in regulation, “even” positions in standard derivatives between core banks were netted out, and after the change in regulation these positions are moved to central counterparties, increasing central clearing but leaving core to core exposures and core to CCP exposures unchanged. The evidence in this section and the appendix suggests that this is not the case as the within-bank fraction of centrally cleared contracts increases more for banks outside the core than for banks inside the core (see Figure 10) and the fraction of aggregate centrally cleared contracts that are accounted by core banks has been declining over time (see Figure 11).²⁸

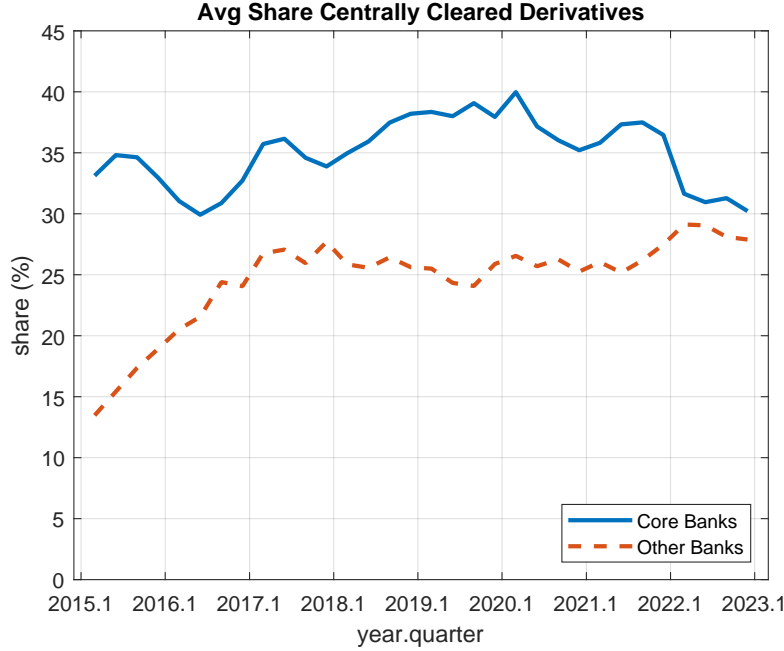
Figure A.2 (in the appendix) presents the fraction of centrally cleared derivatives when exposure is measured using notional value. The average share for core banks is 53.1% and, consistent with the evidence in Figure 10, it appears to be stable since 2015 (or declining in the most recent

²⁶That is, $\omega_{b,t}^K = A_{b,t} / (\sum_{b \in K} A_{b,t})$ where $A_{b,t}$ denotes total assets of bank b in period t .

²⁷As we described before, except for margin requirements for OTC derivatives, other dimensions of the reform of OTC markets (central clearing, reporting, capital requirements) were in place by 2015 in the US.

²⁸Figure A.2 in the appendix shows that the share of centrally cleared interest rate contracts (which are the most common standard derivative contracts) has been steady during the last 10 years (measured using notional amounts). The share of credit contracts (not always standard) has been increasing over time but they account for a small amount of the total notional amount. This is also consistent with the evidence presented by the BIS. In line with this, we find that default fund contributions by banks outside the core have grown at a faster pace than contributions by core banks.

Figure 10: Fraction of Centrally Cleared Derivatives
(core $\bar{s}_t^{c,K}$ and non-core banks $\bar{s}_t^{c,P}$)



Note: “CCP” corresponds to Central Counterparty (centrally cleared derivatives). Core banks refers to banks that report counterparty risk in our FR Y-14Q data. Other Banks corresponds to all other reporting banks. Avg Share corresponds to the asset weighted average of the bank specific CCP share. Source: Consolidated Financial Statements for BHCs (FR Y-9C - HC-R)

quarters).²⁹ Figure A.2 also shows that the fraction of centrally cleared interest rate derivatives (which account for a large fraction of total activity) is higher than the overall average but it also has been stable since 2015.³⁰ In the appendix, we discuss the details of the reforms but the evidence on interest rate derivatives is particularly relevant as the final rules require certain classes of credit default swaps and interest rate swaps to be cleared.³¹

We continue the analysis of how central clearing evolved in the banking sector and compute two additional measures of central clearing activity among core and other banks using credit equivalents. First, we compute the share of total centrally cleared derivatives that are accounted for by core banks. That is, we estimate $\frac{\sum_{b \in K} E_{bc,t}}{\sum_{b \in K} E_{bc,t} + \sum_{b \in P} E_{bc,t}}$ and present this ratio (in percent) in Panel (i) of Figure 11. Second, as growth dynamics during this period across the bank

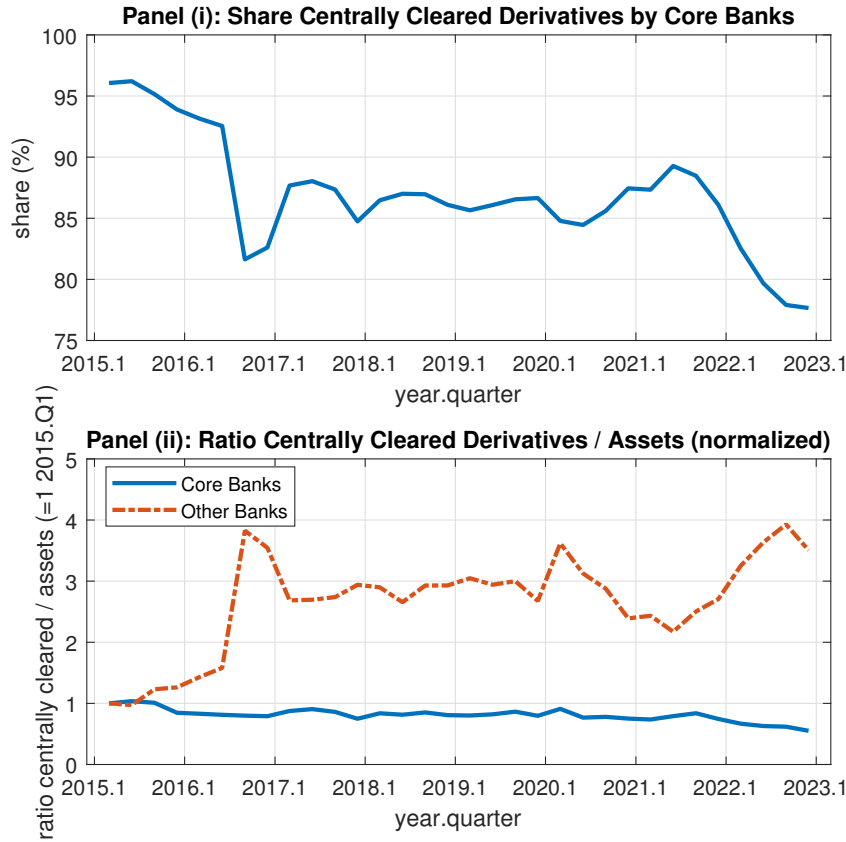
²⁹For most of the analysis we focus on exposures measured using credit equivalents, as notional amounts do not provide a useful measure of market or credit risk.

³⁰While there are differences in the sample of banks and coverage, the evidence in Figure A.2 is broadly consistent with the evidence presented by the Bank of International Settlements (BIS) in their “OTC derivatives statistics”. See, for example, Graph A.8 in the last report (https://www.bis.org/publ/otc_hy2411.htm, link last accessed 3/1/2025) that shows that the share of centrally cleared interest rate derivatives has been stable since 2015. The same figure shows that the share of centrally cleared credit default swaps (part of credit derivatives in our figure) has increased recently as in our data (but since they represent an small fraction of overall activity when using notional amounts they do not have a large impact on the overall share).

³¹It is optional to centrally clear other derivatives such as currency swaps, commodity swaps, equity swaps, and inflation swaps. The list of required derivatives can be found here <https://www.cftc.gov/sites/default/files/idc/groups/public/@otherif/documents/ifdocs/clearingrequirementcharts.pdf>

size distribution differs, we compute $\frac{\sum_{b \in K} E_{bc,t}}{\sum_{b \in K} A_{b,t}}$ and $\frac{\sum_{b \in P} E_{bc,t}}{\sum_{b \in P} A_{b,t}}$ where $A_{b,t}$ represents total assets for bank b in period t . Panel (ii) in Figure 11 displays the evolution of this ratio over time (normalized to 1 in 2015.Q1) one more time using data from the FR Y-9C. The figure makes evident two facts: First, in the US, core banks account for the lion's share of centrally cleared derivatives in the banking sector with close to 85%, on average (Panel (i)). Second, this share has declined in the recent period, going from over 95% in 2015 to just above 75% by the end of 2022 (a decline of 20 percentage points). That is, the importance of other smaller banks in markets for cleared derivatives has increased (Panel (i)). The growth of central clearing for banks outside the core has outpaced the growth of assets in this portion of the banking sector. The decline for core banks in central clearing relative to the growth of assets is significant as it declines by almost 50% (Panel (ii)).

Figure 11: Share of Total Centrally Cleared Derivatives Accounted for by Core Banks

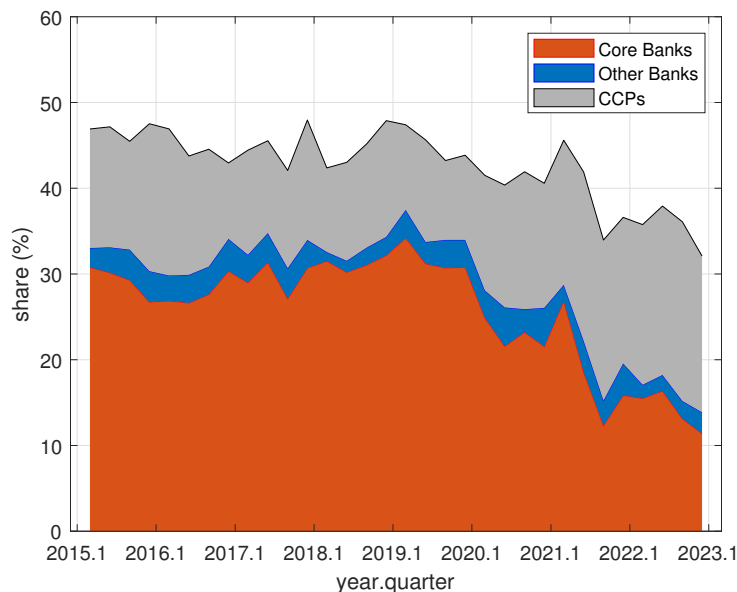


Note: Core banks refers to banks that report counterparty risk in our FR Y-14Q data. Other Banks corresponds to all other reporting banks. Source: Consolidated Financial Statements for BHCs (FR Y-9C - HC-R)

In our next step, we make use of our confidential data as it contains unique information about the derivative profile by counterparty and is aggregated across all counterparties of each reporting bank. We classify counterparties based on information provided by the supervision group at the Federal Reserve Bank of New York, which takes into account, among other things, the ownership structure of financial institutions. Focusing on counterparties in the U.S., we can

identify core banks, other banks, CCPs, non-financial corporations, government entities, non-financial corporations, and other institutions (e.g., financial guarantors, pension funds, special purpose vehicles). Using this information, quarter by quarter, we compute the exposure of each reporting bank to each counterparty type by aggregating information at the individual counterparty level and taking ratios to overall exposures. We use Gross CE as our measure of exposure (pre-collateral exposure after bilateral counterparty netting).³² This measure presents a clear picture of the real exposure of each of the core banks to their counterparties. Figure 12 displays the (asset-weighted) average of Gross CE by counterparty type. We focus on the exposure of core banks to core banks, other banks, and CCPs as they are the most salient groups by exposure in the financial sector and are the focus of our model.³³ Figure 12 shows

Figure 12: Counterparty Exposure Gross CE by counterparty type (core banks)



Note: Asset-weighted average of bank-level Gross credit exposure by counterparty type (core banks to U.S. counterparties). Data from core banks with consistent time series. “CCPs” corresponds to Central Counterparty, “Core” to the reporting banks, “Other Banks” to other banks not in the “Core” category. Source: Consolidated Financial Statements (FR Y-9C) and FR Y-14Q (schedule L)

that exposure to core banks is significant, with the average exposure of core banks to other core banks being 25.6%.³⁴ Core-to-core exposure remains the largest exposure by counterparty type until 2021 Q1. The figure shows that it is relatively flat at approximately 30% between 2015 and 2021.Q1 and averages over 16% during 2021 and 2022.³⁵ That is, the exposure “core to core” remained a significant factor in explaining counterparty risk since 2015 and throughout

³²We discuss below, and present evidence in the appendix when the measure of exposure is net of collateral (i.e., when using Net CE).

³³Figure A.4 in the Appendix presents exposure to the full set of U.S. counterparties by type.

³⁴Reporting restrictions prevent us from disclosing the evolution of exposures at the bank level, but we can mention that not one bank is the main driver of the figure, in the sense that, all banks in our sample present similar patterns.

³⁵Figure A.6 in the Appendix presents similar evidence when using Net Credit Exposure (Net CE) as a measure

the pandemic, and while it has declined since 2021.Q2, it still remains elevated.³⁶ A key insight from our model is that the impact of clearing on coordination failures depends on details beyond the amount of clearing. In the sections that follow, we show that the decline in core-to-core exposure has not affected key properties of the cycles generated by derivative exposures within the core. Of particular relevance is the fact that core banks correspond to only 6 institutions. The average share of the top counterparty among core banks (using Gross CE as the measure of exposure) was 54.9% in 2021.Q4. The average share of the top counterparty by type was 38.8%, 70.5%, 41.7%, and 5.5% for other banks, CCPs, government entities, and non-financial corporations, respectively, also in 2021.Q4. Figure 12 also makes evident that while regulatory changes induced an increase in the exposure to CCPs, the increase is not very dramatic as the average exposure of core banks to CCPs is 12.4% between 2015 and 2019 and 18.7% between 2021 and 2022.³⁷ This one more time is in line with the decoupled clearing case discussed in Proposition 5.

3.4 Mapping the Regulatory Environment to the Model

The changes in regulations can be represented as shifts in the relative cost (δ) of clearing contracts through CCPs versus OTC channels. By analyzing observed preferences, the documented changes in clearing behavior provide insights into how regulations have affected these costs.

Empirically, we find that the core's share of centrally cleared derivatives has remained relatively stable (Figure 10) but has shown a decline relative to total assets (Figure 11). This suggests that the regulatory-induced increase in clearing incentives primarily benefited non-core banks, non-financial corporations, or non-banks, as evidenced by the increased exposure of core banks to institutions other than CCPs in the recent period. Among the possibilities highlighted in Proposition 5, the data points towards the case of $\delta_{PK} < 0 < \delta_{KP}, \delta_{KK}$, where the periphery clears exposures from the core, but the core does not clear internally.

The two most prominent regulatory changes can be summarized as increased CCP transparency relative to OTC contracts and increased collateral costs for OTC relative to CCP contracts. Considering exposures as insurance contracts between banks, the exposed party (in-

of exposure (Net CE equals Gross CE minus the value of collateral). Figure A.6 suggests that core banks are intensive in the use of collateral, and this is reflected as an increase in the relative importance of CCPs exposure compared to the case when exposure is measured using Gross CE.

³⁶Figure A.4 in the Appendix shows that the decline in exposure to core banks post 2021.Q1 is associated with an increase in exposure to non-financial corporations as well as an increase in exposure to nonbank financial institutions. In 2022.Q4 non-financial corporations and nonbank financial institutions account for 40.6% and 9% of total Gross CE exposures (among U.S. counterparties). Figure A.5 presents the average exposure of core banks to all counterparties (U.S. and foreign) and shows that there is a similar increase in exposure to non-financial corporates and nonbank financial institutions with a somewhat larger increase of nonbank financial institutions.

³⁷Figure A.6 in the Appendix shows that when using Net CE as the measure of exposure (bilateral netted exposure net of collateral), the increase in exposure to CCPs is larger as collateral use appears to be larger for other counterparties.

insurance buyer) may signal weakness, increasing funding costs. Thus, transparency might have increased δ (the relative cost of CCP clearing). Conversely, collateral regulations requiring the exposed party to hold regulatory capital proportional to risk might have decreased δ .

The data suggests a bank-specific ranking based on their varying valuations of opacity and collateral. Core banks, facing higher scrutiny but less constrained by capital requirements due to abundant regulatory capital, are likely less incentivized to clear contracts compared to periphery banks. This implies higher transparency costs and lower collateral benefits for core banks. Thus, the system may have transitioned from a state where $0 < \delta_{PK}, \delta_{KP}, \delta_{KK}$ to one where $\delta_{PK} < 0 < \delta_{KP}, \delta_{KK}$.³⁸

Interestingly, the observed change in clearing is consistent with an increase in systemic risk (Φ). The potential unintended consequence of regulation leading to decoupled clearing, where cycles persist but are magnified by larger internal fragility, highlights the need for regulations that incentivize core clearing, not periphery clearing.

Examples of such regulation include designing clearing mechanisms less reliant on specific contract information, alleviating core banks' concerns about exposing themselves and their information to the CCP. A key consideration is incentivizing banks to clear proportionally to their pre-existing clearing rates. This avoids unintended consequences from asymmetrically changing extensive margins while reducing the intensive margins of OTC exposures and mitigating coordination failures.

3.5 Coordination Failure Regions

The model prompts us to examine not only the level of central clearing relative to OTC derivatives but also bilateral exposures. Before delving into confidential counterparty data, we utilize public data to infer whether banks operate within a parameter space conducive to coordination failures. Recall that our model predicts a coordination failure region defined by $\phi' < \alpha < \phi$. We first analyze the evolution of ϕ' and ϕ over time. Specifically, we interpret ϕ'_i as a measure of fundamental economic risk independent of coordination failures, $\phi_i - \phi'_i$ as a measure of coordination failure risk, and ϕ_i as a measure of combined systemic risk.

We do not observe shocks, so we rely on observed \tilde{A}_i to reflect A_i in our constructed measures. In particular, we estimate ϕ_i for each bank i as

$$\hat{\phi}_i \equiv (L_i + D_i)\tilde{A}_i^{-1}, \quad (5)$$

where \tilde{A}_i corresponds to (on-balance-sheet) assets, L_i to total (on-balance-sheet) liabilities, and D_i is measured using the schedule HC-L in the FR Y-9C that captures off-balance sheet debt

³⁸We endogenize costs, exposures, and the intensive margin of clearing in an earlier version of the paper, available upon request. In this paper, we take costs and exposures as given and study the extensive margins of clearing. The resulting insights are nearly identical.

positions using “Gross negative fair value” for all derivative contracts (credit derivatives, interest rate, foreign exchange and gold, equity, and commodity and other contracts), which represents a measure of the exposure bank i poses to its counterparties.³⁹ We can also measure ϕ' for each bank i as

$$\hat{\phi}'_i \equiv (L_i + D_i - E_i)\tilde{A}_i^{-1}, \quad (6)$$

where E_i also comes from schedule HC-L “Gross positive fair value” for all derivative contracts (credit derivatives, interest rate, foreign exchange and gold, equity, and commodity and other contracts) and represents the exposure of bank i to all other counterparties.⁴⁰

The data allows us to look at the evolution of $\hat{\phi}_i$ and $\hat{\phi}'_i$ since the early 2000s. We can measure the evolution of the region that allows coordination failures in the run up to the great financial crisis in 2008 as well as the most recent period. Panels (i) and (iii) in Figure 13 present the full-time series, and panels (ii) and (iv) zoom in on the most recent period (2015-2022). Panel (i) and (ii) present the asset-weighted average of $\hat{\phi}_i$ and $\hat{\phi}'_i$ among core banks. Panels (ii) and (iv) present the components as described in equations (5) and (6). As before, we define the “post-reform” period as the period that starts in 2015.Q1 (the focus of Panels (ii) and (iv)). The vertical dotted lines in Panels (i) and (iii) enclose a period that we defined as a transition period since reforms were already announced but were in the process of being implemented.

The observed patterns are striking. Panel (i) reveals a dramatic increase in the (average) region enabling coordination failures in the lead-up to the crisis, without a corresponding rise in fundamental risk (measured by weighted-average $\hat{\phi}'_i$). This indicates that the majority of the increase in systemic risk (ϕ_i) can be attributed to changes in the difference between average ϕ_i and ϕ'_i .

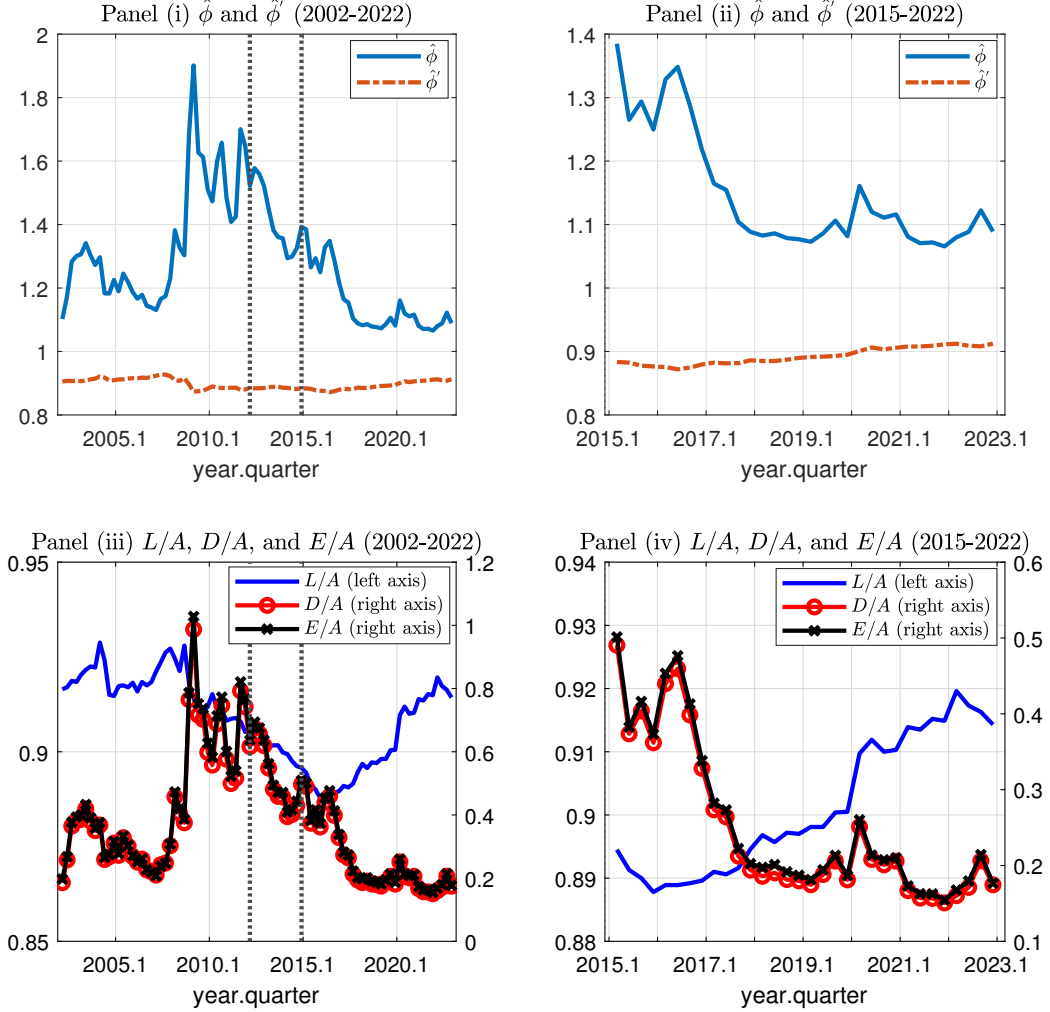
A closer examination of the components underlying ϕ_i and ϕ'_i in Panel (iii) shows a significant rise in interbank assets and liabilities in the pre-crisis period. This supports the notion that the unraveling of complex interbank activity, which would otherwise net out to zero, contributed to the 2008 financial crisis. While L/A remains stable during this period and only declines after the initial shock and subsequent capital regulation changes, Panel (iii) also reveals that the difference between D/A and E/A is generally small relative to the scale of L/A . Thus, under normal conditions, $A - L + E - D$ is positive and sufficiently large. However, even though

³⁹See Appendix for a description of variables used in the analysis. This measure is consistent with the measure used by the OCC in their Quarterly Report on Bank Trading and Derivatives Activities to estimate credit exposure in derivative contracts. The OCC report states, “The total of all contracts with negative value (i.e., derivative payables) to the bank is the gross negative fair value (GNFV) and represents a measurement of the exposure the bank poses to its counterparties.” A drawback of this measure is that it only includes exposures from OTC derivative transactions (see OCC report).

⁴⁰According to the OCC “Measuring credit exposure in derivative contracts involves identifying those contracts a bank would lose value on if the counterparty to a contract defaulted. The total of all contracts with positive value (i.e., derivative receivables) to the bank is the gross positive fair value (GPFV) and represents an initial measurement of credit exposure.” Note that $D_i - E_i$ does not capture any bilateral credit agreement between counterparties.

$D/A - E/A \approx 0$, both D/A and E/A grow significantly. During periods of interbank distrust, potentially triggered by a decline in collateral value, the fulfillment of E/A can drop rapidly, leading to an imbalance where $A - L - D \ll 0$, causing non-payments and justifying the loss in E/A . While A might be large enough to cover L , the disproportionate growth of D/A creates vulnerability. This is evident in Panel (i), as the weighted average $\hat{\phi}_i$ increases significantly during the crisis while average $\hat{\phi}'_i$ remains stable or slightly declines.

Figure 13: Coordination Failure Region and Determinants (average)



Note: The figure presents the asset-weighted average of $\hat{\phi}_i$ and $\hat{\phi}'_i$ as defined in equations (5) and (6). Data for Goldman Sachs and Morgan Stanley only start after 2009 (when they became commercial banks). L/A corresponds to liabilities over assets, D/A corresponds to total (interbank) debt over assets. Dotted vertical lines correspond to a period of transition after reforms were announced but not yet fully implemented. We define the post-reform period as starting in 2015.Q1. Source: Consolidated Financial Statements (FR Y-9C)

Therefore, as Figure 13 shows, the pre-reform period, including the financial crisis, serves as a benchmark or indicator of the OTC system approaching high systemic risk, validating our model's measure. Panels (i) and (ii) further demonstrate that the region allowing for coordination failures begins to shrink after its 2008 peak but remains positive, suggesting that a

systemic crisis due to coordination failures remains feasible according to our model’s predictions. The data suggests that post reform it is less likely that coordination failures get triggered inside the core. However, the region where coordination failures are allowed does not shrink enough to eliminate cycles completely. In addition, since we also find evidence of decoupling (as defined in Theorem 5), we find that if coordination failures get triggered, they might spread and cause more damage than in the past. The effects of a crisis will get amplified via the CCP.

We explore whether bank heterogeneity plays a role in the described dynamics. Figure 14 plots ϕ_i and ϕ'_i for each bank over time, zooming in on the recent period.⁴¹ Coming out from the financial crisis, the region of coordination failures declines in size in the post-GFC period but remains non-negligible for most banks (the exception is Wells Fargo - Panel (vi)). That is, the regulatory changes do not seem to affect in a fundamental way the possibility of coordination failures that can suddenly expand as during the great financial crisis. In fact, Figure 14 Panels (i)-(v) suggest that there was an increase in systemic risk during the early periods of the pandemic with significant heterogeneity across banks. For example, at the early stage of the pandemic the gap between $\hat{\phi}_i$ and $\hat{\phi}'_i$ increased by 32.5% and 51.7% for Goldman Sachs and Morgan Stanley, respectively, relative to the last quarter of 2019. Consistent with Figure 13, Figure 14 also shows that exposures are growing, increasing the fundamental risk, whereas coordination failure risk remains stable but has also grown during the post-reform period.

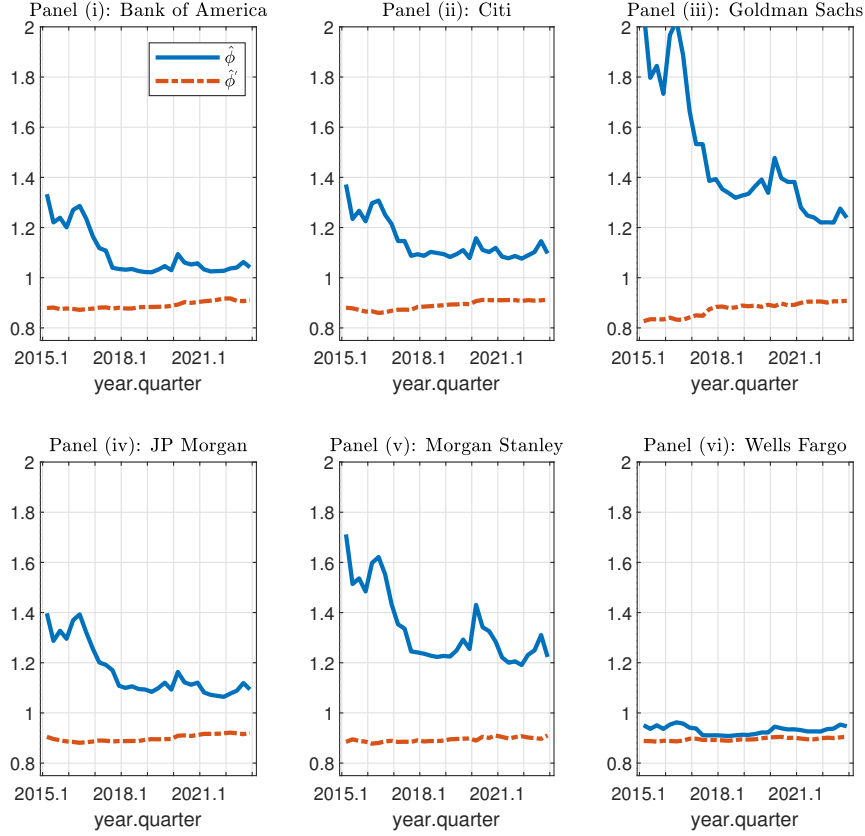
Theories of Systemic Risk. These results contribute to the debate between the “popcorn” and “domino” theories of financial crises, as detailed in Erol and Vohra (2022). The popcorn theory attributes crises primarily to common exposures to external factors, while the domino theory emphasizes cascading failures due to interbank exposures.

Our model accommodates both theories by demonstrating how common exposures can erode confidence and trigger cascading failures. We introduce a theory of an endogenous common shock, the coordination failure, arising from the dynamic interaction between exogenous shocks and interconnectedness. This can be likened to a “dome” theory. The hemispherical structure of a dome balances itself by distributing weight in all directions, providing earthquake resistance without external support. However, when the earthquake’s magnitude exceeds a threshold, the self-supporting system collapses suddenly and completely. The financial network of derivative exposures represents the structural integrity and weight of the dome.

Our findings indicate that, in the context of derivatives and the financial crisis of 2008, the popcorn or domino theories alone (changes in ϕ') are less significant contributors to systemic risk (changes in ϕ) compared to our dome theory represented by coordination failures (changes in $\phi - \phi'$). This highlights the importance of considering both external shocks and the interconnectedness in combination in understanding and mitigating systemic risk.

⁴¹Figure A.7 in the Appendix presents the full-time series. Consistent with the average presented in Figure 13, data for each bank reveals that the coordination failure region (ϕ'_i, ϕ_i) expands dramatically in the buildup towards the financial crisis in 2008.

Figure 14: Coordination Failure Region (ϕ and $\hat{\phi}'$) by bank - Post Reform



Note: Figure shows $\hat{\phi}$ (see equation 5) and $\hat{\phi}'$ (see equation 6) by bank.
Source: Consolidated Financial Statements for BHCs (FR Y-9C)

4 The Anatomy of Cycles within the Core

Our theory emphasizes that cyclic exposures are a prerequisite for coordination failures. In addition to their necessity, the properties of cycles significantly influence the prevalence of coordination failures and systemic risk. Access to confidential regulatory data allows us to examine key characteristics of cycles among major players.

The necessity of cycles highlights the possibility of self-fulfilling cyclic payment failures. Each cycle can be a source of such failures under certain conditions. This concept can be mapped to our model by defining weaker notions of coordination failures, such as a (weak) coordination failure defined as the self-fulfilling failure of a specific subset of banks. The possibility of such a failure would necessitate the presence of a cycle-rooted tree within the subnetwork of the subset of banks (exposures with banks outside the subset would be treated as external assets and liabilities). This suggests that each cycle can trigger a cyclic payment failure among the banks within it under specific shock combinations. This failure, initiated on the cycle, can then propagate outwards through acyclic exposures, as indicated by the cycle-rooted tree in Figure 2. The extent of propagation depends on the reach of the “branches” of this tree, potentially

escalating a cyclic failure into a systemic event. In a sense, cycles within central network locations (like the core) constitute systemically important groups of banks rather than unstructured groups of systemically important individual banks.

Building on this insight, we propose and explore notions of network complexity and bank centrality, measured using our confidential dataset. Network complexity is assessed based on the prevalence of cycles (extensive margin) and the exposures within these cycles (intensive margin). Bank centrality is determined by the bank’s presence within cycles, which can increase the cycle’s, and hence the system’s, exposure to that particular bank.

These findings lead to network-prudential policy suggestions. Complexity serves as a measure of systemic vulnerability to various manifestations of non-fundamental risk. However, complexity does not pinpoint the origin or propagation of problems. Centrality, on the other hand, identifies vulnerable locations within a complex network. If the market perceives trouble at a high-centrality bank, numerous subsets of banks may lose confidence in their counterparties due to inductive reasoning about potential cyclic failures. Thus, perceived problems with high-centrality banks can trigger systemic events.

In the following sections, we identify and describe cycles within the core of the U.S. banking system over time, then propose and explore various notions of complexity and centrality.

4.1 Identifying Cycles

We identify cycles using the FR Y-14Q - Schedule L (i.e., our data source used for stress testing purposes with bilateral information). We continue to use Gross CE as the measure of exposure of one bank to another as it aligns with the definition of credit equivalent (CE) in the call report data that we used before, and it is immune to fluctuations or assumptions about the value of collateral.⁴² As we described before, the banks for which we can construct consistent time series are Citi, Bank of America, Wells Fargo, Morgan Stanley, Goldman Sachs, and J.P. Morgan Chase. Disclosure limitations prevent us from providing the name of the banks so we randomly assign a number between 1 and 6 when presenting the cycles within the core.

Figure 15 presents the direction of exposures between “core” banks before and after regulatory changes.⁴³ Arrows going from bank “B” to bank “A” correspond to how exposed bank “A” is to bank “B” (i.e., the pre-collateral fair value (when positive) of the netted exposure of bank “A” to bank “B”).⁴⁴ We observe some fluctuations across time but we do not observe fundamental

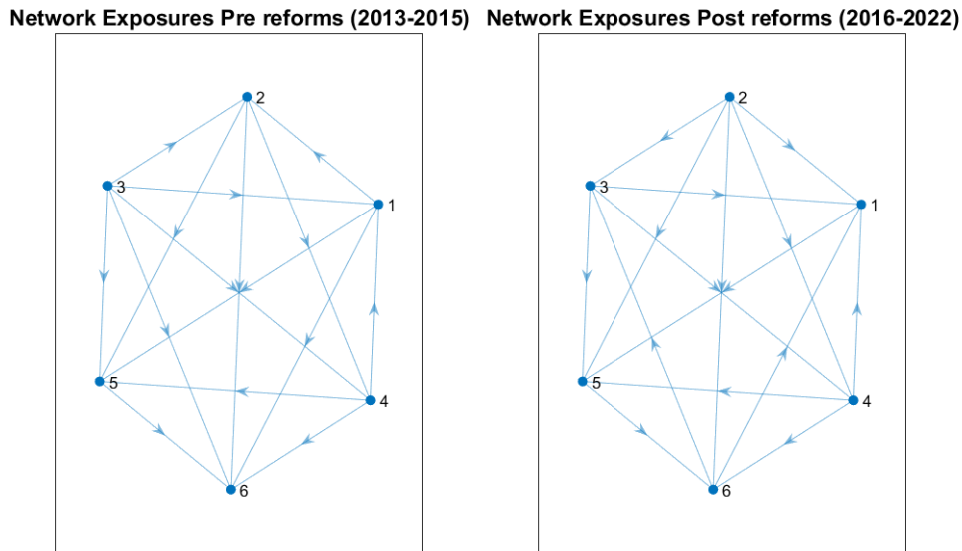
⁴²The OCC uses GCE as its primary metric to evaluate credit risk in bank derivative activities in its Quarterly Derivatives Report. The measure (called Net Current Credit Exposure) is available at the level of total derivatives from the Call Reports Schedule RC-R.

⁴³The figure shows only the direction of exposures as the data clearance process prevented us from showing the values or intensities. We construct the time series average for each exposure pair and present the network based on these average exposures pre and post reforms. Below, we describe specific quarters.

⁴⁴This is effectively the potential market value of losses in the event bank “B” defaults on commitments to bank “A”.

changes in how connected core banks are among themselves. It is immediately clear from this comparison that the system within the core was, before regulation, completely integrated in terms of exposures, and this remained the case after regulation. We observe that the direction of the exposure reverses in 4 out of 15 pairs, but the fundamental links are similar across time periods. Not all these exposures, however, are part of a cycle, as we explain next.

Figure 15: Counterparty Exposure (GCE) (“core”) Average Pre Reform (2013-2015) and Post Reform (2016-2022)



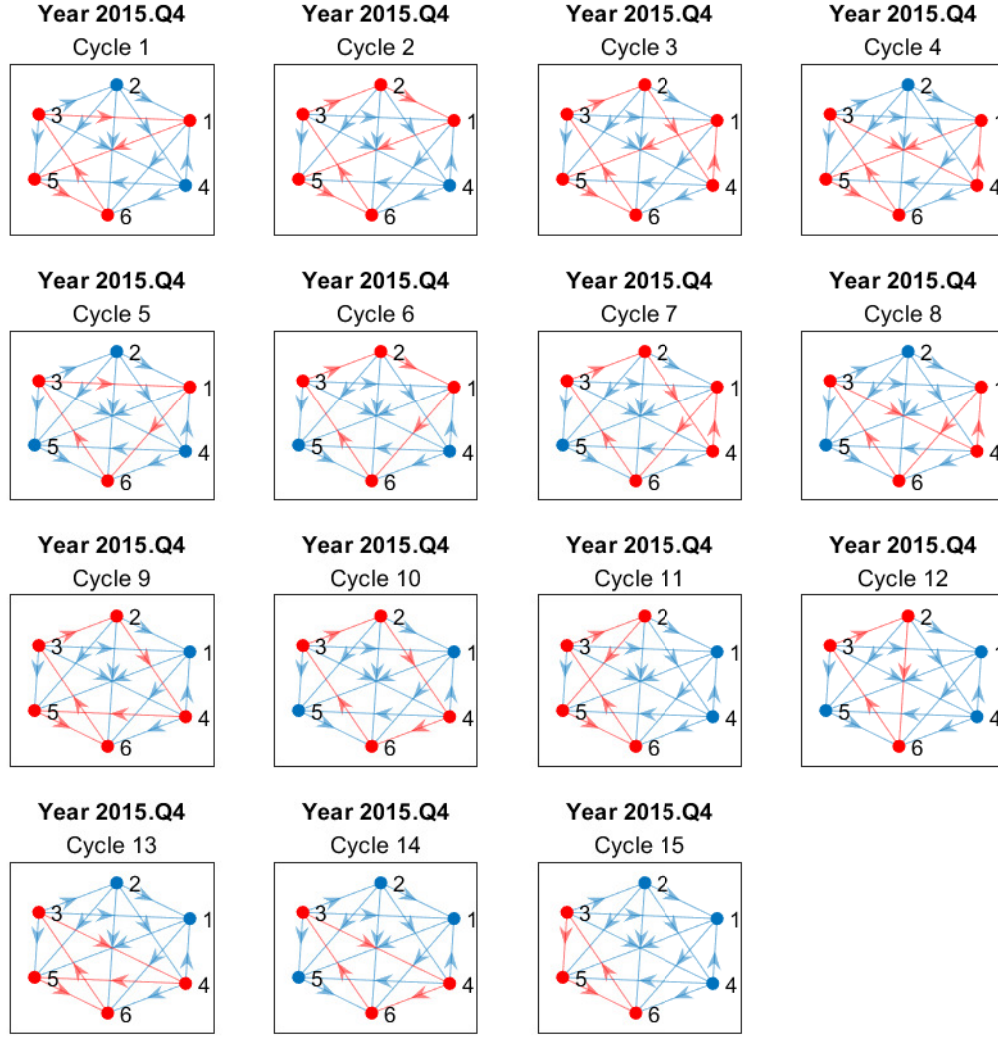
Note: Figures show exposures across core banks (numbered 1-6) of GCE (Gross Credit Exposure). We construct the time series average for each exposure pair conditional on years pre and post reform and present the network based on these average exposures for each period. Direction of arrows $j \rightarrow i$ indicates bank i is exposed to j . Source: BHCs FR Y-14Q Schedule L

We explore further the linkages between core banks, paying particular attention to cycles that are derived from exposures within the core. We also evaluate whether these cycles have changed in the post-reform period. Figure 16 displays all the existing cycles in 2015.Q4 (highlighted in red on top of the base network).⁴⁵ There are 15 cycles, and the average number of nodes in each cycle is approximately 4 banks. Each cycle makes up the root of a directed tree of exposures along the lines of Figure 2. This means, there are 15 different cycles that could trigger coordination failures and cyclic self-fulfilling losses, which can then propagate to other banks. Figure 16 summarizes all the different paths a lack of payment can flow through the system in a self-confirming fashion.

Figure 17 depicts all the cycles that existed four years later, during 2019.Q4 (the quarter prior to the beginning of the pandemic). In 2019.Q4, there were 6 cycles, also with an average number of nodes in each cycle of approximately 4 banks. In this quarter, for instance, Bank 2 is not exposed to any other bank (this can be seen as there are no arrows coming into Bank

⁴⁵As in the previous picture, disclosure limitations prevent us from showing the intensity of the exposures between banks.

Figure 16: Cycles Banking Network 2015.Q4

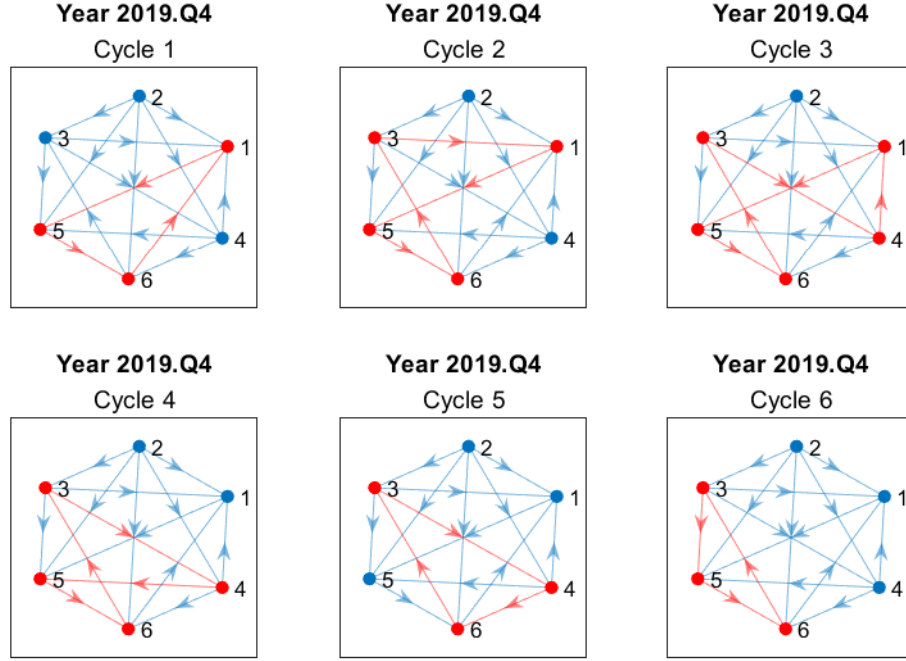


Note: Each panel shows exposures across core banks (numbered 1-6) of GCE (Gross Credit Exposure). Links highlighted in each panel correspond to a given cycle. Direction of arrows $j \rightarrow i$ indicates bank i is exposed to j . Source: BHCs FR Y-14Q Schedule L

2).⁴⁶ That is, Bank 2 is neither a part of a cycle nor exposed indirectly to a cycle along the lines of Figure 2. This observation is relevant because it implies that in 2019.Q4, a complete coordination failure involving a self-fulfilling default of *all* banks was not possible. However, there is the possibility of a coordination failure involving five of them. We could identify the probability that a specific subset of banks defaults by extending our theory to the subnetwork of exposures among the specific subset of banks. Still, as we will see, it is quite informative that in most periods all banks seem to be connected to at least one cycle within the core providing additional evidence in favor of the case where $\delta_{KK} > 0$.

⁴⁶Figure A.8 in the Appendix presents the cycles for the most recent quarter in our sample 2022.Q4 with no additional significant insights. In 2022.Q4 there are 7 cycles with Bank 2 being part of all of them and Bank 6 becoming the bank that is not exposed to other banks.

Figure 17: Cycles Banking Network 2019.Q4



Note: Each panel shows exposures across core banks (numbered 1-6) of GCE (Gross Credit Exposure). Links highlighted in each panel correspond to a given cycle. Direction of arrows $j \rightarrow i$ indicates bank i is exposed to j . Source: BHCs FR Y-14Q Schedule L

Using the cycles depicted in Figure 17 for 2019.Q4 as an example, it is also relevant to note that while Bank 2 is not a node in any cycle, this does not immediately imply that Bank 2 is not relevant from a systemic risk perspective. All other banks are exposed to Bank 2, which may then be a potential source of aggregate risk in and of itself. The idiosyncratic risks of Bank 2 becomes aggregate risks of the other 5 banks, contributing to their coordination failure region. Therefore, a weaker, yet strong enough notion of coordination failures can persist. We explore these in the ideas next.

4.2 Complexity

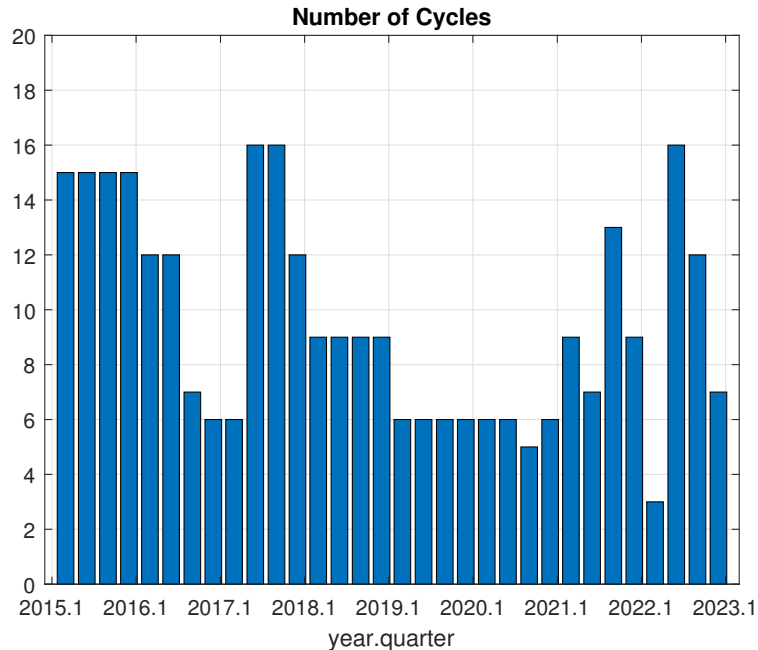
While a broadly applicable measure of cycle-related complexity does not exist, certain indicators can inform us about systemic risk. Our measure accounts for the number of cycles in the network, weighted appropriately by key exposures to reflect their significance.⁴⁷

Number of cycles: Figure 18 presents the number of cycles over time. Given that our theoretical framework allows for arbitrary correlations in shocks, each cycle can potentially be triggered under specific shock combinations affecting its members and their exposures.

⁴⁷In addition to the weighted number of cycles, Figure A.9 in the appendix presents measures based on the number of nodes across the observed cycles. The number of nodes on a cycle can reflect the difficulty of trust and coordination in avoiding cyclic losses, as well as affect the extent and reach of cyclic failures.

Overall, this measure of complexity suggests a slight decline over time, as the number of cycles fluctuates between 12 and 14 in the early periods but narrows to a range of 6 to 8 between 2018 and 2021. However, recent volatility is evident, with the number of cycles ranging between 2 and 16 during 2022. This increased volatility in the number of cycles indicates a potential rise in network complexity and warrants further investigation.

Figure 18: Number of Cycles



Note: Links highlighted in each panel correspond to a given cycle. Source: Consolidated Financial Statements for BHCs FR Y-9C and FR Y-14Q

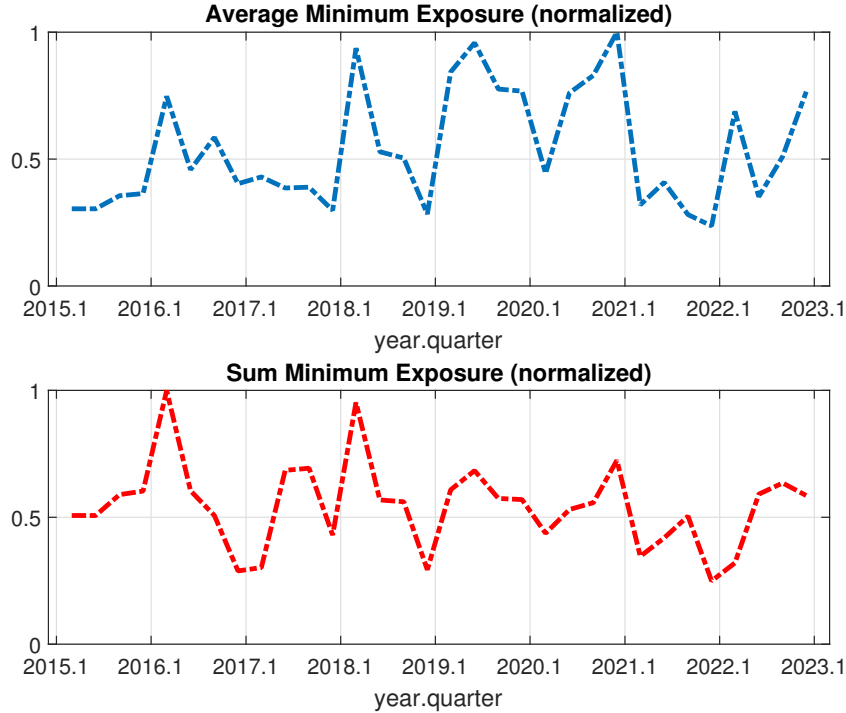
Our theory refines this measure of complexity. It's not just the number of cycles that matters, but also the magnitude of exposures within them. A cyclic failure occurs when the non-payment of a certain amount by one bank to another leads to a chain reaction of defaults within the cycle. This self-fulfilling loss cannot exceed any bilateral obligation in the cycle. For example, if A pays $\$x$ less than its original obligation to B, then possibly B is $\$x$ short and pays $\$x$ less than its obligation to C, then possibly C is $\$x$ short and pays $\$x$ less than its obligation to A, so A is $\$x$ short and pays $\$x$ less than its obligation to B. As we see here, the amount of cyclic loss, $\$x$, cannot exceed any of the obligations along the cycle. Therefore, the minimum exposure along a cycle is an upper bound on the potential cyclic loss.

We utilize the minimum exposure along a cycle as a measure of the riskiness of the cycle. For example, a cycle with a minimal smallest exposure (e.g., one cent) can only trigger a small loss for all banks involved. For this to trigger cascading defaults, each bank must already be on the brink of default with a minuscule shortfall. Such a scenario warrants less attention from a theory of self-fulfilling failures compared to cycles with larger exposures. Therefore, weighting each cycle with the minimum exposure within a cycle provides a more accurate assessment of

the potential risk the cycle poses.

Figure 19 implements this idea by weighting the cycle by the minimum exposure on the cycle in each quarter. For each quarter q and cycle χ , we compute the minimum level of Gross CE exposure. We denote this value as $gce_{\chi,q}^{min}$. We then compute the average as $\overline{gce}_{\chi,q}^{min} = \sum_{\chi} gce_{\chi,q}^{min} / N_q^{\chi}$ where N_q^{χ} is the number of cycles observed in quarter q . In addition, we compute the sum of minimum exposures $Sgce_{\chi,q}^{min} = \sum_{\chi} gce_{\chi,q}^{min}$. Figure 19 presents the average $\overline{gce}_{\chi,q}^{min}$ and the sum $Sgce_{\chi,q}^{min}$ in the top panel and bottom panel, respectively. In both cases, we normalize these measures so the maximum value in the time series equals 1, which happens in 2013.Q2. This figure suggests that, in spite of the fluctuations in the number of cycles, when weighted by the minimum exposure (the relevance of each cycle), either in total or in average, there is not a considerable change over time.

Figure 19: Average and Sum of Minimum Exposures across cycles



Note: The top panel presents $\overline{gce}_{\chi,q}^{min}$ and the bottom panel $Sgce_{\chi,q}^{min}$. We normalize these measures so the maximum value in the time series equals 1. Source: Consolidated Financial Statements for BHCs FR Y-9C and FR Y-14Q

4.3 Centrality

Measures of centrality are used to quantify positions, prevalence, and importance of nodes in networks. In our context, we are interested in measures that reflect the importance of each bank with regard to their contribution to systemic risk. We propose two main measures. The first is related to the frequency with which a given bank is part of a cycle. We call this *involvement*.

The second is related to resilience of each bank to shocks that can trigger cyclic failures. We call this *exposure to the cycles*.

Involvement of banks in cycles. A bank’s contribution to coordination failures depends on its frequency of participation in cycles. Figure 20 presents the fraction of total cycles per quarter in which each bank participates.

Notably, not all banks participate in every cycle, as evidenced by the average of 4 banks per cycle. However, there is heterogeneity in involvement. Some banks, particularly Bank 6 and, to a lesser extent, Bank 3, participate in nearly all cycles. In contrast, Banks 1 and 2 participate less frequently, with Bank 2 absent from any cycles during 2018 and 2019.

This observation is crucial for policy implications regarding cycle analysis. Bank 6, for instance, plays a central role in cycles, exposing it to potential coordination failures originating from shocks to other banks. When a bank is involved in numerous cycles, monitoring its portfolio to ensure resilience against cyclic shocks becomes crucial. Eliminating Bank 6’s exposure would significantly reduce coordination failures across most cycles. Conversely, improving Bank 2’s conditions and reducing its exposure would have a limited impact on mitigating other coordination failure channels.

Therefore, understanding bank involvement in cycles is essential for identifying key players and targeting interventions to effectively reduce systemic risk.

Self-exposures of cycles. As previously discussed, all cycles can potentially generate coordination failures, but their magnitudes differ. The minimum exposure within a cycle determines the maximum cyclic self-fulfilling loss, thus serving as a proxy for the risk posed by the cycle. We can also examine each bank’s contribution to this risk within a cycle.

To identify the bank most reliant on others fulfilling their obligations, we determine the bank holding the minimum exposure in each cycle and attribute this amount as a risk imposed by that bank. A bank frequently holding minimum exposures across cycles is more susceptible to self-fulfilling interbank losses and should be monitored closely as a potential early defaulter in a brewing coordination failure.

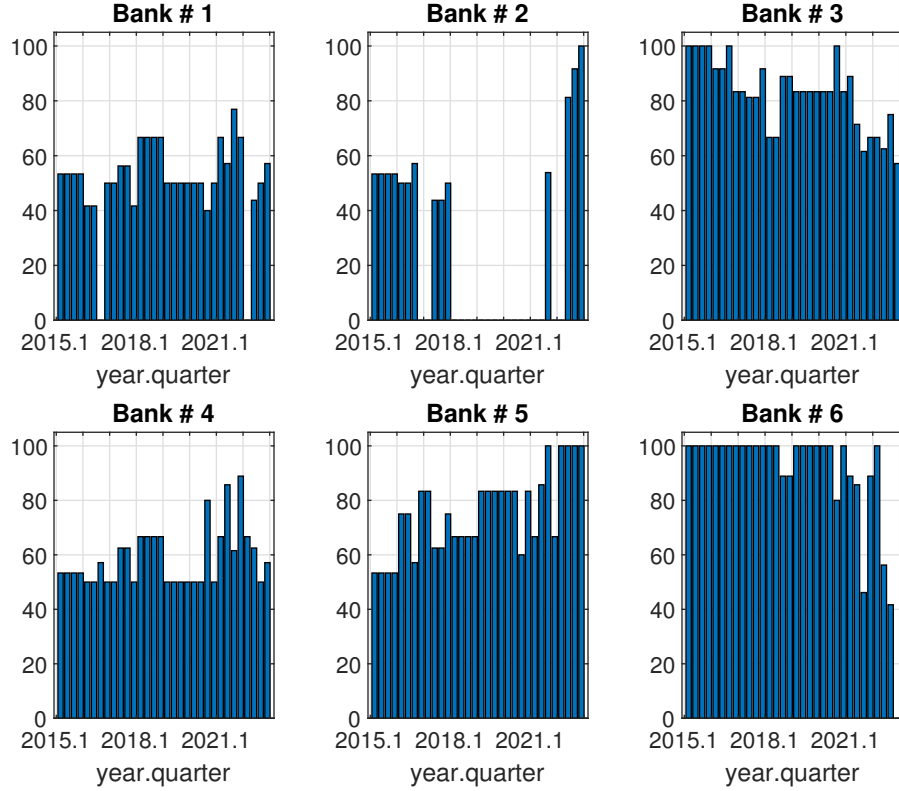
To evaluate the frequency of a bank holding the “key link,” we compute the fraction of cycles per quarter where bank i induces the minimum exposure (i.e., the exposure of bank j to bank i is the minimum within the cycle). Let $\chi \in \chi_q = \{1, \dots, N_q^\chi\}$ denote the set of cycles in quarter q , and $gce_{\chi,q}^{min}$ denote the minimum exposure in cycle χ . For each bank i , we compute:

$$N_{i,q}^{min} = \sum_{\chi \in \chi_q} \mathbb{I}_{\{gce_{\chi,q}^i = gce_{\chi,q}^{min}\}} \times \mathbb{I}_{\{i \in \chi, q\}}$$

, where $gce_{\chi,q}^i$ is the exposure induced by bank i in cycle χ during quarter q . Note that $N_{i,q}^{min} \in \{0, \dots, N_q^\chi\}$.⁴⁸

⁴⁸It can be zero if the bank is not part of any cycle or if it does not induce the minimum exposure in any cycle

Figure 20: Fraction of cycles bank i participates in



Note: Total corresponds to the total number of cycles in a quarter. Number of cycles bank i corresponds to the number of cycles in which bank i is one of the nodes. Source: Consolidated Financial Statements for BHCs FR Y-9C and FR Y-14Q

Figure 21 presents the ratio $N_{i,q}^{min}/N_q^x$ for each bank and quarter, indicating how frequently a bank holds the minimum exposure and thus how reliant its repayment ability is on receiving full interbank assets. Banks 2, 4, and 5 appear robust, participating in few cycles and rarely holding minimum exposures. Conversely, Banks 1, 3, and especially 6 exhibit non-negligible susceptibility to failures.

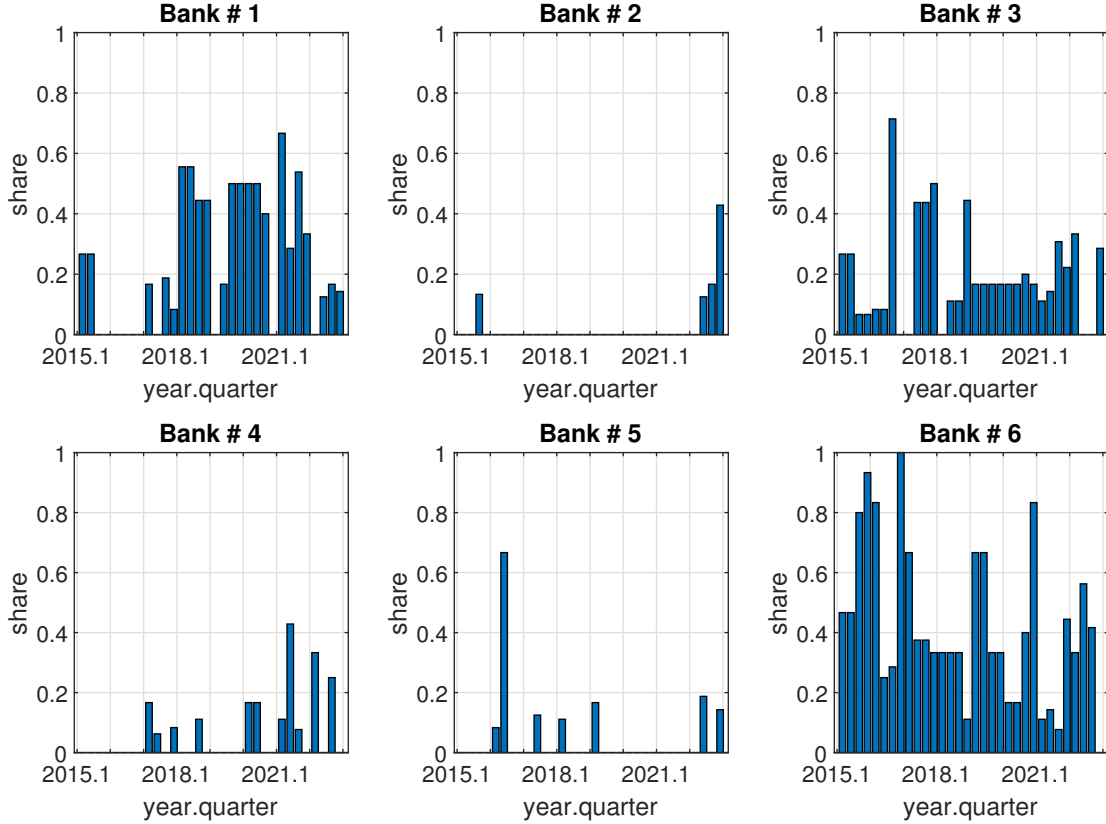
This measure complements the previous analysis on the number of cycles a bank participates in. For example, Bank 6 is central to numerous cycles, implying frequent exposure to coordination failures originating from shocks to other banks. This measure reveals that Bank 6 also often holds the minimum exposure, making it the weakest link in many cycles.

These findings have policy implications. Banks 1, 3, and 6 require close monitoring, not due to their inherent riskiness but because they are the most vulnerable to initial defaults in coordination failures. Strengthening these banks and their portfolios would be crucial in preventing the spread of coordination failures.

Self-Exposures of Cycles to Involved Banks. Finally, we consider instances where a

it belongs to. Conversely, it equals N_q^x if the bank is part of every cycle in quarter q and induces the minimum exposure in all of them.

Figure 21: Share of cycles in which bank i induces minimum exposure



Note: This figure shows $N_{i,q}^{min}/N_q^x$ for each bank. Source: Consolidated Financial Statements for BHCs FR Y-9C and FR Y-14Q

bank holds the minimum exposure in a cycle, weighting this by the magnitude of the exposure. This provides a refined measure for identifying banks requiring close monitoring, combining their likelihood of signaling systemic problems with the size of the potential problem.

For each quarter, we calculate the sum of minimum exposures induced by bank i :

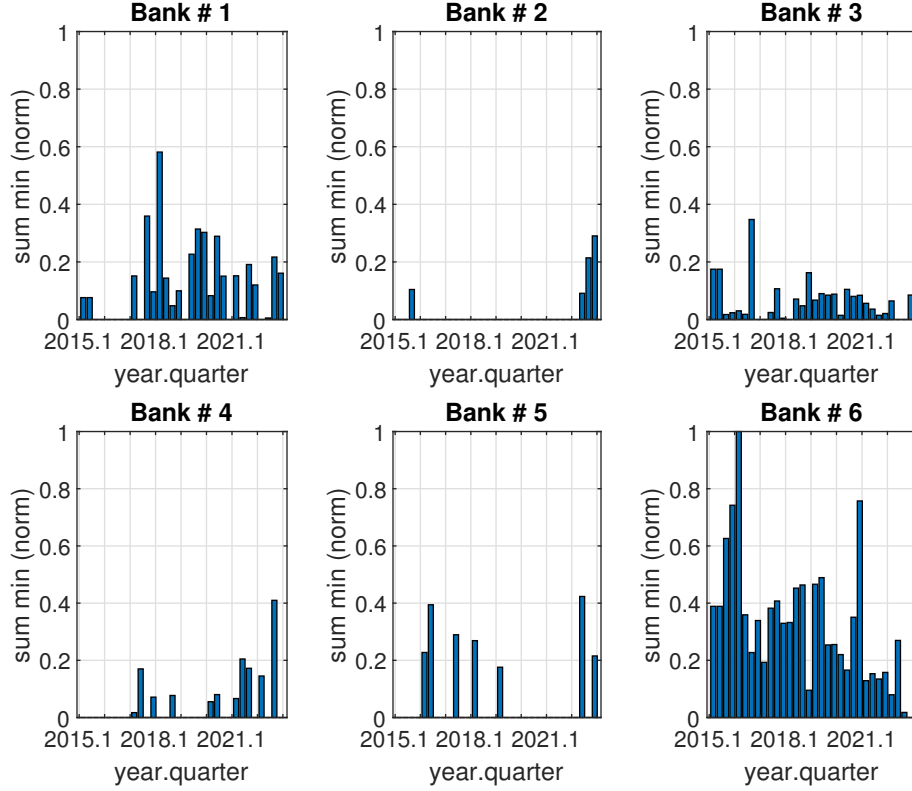
$$Sgce_q^{i,min} = \sum_{\chi \in \chi_q} gce_{\chi,q}^i \times \mathbb{I}_{\{gce_{\chi,q}^i = gce_{\chi,q}^{min}\}} \times \mathbb{I}_{\{i \in \chi,q\}}$$

Figure 22 presents this indicator normalized by the maximum value across banks and quarters. Bank 6 stands out, followed by Bank 1. This measure adds valuable information for policy considerations. Bank 6 is not only exposed to most cycles but also holds the highest exposure in terms of both frequency and magnitude, making it central to the spread of coordination failures.

Conversely, Bank 2 appears irrelevant to coordination cycles, being neither involved nor central. However, this raises a different policy concern. While Bank 2 is unlikely to propagate failures, it could be a trigger and source of failures. Its limited exposure to cycles implies that many other banks are exposed to it. Thus, a shock leading to Bank 2's default could trigger a cascade. Policymakers should not only monitor the resilience of Bank 6 against defaults but

also the health of Bank 2 to prevent it from defaulting.

Figure 22: Normalized sum of minimum exposure by cycle and bank



Note: Figure shows $Sgce_{\chi,q}^{i,min} / \max_{i,q} \{Sgce_{\chi,q}^{i,min}\}$. Source: Consolidated Financial Statements for BHCs FR Y-9C and FR Y-14Q

5 Conclusions

In this paper, we examine the effects of recent regulations promoting central clearing of derivative contracts and offer a cautionary perspective. While these regulations assume that increasing clearing reduces systemic risk, we emphasize that the identity of the clearing parties and the details of clearing patterns are crucial. If multilateral netting is promoted at the expense of bilateral netting due to asymmetric or imbalanced clearing by counterparties, systemic risk may actually rise. Although more clearing may reduce the likelihood crises originate at the core of the system, asymmetric clearing may increase the contagion towards periphery banks.

We present empirical evidence demonstrating asymmetric clearing of derivatives between periphery and core banks in the U.S. over the past decade. While core banks have maintained their relative rate of clearing, periphery banks have increased their clearing. This asymmetric response implies greater exposure to self-fulfilling cyclic failures, and systemic risk may indeed have increased within the banking system.

Theoretically, we propose a ‘dome theory’ of financial crises in which cycles are necessary for

self-fulfilling coordination failures and their propagation through the network. We characterize the anatomy and evolution of cycles within the core, revealing the heterogeneous roles of banks. Some banks serve as potential conduits of contagion, while others are positioned at the source of shocks. Using confidential data, we provide evidence of the empirical relevance of these network properties within the U.S. banking system.

Our findings have several policy implications. First, regulators should monitor not only the extent of multilateral netting through clearing but also the evolution of bilateral netting among banks connected to cycles. Second, supervisors should pay attention to the diverse roles of banks within a cycle. Some banks act as potential conduits for contagion, necessitating robust portfolios to withstand counterparty defaults and break the cycle. Others are potential sources of contagion, requiring measures to minimize their default likelihood.

References

- Gara Afonso and Ricardo Lagos. Trade dynamics in the market for federal funds. *Econometrica*, 83:263 – 313, 2015.
- Julia Lees Allen. Derivatives clearinhouses and systemic risk: A bankruptcy and dodd-frank analysis. *Stanford Law Review*, 64:1079–1108, 2012.
- Haelim Anderson, Selman Erol, and Guillermo Ordonez. Interbank networks in the shadows of the federal reserve act. University of Pennsylvania, Working Paper, 2019.
- Andrew Atkeson, Andrea Eisfeldt, and Pierre-Olivier Weill. Entry and exit in otc derivatives markets. *Econometrica*, 83:2231–2292, 2015.
- Vincent Bignon and Guillaume Vuillemeys. The failure of a clearinghouse: Empirical evidence. *Review of Finance*, Forthcoming, 2019.
- Ricardo J Caballero and Alp Simsek. Fire sales in a model of complexity. *The Journal of Finance*, 68(6):2549–2587, 2013.
- Agostino Capponi, Jessie Wang, and Hongzhong Zhang. Central clearing and the sizing of default funds. Working Paper, Columbia University, 2019.
- Rama Cont and Thomas Kokholm. Central clearing of otc derivatives: bilateral vs multilateral netting. *Risk Management*, 31:3–22, 2014.
- Darrell Duffie. Resolution fo failing central counterparties. In Kenneth Scott Thomas Jackson and John Taylor, editors, *Making Failure Feasible: How Bankruptcy Reform Can End 'Too Big To Fail*. Hoover Institution Press, 2015.
- Darrell Duffie, Nicolae Garleanu, and Lasse Pedersen. Over-the-counter markets. *Econometrica*, 73:1815–1847, 2005.
- Darrell Duffie, Martin Scheicher, and Guillaume Vuillemeys. Central clearing and collateral demand. *Journal of Financial Economics*, 116:237–256, 2015.
- Larry Eisenberg and Thomas H Noe. Systemic risk in financial systems. *Management Science*, 47(2):236–249, 2001.
- Selman Erol and Guillermo Ordonez. Network reactions to banking regulations. *Journal of Monetary Economics*, 89:51–67, 2017.
- Selman Erol and Rakesh Vohra. Network formation and systemic risk. *European Economic Review*, 148:104213, 2022.

- Financial Stability Board FSB. Implementing otc derivatives market reforms. 2010.
- Samim Ghamami and Paul Glasserman. Does otc derivatives reform incentivize central clearing? *Journal of Financial Intermediation*, 32:76–87, 2017.
- Julien Hugonnier, Benjamin Lester, and Pierre-Olivier Weill. Frictional intermediation in over-the-counter markets. *Review of Economic Studies*. Forthcoming., 2019.
- John Chi-Fong Kuong and Vincent Maurin. The design of a central counterparty. *Journal of Financial and Quantitative Analysis*, 59(3):1257–1299, 2024.
- Ricardo Lagos and Guillaume Rocheteau. Liquidity in asset markets with search frictions. *Econometrica*, 77:403–426, 2009.
- Paul McBride. The dodd-frank act and otc derivatives: The impact of mandatory central clearing on the global otc derivatives market. *The International Lawyer*, 44:1077–1122, 2010.
- Mark Paddrik and H Peyton Young. How safe are central counterparties in credit default swap markets? *Mathematics and Financial Economics*, 15(1):41–57, 2021.
- Chester S. Spatt. Designing reliable clearing and settlement systems for enhancing the transparency and stability of derivative markets. *working paper*, 2017.

Appendix

A-1 Regulatory Reforms

In this section, we provide a somewhat more detailed description of the regulatory reforms.⁴⁹ The financial crisis in 2008 triggered a set of reforms aimed at increasing the resiliency of the financial sector. These reforms included changes in capital and liquidity requirements. Of particular importance for our analysis were changes in regulations that focus on reducing counterparty credit risk via increasing central clearing.⁵⁰ These reforms included two key elements:

1. **Restrictions:** Standardized over-the-counter (OTC) derivatives are mandated to be cleared through central counterparties (CCPs).⁵¹
2. **Incentives:** Non-cleared derivatives are subject to higher capital (higher risk-weights) and collateral requirements.⁵²

Most of the final rules were implemented between 2012 and 2015.⁵³ For most of the analysis, and consistent with our reading of the changes in the financial system, we focus on the period that starts in 2015.Q1 as the post-reform period.

Clearing Mandate: Among the new regulations, a key restriction arose from the mandate to clear a particular set of derivatives. The final rules require certain classes of credit default swaps and interest rate swaps to be cleared. The relevant provisions for what derivatives were mandated to be cleared through a CCP are detailed within the Dodd-Frank Act, and enforced by the Commodity Futures Trading Commission (CFTC) and the Securities and Exchange Commission (SEC). In 2012, the CFTC issued final rules to implement the clearing requirement determination under section 723 of the Dodd-Frank Wall Street Reform and Consumer Protection Act. The final rules require certain classes of credit default swaps and interest rate swaps to be cleared by Derivative Clearing Organizations (DCOs) registered with the Commission.^{54'55} It is optional to centrally clear other derivatives such as

⁴⁹See also Ghamami and Glasserman (2017) and the FSB progress reports published since 2010 (<https://www.fsb.org/>).

⁵⁰The initial proposal for reform was made in 2009, when G-20 Leaders agreed that all standardized OTC derivative contracts should be traded on exchanges or electronic trading platforms, where appropriate, and cleared through central counterparties (see FSB (2010)).

⁵¹A centrally cleared derivative contract is defined as “an exposure associated with an outstanding derivative contract that an institution, or an institution that is a clearing member has entered into with a central counterparty (CCP), that is, a transaction that a CCP has accepted.” (see www.federalreserve.gov/reportforms/forms/FR_Y-9C20191231_i.pdf, link last accessed 05/24/2024). In our framework, these are the cleared exposures. Any other derivative contract is called OTC.

⁵²Derivatives cleared through a CCP incur not only the capital charge due to the trade exposure but also a default fund capital charge (on average small).

⁵³The original proposal also included collateral costs for OTC derivatives via margin requirements but those reforms were postponed several times and implemented only recently.

⁵⁴In 2016, the CFTC issued a notice of proposed rulemaking that would require additional interest rate swaps to be cleared by DCOs registered with the Commission.

⁵⁵See CFTC <https://www.cftc.gov/LawRegulation/DoddFrankAct/Rulemakings/ClearingRequirement/index.htm> for a list of the final rules (link last accessed 5/24/2024). The list of required derivatives can be found here <https://www.cftc.gov/sites/default/files/idc/groups/public/@otherif/documents/ifdocs/clearingrequirementcharts.pdf>

currency swaps, commodity swaps, equity swaps, and inflation swaps.⁵⁶

Capital Regulation: Additionally, in order to increase the incentives to clear derivatives, risk-weights for OTC derivatives were set higher than for centrally cleared derivatives. More specifically if, as opposed to being traded over-the-counter, a derivative is centrally cleared, the risk weight of the underlying exposure (e.g., 20%, 50%, or 100%) is replaced with the risk weight of the CCP (2% or 4% based on the conditions of the derivative). OTC derivatives are subject to capital requirements for counterparty credit risk as well as Credit Valuation adjustment (CVA) risk.⁵⁷ One important difference between cleared and non-cleared derivatives is that trades through a CCP incur not only a trade exposure capital charge but also a default fund capital charge. The default fund is a contribution that CCPs require of clearing members so that losses to the clearinghouse from the failure of one member could be mutualized among surviving members (see Ghamami and Glasserman (2017)). The contribution of the default fund to risk-weighted assets is on average small.

Collateral Costs: Both cleared and non-cleared derivatives involve collateral costs through margin requirements. However, CCPs require initial margins for clearing which can be separate from margins between original counterparties. Typically, derivatives that are centrally cleared require larger margin requirements than non-centrally cleared derivatives.⁵⁸

A-2 Data Appendix

A-2.1 Data Sources and Variables

We work primarily with two data sets: (1) the Consolidated Financial Statements for Holding Companies (FR Y-9C) and (2) the Capital Assessments and Stress Testing Data (FR Y-14Q - Schedule L “Trading and Counterparty”). The FR Y-9C is public and collects financial data (balance sheet, income statement, and several other schedules including institution level values of off-balance sheet items) at the bank holding company (BHC) level on a consolidated basis.⁵⁹ Only bank holding com-

⁵⁶By far the largest proportion of activity is in interest rate derivatives. The next largest proportion of activity is in foreign exchange derivatives, followed by credit derivatives.

⁵⁷The default capital charge is intended to cover losses due to default of the counterparty, while the CVA capital charge addresses the potential mark-to-market loss caused by an increase in the credit spread of the counterparty.

⁵⁸While the original Basel Committee proposal included a formal margin requirement for non-centrally cleared derivatives but the introduction of this requirement was only implemented after the pandemic. More specifically, in 2011, the G20 agreed to add margin requirements on non-centrally cleared derivatives. In 2015, the implementation of margin requirements was delayed until 2020 when due to the impact of the pandemic it was delayed an additional year. See BIS (2013) “Margin requirements for non-centrally cleared derivatives” (<https://www.bis.org/publ/bcbs261.htm>) and the versions of the document that followed. Regulatory guidelines require initial margin levels for non-cleared contracts to cover a 99% loss quantile of the netting set over a horizon of 10 days, as opposed to 3 to 5 days for cleared OTC contracts. For variation margin, the full amount necessary to fully collateralize the mark-to-market exposure of the non-centrally cleared derivatives must be exchanged.

⁵⁹The information is used to assess and monitor the financial condition of holding company organizations, which may include parent, bank, and nonbank entities. See https://www.federalreserve.gov/apps/reportingforms/Report/Index/FR_Y-9C for a full description of the data and reporting forms and instructions.

panies (“banks”) with more than \$3 billion in assets are required to report.⁶⁰ This report is published quarterly, on the last calendar day of the quarter.⁶¹ Our second data source, the FR Y-14Q (schedule L), is confidential and used to support supervisory stress testing models and for continuous monitoring by the Federal Reserve.⁶² We gained access to the “Trading and Counterparty” schedule that is submitted by the BHCs subject to supervisory stress tests each quarter.⁶³ Schedule L, which includes key information on counterparty risk, is submitted by banks with significant derivative activity and allows us to construct a consistent time series for 6 reporting banks (most other banks start reporting after 2019 and not at a consistent frequency). These are the largest banks in the U.S. when sorted by assets: J.P. Morgan Chase, Bank of America, Wells Fargo, Citibank, Morgan Stanley, and Goldman Sachs. This is not much of a restriction since derivative activity is highly concentrated. Four banks with the most derivative activity (J.P. Morgan Chase Bank, Bank of America, Citibank, and Goldman Sachs, which are included in our sample) hold 87.4 percent of all bank derivatives (by notional value). We call the six banks for which we construct the full picture of counterparty exposure in our sample “core” banks. We think of core banks as large and interconnected banks that pose systemic risks.

We combine primarily two non-confidential schedules from the FR Y-9C report: schedule HC-R (“Regulatory Capital”) and schedule HC-L (“Derivatives and Off-Balance Items”). Using the schedule HC-R we can obtain estimates of derivative activity by risk-weights. Prior to 2015 it is not possible to distinguish between centrally cleared and non-cleared derivatives. However, since 2015, the report makes a distinction between over-the-counter derivatives and centrally cleared derivatives across asset risk-weights.⁶⁴ This schedule also provides information on the type of derivative contract (e.g. interest rate, foreign exchange and gold, credit) and maturity buckets (e.g. 1 year or less, over one year through five years). Schedule HC-L also provides information on notional amounts by derivative type as well as the gross positive fair value (GPFV) and the gross negative fair value (GNFV). The GPFV corresponds to the total of all contracts with positive value (i.e., derivative receivables) to the bank and represents a key measure of credit exposure (i.e., these are the contracts on which a bank would lose value if the counterparty of a contract defaulted). The GNFV represents a measure of the exposure the bank poses

⁶⁰This asset threshold was implemented in 2018. The reporting threshold was \$150 million before 2006, \$500 million between 2006 and 2015, and \$1 billion between 2015 and 2018.

⁶¹For example, the OCC Quarterly Report on Bank Trading and Derivative Activities is based on the FR-Y9C report. The latest report can be found here: <https://www.occ.gov/publications-and-resources/index-publications-and-resources.html> (link last accessed 5/24/2024).

⁶²More information about FR Y-14Q reporting requirements, instructions and forms can be found at: https://www.federalreserve.gov/apps/reportingforms/Report/Index/FR_Y-14Q.

⁶³Banks that comply with the following requirements submit these regulatory forms: (1) have aggregate trading assets and liabilities of \$50 billion or more, or aggregate trading assets and liabilities equal to 10 percent or more of total consolidated assets, and (2) are not “large and noncomplex firms” under the Board’s capital plan rule. A large and noncomplex firm is a BHC with total consolidated assets of at least \$50 billion but less than \$250 billion, total consolidated nonbank assets of less than \$75 billion, and is not a U.S. globally systemically important bank (GSIB).

⁶⁴When using this split the report uses credit equivalent which adds current credit exposure (sometimes referred to as the replacement cost) plus the potential future exposure over the remaining life of the derivative contract. The current credit exposure is (1) the fair value of the contract when the fair value is positive and (2) zero when the fair value is negative or zero. Bilateral netting agreement between the reporting bank and a counterparty may be taken into consideration.

to its counterparties.

The L schedule from the FR Y-14Q contains 18 sub-schedules and provides unique information about the derivative profile by counterparty as well as aggregated across all counterparties of each reporting bank. We use sub-schedules L1.a, L1.b, L1.c, L1.d, and L1.e for the analysis.⁶⁵ Sub-schedule L1.e provides information at the aggregate level distinguishing between exposures where the counterparty is a CCP and not. Sub-schedule L1.a report Top counterparties comprising 95% of firm Credit Valuation Adjustment (CVA) ranked by CVA, L1.b reports the Top 20 counterparties (for earlier periods) or the Top counterparties comprising 95% of firm stressed CVA for the most recent periods, L1.c and L1.d (available only until 2020.Q1) report the top 20 counterparties ranked by Net (of collateral) Credit Exposure and the Top 20 collateralized counterparties ranked by Gross Credit Exposure, respectively.⁶⁶ Counterparties are not repeated across sub-schedules so aggregating across all of them provides a comprehensive picture.⁶⁷

Possible BHC counterparties include (but are not limited to) other BHCs, financial institutions (domestic and foreign), sovereigns and central counterparties. Designated CCP exposures include both cleared over-the-counter (OTC) derivatives and exchange-traded derivatives. All counterparties have a unique identifier and firms provide the name and type of the counterparty, which allows us to track relationships over time, with information on the industry code (six digit NAICS code), the country of domicile of the counterparty, an internal rating, and (when available) the external rating of the counterparty.⁶⁸ We focus on the network within U.S. counterparties. We document the changes in exposures using mostly Gross Credit Exposure (Gross CE). Gross CE is pre-collateral exposure after bilateral counterparty netting. Sometimes referred to as the replacement cost or current credit exposure, Gross CE is the fair value of a derivative contract when that fair value is positive. Gross CE is zero when the fair value is negative or zero. The reports also include information about Net Credit Exposure (Net CE), which is Gross CE less the value of collateral posted by the counterparty to secure those trades. Only collateral that was actually exchanged is incorporated in the Net CE reporting. This appendix provides more information about this measure and how exposure evolves over time when using Net CE.

Table A.1 presents the key variables we use from each source.

⁶⁵The most recent reports only contain sub-schedules L1.a and L1.b and incorporate a sub-schedule L1.f. See https://www.federalreserve.gov/apps/reportingforms/Report/Index/FR_Y-14Q for the most recent instructions (link last accessed 3/1/2025) .

⁶⁶CVA is the value of credit risk for a particular counterparty.

⁶⁷We discuss the coverage below as some large exposures can have small CVA exposure and not be included in sub-schedules L1a and L1b, which provide the bulk of the exposure data. Changes to the reporting format and variables included affect the construction of the time series for some variables. Sub-schedule L1.e allows us to obtain a comprehensive picture of total CCP exposure.

⁶⁸The reporting requirements by type of counterparty changed over time as the data requirements evolved during the last decade.

Table A.1: Key Variables by Source

Variable		Period	Source
Assets	bhck2170	1981.q2 - today	FR Y-9C
Liabilities	bhck2948	1981.q2 - today	FR Y-9C
Equity	bhck3210	1981.q2 - today	FR Y-9C
Gross Positive Fair Value	bhcke219 + bhcke221 + bhck8733 + bhck8734 + bhck8735 + bhck8736 + bhck8741 + bhck8742 + bhck8743 + bhck8744	2002.q1 - today	FR Y-9C
Gross Negative Fair Value	bhcke220 + bhcke222 + bhck8737 + bhck8738 + bhck8739 + bhck8740 + bhck8745 + bhck8746 + bhck8747 + bhck8748	2002.q1 - today	FR Y-9C
OTC Derivatives (ce) by risk-weight	bhcks542 + bhckh309 bhcks543 bhckhk00 bhckhk01 bhcks544 bhcks545 bhcks546 bhcks547 bhcks548 bhckh309	2015.q1 - today 2015.q1 - today	FR Y-9C FR Y-9C
OTC Derivatives (notional)	bhcks582 + bhcks583 + bhcks584 bhcks585 + bhcks586 + bhcks587 bhcks588 + bhcks589 + bhcks590 bhcks591 + bhcks592 + bhcks593 bhcks594 + bhcks595 + bhcks596 bhcks597 + bhcks598 + bhcks599 bhcks600 + bhcks601 + bhcks602	2015.q1 - today	FR Y-9C
Centrally Cleared Derivatives (ce) by risk-weight	bhcks549 bhcks550 bhcks551 bhcks552 bhcks554 bhcks555 bhcks556 bhcks557	2015.q1 - today 2015.q1 - today	FR Y-9C FR Y-9C
Centrally Cleared Derivatives (notional)	bhcks603 + bhcks604 + bhcks605 bhcks606 + bhcks607 + bhcks608 bhcks609 + bhcks610 + bhcks611 bhcks612 + bhcks613 + bhcks614 bhcks615 + bhcks616 + bhcks617 bhcks618 + bhcks619 + bhcks620 bhcks621 + bhcks622 + bhcks623	2015.q1 - today	FR Y-9C
Subschedule ID	cacvm926	2015.q3 - today	FR Y-14Q
Counterparty Name	cacvm900	2013.q3 - today	FR Y-14Q
Industry Code	cacvr620	2013.q3 - today	FR Y-14Q
Country	cacvm905	2013.q3 - today	FR Y-14Q
Gross Current Exposure (GCE)	cacvm908	2013.q3 - today	FR Y-14Q
Net Current Exposure (NCE)	cacvm912	2013.q3 - today	FR Y-14Q
Credit Valuation Adjustment (CVA)	cacvm916	2013.q3 - today	FR Y-14Q
Default Fund (CCPs)	cacsr554	2015.q3 - today	FR Y-14Q

Table A.2: Summary Statistics

	Source	No Core Banks		Core Banks	
		Mean	Std Dev	Mean	Std Dev
Assets	FR Y-9C	21.00	60.50	1910.00	781.00
Liabilities/Assets	FR Y-9C	88.55	5.54	90.21	1.27
Equity/Assets	FR Y-9C	11.37	5.51	9.72	1.28
Gross Positive Fair Value / Assets (ce)	FR Y-9C	0.55	5.76	30.05	23.17
Gross Negative Fair Value / Assets (ce)	FR Y-9C	0.52	5.81	28.92	21.96
Centrally Cleared Contracts / Assets (ce)	FR Y-9C	0.16	1.69	4.78	2.51
OTC Contracts / Assets (ce)	FR Y-9C	0.41	2.20	9.66	5.64
All Contracts / Assets (ce)	FR Y-9C	0.56	3.74	14.45	7.79
Ratio Centrally Cleared / Total Contracts (ce)	FR Y-9C	9.37	22.34	34.25	7.46
Centrally Cleared Contracts / Assets (notional)	FR Y-9C	44.13	727.50	1550.51	884.64
OTC Contracts / Assets (notional)	FR Y-9C	53.07	483.10	1294.69	740.78
All Contracts / Assets (notional)	FR Y-9C	96.55	1000.50	2845.2	1459.05
Ratio Centrally Cleared / Total Contracts (notional)	FR Y-9C	10.89	23.90	54.31	11.21
Interest Rate Contracts / Assets (notional)	FR Y-9C	87.21	988.40	2257.01	1193.37
Foreign Exchange Rate and Gold Contracts / Assets (notional)	FR Y-9C	5.39	50.55	361.31	194.76
Equity Contracts / Assets (notional)	FR Y-9C	2.77	30.82	127.72	91.62
Credit Contracts / Assets (notional)	FR Y-9C	0.46	4.95	73.81	52.44
All Other Contracts / Assets (notional)	FR Y-9C	1.63	26.66	25.34	15.57
Centrally Cleared Contracts / Assets (gross ce)	FR Y-14Q	-	-	0.20	0.23
All Contracts / Assets (gross ce)	FR Y-14Q	-	-	1.26	0.75
Centrally Cleared Contracts / Assets (net ce)	FR Y-14Q	-	-	0.79	0.92
All Contracts / Assets (net ce)	FR Y-14Q	-	-	1.28	1.05
# obs.		15,430		192	
# banks		792		6	
Sample Period		2015-2022		2015-2022	

Note: All ratios reported in percent (%). “(ce)” denotes variable reported using credit equivalent as defined in FR Y-9C, “(notional)” denotes variable reported using notional value of the contract as defined in FR Y-9C, “(gross ce)” and “(net ce)” correspond to variable reported using gross and net credit equivalent as defined in FR Y-14Q. Source: FR Y-9C and FR Y-14Q

Figure A.1 presents the time series of aggregate notional amounts and credit equivalents of derivative contracts that are centrally cleared.

Figure A.2 presents the share of centrally cleared derivative contracts when exposure is measured using notional amounts. Panel (i) shows the evolution over time of this share for core banks and Panel (ii) the evolution of the same share but conditional on the type of derivative contract.

Figure A.3 presents a comparison between the aggregate levels reported in sub-schedule L1e and the aggregate values from sub-schedules L1a-d. The coverage is significant both for Gross CE and Net CE. It is important to note that sub-schedule L1e provides the aggregate exposure to CCP so this figure shows a lower bound on the coverage of our data when discussing patterns at the counterparty type level.

Figure A.4 shows that the decline in exposure to core banks post 2021.Q1 is associated with an

increase in exposure to non-financial corporations as well as an increase in exposure to nonbank financial institutions. In 2022.Q4 non-financial corporations and nonbank financial institutions account for 40.6% and 9% of total GCE exposures (among U.S. counterparties).

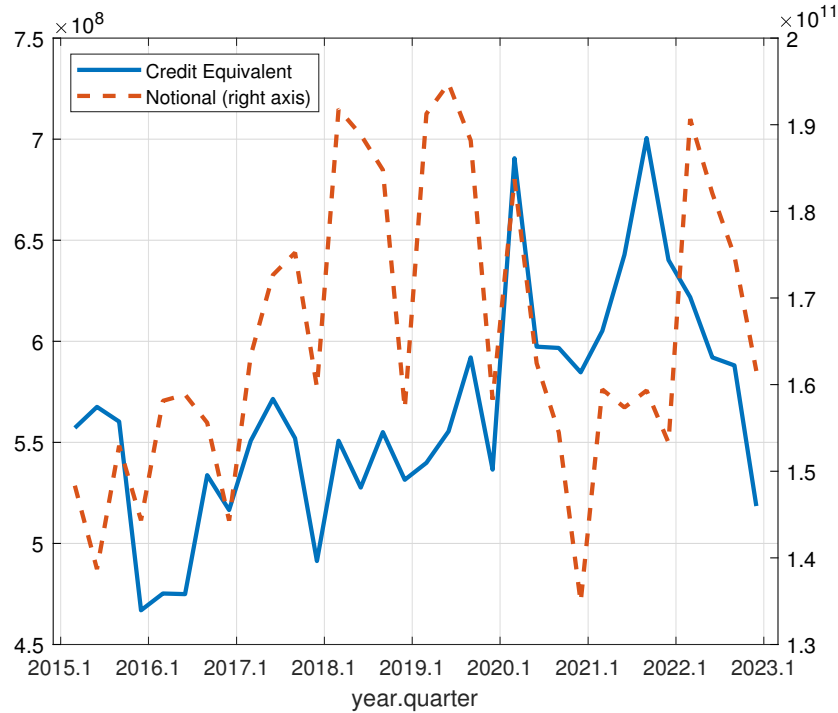
Figure A.5 presents exposure by counterparty types using GCE for all counterparties (U.S. and foreign).

Figure A.6 presents the average exposure for core banks when using Net CE as the measure of exposure.

Figure A.7 presents the coordination failure region (ϕ and $\hat{\phi}'$) by bank. Figure A.8 shows the cycles in the banking network in 2022.Q4.

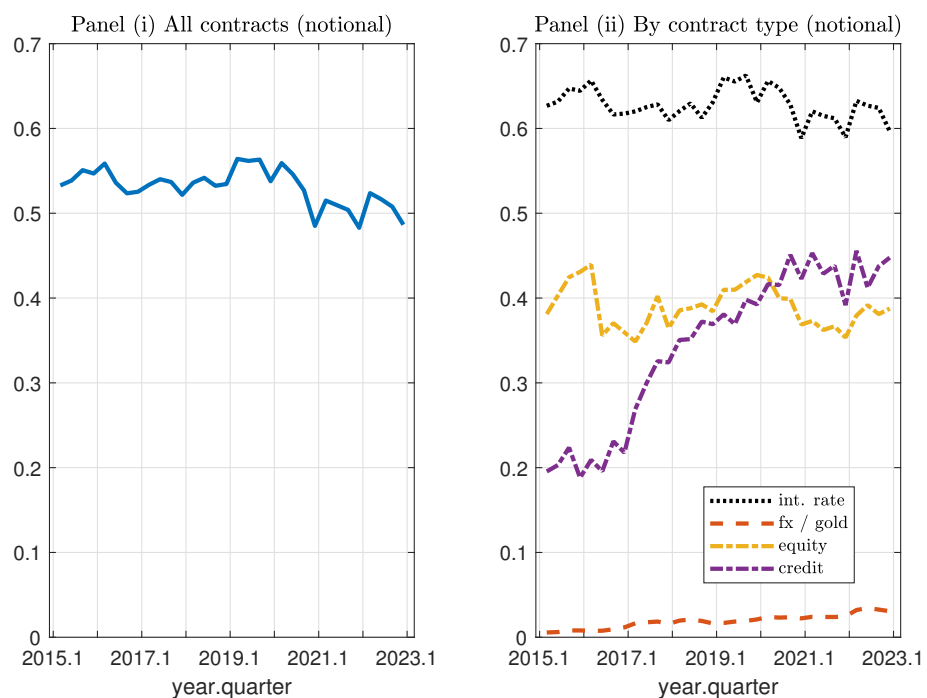
Nodes per cycle: Figure A.9 shows the number of cycles, the minimum number of nodes, the maximum number of nodes, and the average number of nodes involved in a cycle for every period in our sample. This is an important part of the anatomy of cycles when extending the model to efforts to coordinate and avoid the coordination failure. In principle, the more banks are involved in a cycle the harder it is to coordinate and avoid self-fulfilling defaults. As it is clear from the figure, we need at least three banks on a cycle, but in average there are 4 banks involved. This is also the case in which the anatomy of cycles has not changed much in our studied timeframe.

Figure A.1: Aggregate Centrally Cleared Derivatives (all banks in \$000's)



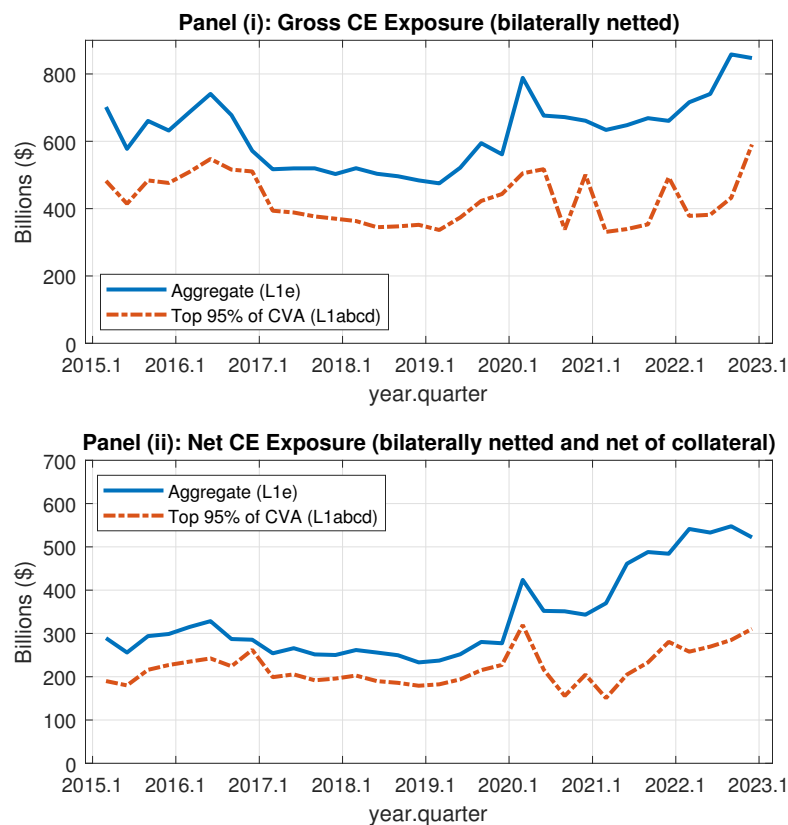
Note: Aggregate amounts of banks reporting in FR Y-9C. Values reported in thousands (\$000's). Source: Consolidated Financial Statements for BHCs (FR Y-9C - HC-R)

Figure A.2: Fraction of Centrally Cleared Derivatives (Notional)
 (core $\bar{s}_t^{cc,C}$ and non-core banks $\bar{s}_t^{cc,NC}$)



Note: Fraction of Centrally Cleared Derivatives corresponds to the asset weighted average of the bank specific ratio of centrally cleared derivatives to total derivatives. Source: Consolidated Financial Statements for BHCs (FR Y-9C - HC-R)

Figure A.3: Comparison L1 Sub-schedules a, b, c, d, e (core banks)

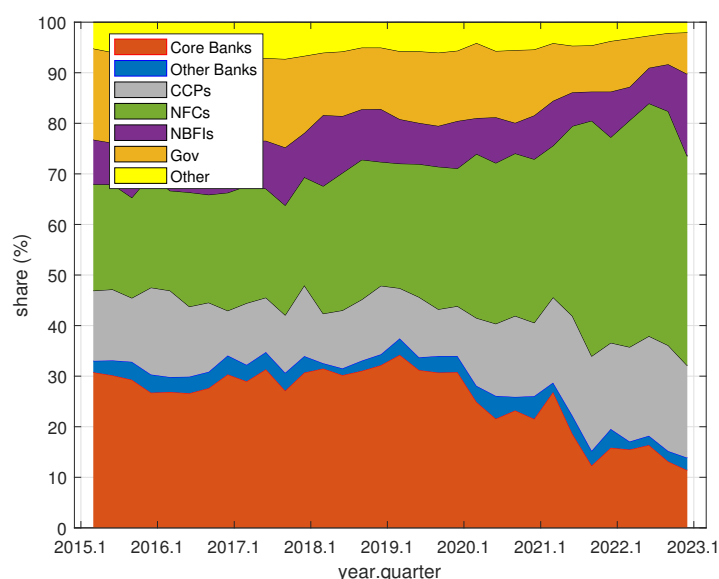


Note: Gross CE corresponds to Gross Credit Exposure and Net CE to Net Credit Exposure. Aggregate (L1e) refers to the totals according to sub-schedule L1e, which reports aggregate data by rating and collateralization.

Top 95% of CVA (L1abcd) correspond to aggregates using sub-schedules L1a, L1b, L1c, L1d, which report exposures by counterparty for counterparties comprising 95% of firm Credit Valuation Adjustment (CVA).

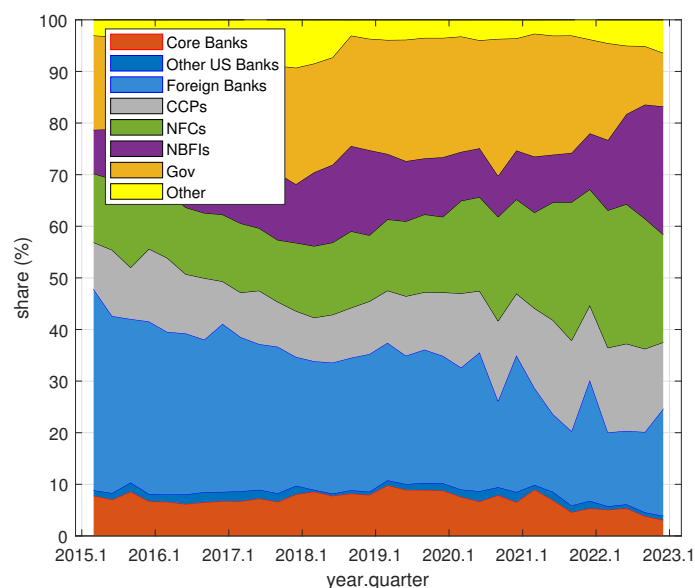
Source: Consolidated Financial Statements for BHCs (FR Y-9C) and BHCs FR Y-14Q (schedule L)

Figure A.4: Counterparty Exposure Gross CE (all U.S. counterparties by type)



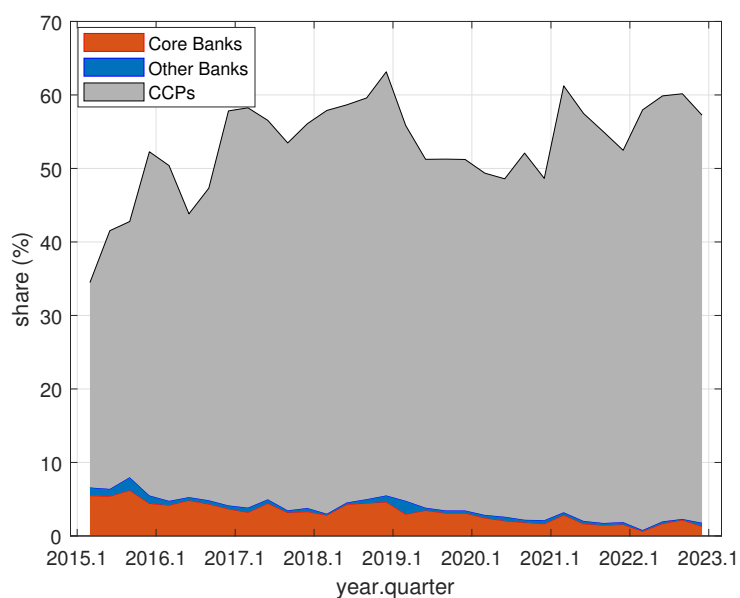
Note: Asset weighted average of bank level GCE. GCE refers to Gross credit exposure (bilaterally netted). Figure presents exposures for US counterparties. “CCPs” corresponds to Central Counterparty, “Other Banks” to other banks not in the “Core Banks” category, “NFCs” corresponds to Non-Financial Corporations, “NBFIs” corresponds to nonbank financial intermediaries and includes insurance companies, pension funds, special purpose vehicles, and other nonbank financial companies, “Gov” refers to government entities, “Other” includes all counterparties not previously classified. Source: Consolidated Financial Statements for BHCs (FR Y-9C) and BHCs FR Y-14Q (schedule L)

Figure A.5: Counterparty Exposure Gross CE (all counterparties by type)



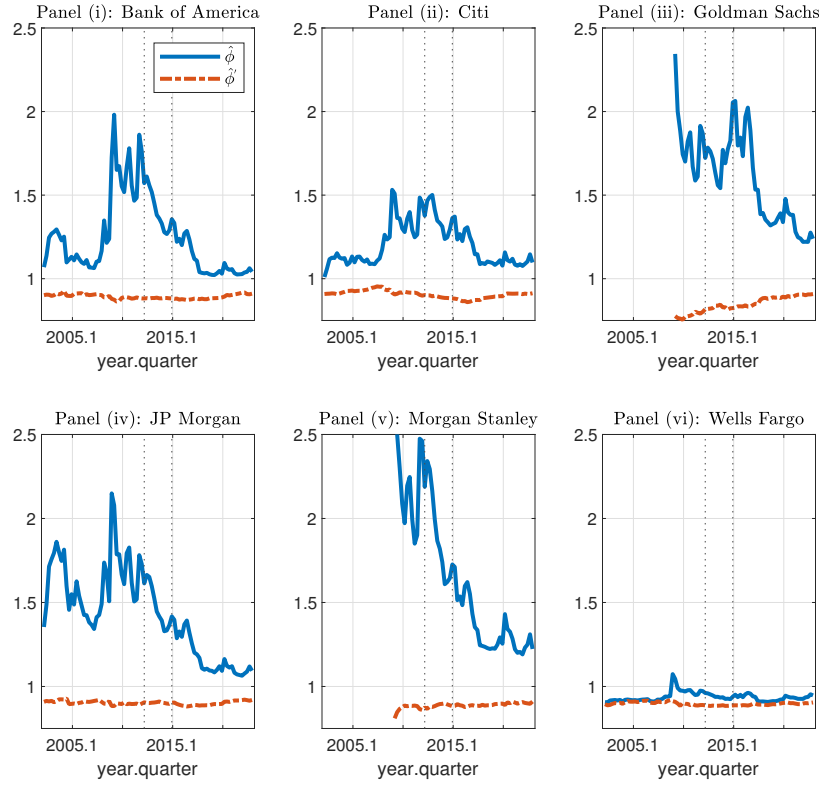
Note: Asset weighted average of bank level GCE. GCE refers to Gross credit exposure (bilaterally netted). Figure presents exposures for all counterparties (i.e., US and Foreign). “CCPs” corresponds to Central Counterparty, “Other US Banks” to other US banks not in the “Core Banks” category, “Foreign Banks” refers to foreign banks, “NFCs” corresponds to Non-Financial Corporations, “NBFIs” corresponds to nonbank financial intermediaries and includes insurance companies, pension funds, special purpose vehicles, and other nonbank financial companies, “Gov” refers to government entities, “Other” includes all counterparties not previously classified. Source: Consolidated Financial Statements for BHCs (FR Y-9C) and BHCs FR Y-14Q (schedule L)

Figure A.6: Counterparty Exposure Net CE (U.S. counterparties by type)



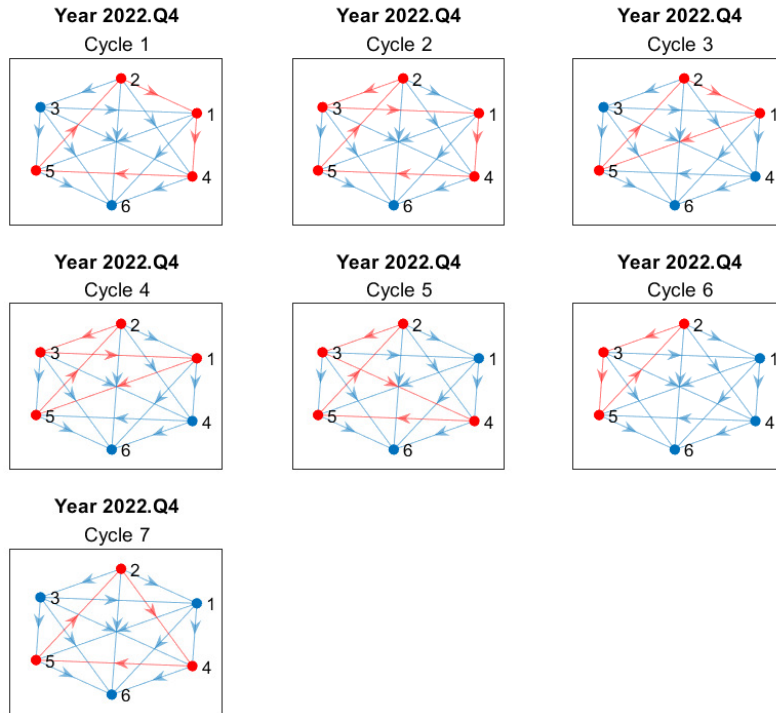
Note: Asset weighted average of bank level Net credit exposure by counterparty type. Net Credit Exposure corresponds to Gross credit exposure (bilaterally netted) net of collateral. Figure presents exposures for US counterparties. “CCPs” corresponds to Central Counterparty, “Core Banks” corresponds to the reporting banks, “Other Banks” to other banks not in the “Core” category. Source: Consolidated Financial Statements for BHCs FR Y-9C and BHCs FR Y-14Q (schedule L)

Figure A.7: Coordination Failure Region (ϕ and $\hat{\phi}'$) by Bank



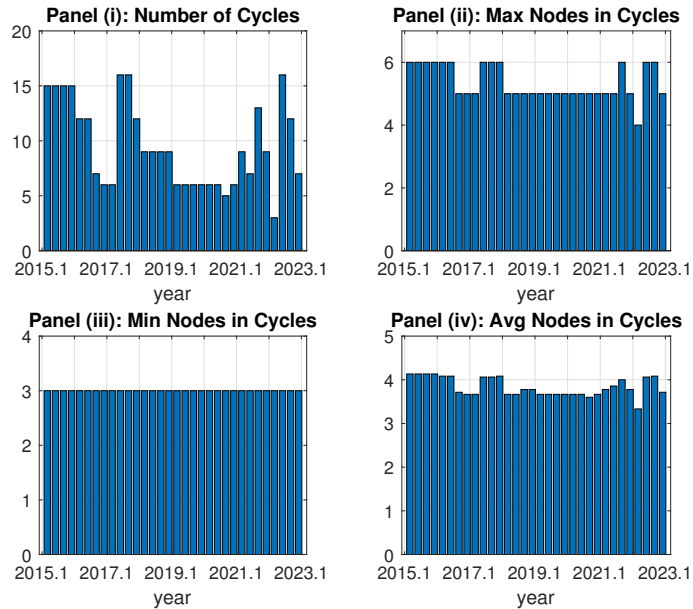
Note: Figure shows $\hat{\phi}$ (see equation 5) and $\hat{\phi}'$ (see equation 6) by bank. Dotted vertical lines correspond to a period of transition after reforms were announced but not yet fully implemented. We define the post-reform period that starts in 2015.Q1 Source: Consolidated Financial Statements for BHCs (FR Y-9C)

Figure A.8: Cycles Banking Network 2022.Q4



Note: Each panel shows exposures across core banks (numbered 1-6) of GCE (Gross Credit Exposure). Links highlighted in each panel correspond to a given cycle. Direction of arrows $j \rightarrow i$ indicates bank i is exposed to j . Source: BHCs FR Y-14Q Schedule L

Figure A.9: Cycles Statistics



Source: BHCs FR Y-14Q

A-3 Theory Appendix

Proofs of Proposition 1, Proposition 2, Theorem 3 follow immediately from the discussions in the main body.

Proof of Theorem 4

In the benchmark of no clearing, we have

$$\begin{aligned} i \in K : D_i &= \sum_{j \in K} \langle D_{ij}^{**} - D_{ji}^{**} \rangle + \sum_{j \in P} \langle D_{ij}^{**} - D_{ji}^{**} \rangle \\ i \in P : D_i &= \sum_{j \in K} \langle D_{ij}^{**} - D_{ji}^{**} \rangle \end{aligned}$$

For $i \in P$, let $X_{ij} \in [0, D_{ji}^{**}]$ be the amount cleared by i from its exposures $E_{ij}^{**} = D_{ji}^{**}$ to j . Then

$$\begin{aligned} i \in K : D'_i &= \sum_{j \in K} \langle D_{ij}^{**} - D_{ji}^{**} \rangle + \sum_{j \in P} \langle (D_{ij}^{**} - X_{ji}) - D_{ji}^{**} \rangle + \langle \sum_{j \in P} X_{ji} \rangle \geq D_i \\ i \in P : D'_i &= \sum_{j \in K} \langle D_{ij}^{**} - (D_{ji}^{**} - X_{ij}) \rangle + \langle \sum_{j \in P} -X_{ij} \rangle \geq D_i \end{aligned}$$

For $i \in K$, equality $D'_i = D_i$ holds iff $X_{ji} \leq D_{ij}^{**} - D_{ji}^{**}$ for all $j \in P$. For $i \in P$, equality $D'_i = D_i$ holds iff $X_{ij} = 0$ for all $j \in K$. So in general, coordination failure region expands strictly unless there is no clearing by the periphery either.

Proof of Proposition 5

If $\delta_{KK} < 0$, all cycles are cleared out. So $\Phi = 0$.

If $\delta_{KK} > 0$, $\delta_{KP} > 0$, $\delta_{PK} > 0$ is the benchmark case of no clearing.

$$\begin{aligned} D_{i \in K}^* &= \sum_{j \in K} \langle D_{ij}^{**} - D_{ji}^{**} \rangle + \sum_{j \in P} \langle D_{ij}^{**} - D_{ji}^{**} \rangle \\ D_{i \in P}^* &= \sum_{j \in K} \langle D_{ij}^{**} - D_{ji}^{**} \rangle \end{aligned}$$

If $\delta_{KK} > 0$, $\delta_{KP} < 0$, $\delta_{PK} < 0$,

$$\begin{aligned} D_{i \in K} &= \sum_{j \in K} \langle D_{ij}^{**} - D_{ji}^{**} \rangle + \langle \sum_{j \in P} D_{ij}^{**} - D_{ji}^{**} \rangle \leq D_{i \in K}^* \\ D_{i \in P} &= \langle \sum_{j \in K} D_{ij}^{**} - D_{ji}^{**} \rangle \leq D_{i \in P}^* \end{aligned}$$

So bank by bank, ϕ_i decreases.

If $\delta_{KK} > 0$, $\delta_{KP} > 0$, $\delta_{PK} < 0$,

$$D_{i \in K} = \sum_{j \in K} \langle D_{ij}^{**} - D_{ji}^{**} \rangle + \sum_{j \in P} \langle -D_{ji}^{**} \rangle + \langle \sum_{j \in P} D_{ij}^{**} \rangle \geq D_{i \in K}^*$$

$$D_{i \in P} = \sum_{j \in K} \langle D_{ij}^{**} \rangle + \langle \sum_{j \in K} -D_{ji}^{**} \rangle \geq D_{i \in P}^*$$

So bank by bank, ϕ_i increases.

If $\delta_{KK} > 0$, $\delta_{KP} < 0$, $\delta_{PK} > 0$,

$$D_{i \in K} = \sum_{j \in K} \langle D_{ij}^{**} - D_{ji}^{**} \rangle + \sum_{j \in P} \langle D_{ij}^{**} \rangle + \langle \sum_{j \in P} -D_{ji}^{**} \rangle \geq D_{i \in K}^*$$

$$D_{i \in P} = \sum_{j \in K} \langle -D_{ji}^{**} \rangle + \langle \sum_{j \in K} D_{ij}^{**} \rangle \geq D_{i \in P}^*$$

So bank by bank, ϕ_i increases.