Regulating Clearing in Networks *

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November 9, 2022

Abstract

Recent regulations in the U.S. and Europe incentivize the use of central counterparty clearing houses (CCP) to clear derivatives, arguably to create a less complex and more transparent interbank network that is less prone to financial instabilities. We construct a network model with endogenous exposures and show that the core and the periphery react asymmetrically to these regulations. The core values opacity more and adopts clearing less. Consequently, bilaterally netted exposures to the core increase. The regulation also makes the CCP more exposed to the core than periphery was pre-regulation. This endogenous network reaction to the regulation creates the unanticipated effect of reducing financial stability through more frequent coordination failures that start at the core and spread to the periphery and the CCP. A novel dataset on U.S. counterparty exposures, before and after the regulations, confirm the model's testable implications.

Keywords: Central Counterparty (CCP), Over-the-counter Trading (OTC), Interbank Networks, Information Transparency, Network Reactions

JEL Classifications: G20, E50, N22

*We thank Chester S. Spatt, Matthew O. Jackson, and the participants at SED 2019 and RINSE 2021. Erol and Ordoñez received support from the NSF through grants 1919351 and 1919029. The views expressed in this paper do not necessarily reflect those of the Federal Reserve Bank of Philadelphia or the Federal Reserve System.

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1 Introduction

The recent global financial crisis had its epicenter at the malfunctioning of derivative markets, most notably credit default swaps (CDS) that were insufficient to cover the wave of potential defaults channeled through a large and complex network of derivative exposures among financial counterparties. This experience motivated the implementation of the Dodd-Frank Wall Street Reform and the Consumer Protection Act, oriented towards putting constraints on the buildup of financial systemic risk and the likelihood of financial crises.

Two of the most salient objectives of these new regulations involved (i) a greater oversight over derivatives transactions, particularly those executed via over-the-counter (OTC) markets (this is, bilateral transactions of non-standard derivatives) and (ii) a greater level of transparency about these transactions. A controversial tool created to tackle both objectives was increasing the risk weights applicable towards computing capital requirements of derivatives transacted in relatively less transparent OTC markets whereas reducing the risk weights applicable to those cleared through a relatively more transparent central counterparty clearing house (CCP). [1] While the average risk weight applied to most derivatives before the new regulations was around 20 percent, after the reform there was an increase to an average of 50 percent for OTC derivates and a reduction to an average of around 3 percent for CCP derivatives.[2]

This new asymmetric regulation, which taxes OTC derivative trading and subsidizes CCP trading has the explicit goal of shrinking OTC trades. But why do financial institutions used to (and still do) rely so much on OTC contracts instead of CCPs? In this paper we construct an endogenous network model of interbank derivative exposures, in which banks value the opacity offered by OTC contracts as it allows for more insurance, but do not internalize their systemic danger via coordination failures. The model then uncovers various topological, stability, and welfare consequences of regulation due to an asymmetric response to regulation between the core and the periphery. Exploiting a novel dataset on the bilateral derivative exposure of bank holding companies in the U.S. financial system, we show that the new regulations were successful on expanding the use of CCPs between bank holding companies and periphery institutions, but not among bank holding companies, which is indeed where the coordination failures are more prevalent and systemic.

In our model, banks house bankers who sign contracts on behalf of their banks. Random pairs of bankers meet and there are gains for them to sign derivative contracts for insurance purposes, because of asymmetric risk positions, for instance. If the derivative contract is observable, the bank "buying" insurance reveals that it holds a riskier asset than the bank "selling" insurance. This revelation may have implications for the bank's funding possibilities if outside investors are less inclined to fund riskier banks (or they are willing to fund it charging a corresponding higher rate). With a transparent contract, the bank in need of insurance faces a *trade-off insurance-funding* that discourages efficient use of insurance in the market. This captures an efficiency gain of opacity: it implements insurance without fear of affecting the allocation of funds in the economy. As long as a derivative traded in OTC markets is more opaque than a derivative traded via CCPs, as argued by regulators, there is an efficiency loss of using CCPs. This view

[1]See BCBS and IOSCO (2015) "Margin requirements for non-centrally-cleared derivatives" Technical report, BIS and OICU-IOSCO, Basel, Switzerland, for a discussion of this regulatory change.

[2]These changes were based on the transaction clearing platform, while more generally risk weights also depend on the transaction counterparty. For instance, sovereign exposures receive risk-weights from 0 to 150 percent (determined by OECD country risk); domestic banks of 20 percent; foreign banks from 20 to 150 percent; and corporate exposures of 100 percent.

indeed rationalizes the scarce use of CCPs previous to the regulatory change.

Facing transparency costs of clearing and the potential failure to secure financing, bankers decide whether to sign insurance contracts, and if they do, they decide whether to clear the contract through a CCP. The aggregation of positions in contracts signed by bankers form the exposures between banks.

These exposures can lead to contagion across banks. As equity is invariant to clearing, we focus on self-fulfilling financial collapse, which we call a coordination failure. To fix ideas about the possibility of coordination failures in the absence of CCPs, take three banks A, B and C, that have developed a network of exposures. Assume that A is a net insurance seller to B, B to C and C to A, all for the same net amounts. If A can not pay B, then B can not pay C, then C can not pay A, then A can not pay B. Coordination failures trigger a self-fulfilling collapse on derivative networks. In the presence of central clearing, however, the implicit multilateral netting through bilateral netting with the CCP eliminates all exposures, and then the possibility of coordination failures disappear – a benefit of central clearing not internalized by banks that rationalizes the new regulation.

Despite its potential to completely eliminate coordination failures if adopted, widespread clearing is practically not mandated. Asymmetric risk weights in capital regulation incentivize clearing. The question is then to identify the effective target of regulation. Are the intended exposures, such as cycles, cleared, or not?

To answer these questions, we use a novel and confidential dataset on derivative exposure by counterparty. This data is reported in BHCs FR Y-14Q filings, a quarterly regulatory collection which supports the Federal Reserve supervisory stress tests, and we consolidate it with other publicly data available from the Bank Holding Companies (BHCs) in the U.S. (Consolidated Financial Statements for BHCs Y-9C).[3] We compare the use of CCPs for derivative transactions before and after the new regulations. Not surprisingly, given the relative reduction in risk weights applied to CCP transactions when computing capital requirements, a higher volume of derivatives were channeled through CCPs. This was, however, not uniformly true within the interbank network. While there was a sizable substitution of OTC transactions for CCP transactions between the core and the periphery, this was not the case among intermediaries at the core, which remain operating through OTC markets in spite of the higher regulatory cost.

This finding suggests that the gains from opacity between core and periphery does not justify paying the extra cost in terms of capital requirements from channeling transactions through OTC contracts. This may be because a bank in the core transacts infrequently with an institution in the periphery, reducing the signal to noise ratio of any individual derivative, or because the volume of those exposures are small enough for such information to be irrelevant for a core bank. The fact that transactions within the core remains OTC, in contrast, suggests that their derivative transactions are more opaque-prone. We also document that transactions within the core are heavily collateralized, orders of magnitude more than between core and periphery. This fact may also justify the extra gains of opacity in terms of information about posted collateral, not a relevant consideration when a core bank transacts with a peripheral institution.

As both the gains from opacity and potential for coordination failures are concentrated in the segment of the market with high frequency and magnitude of connections, such as the core, our empirical findings suggest that regulations may be ineffective exactly in segments of the markets

[3] This data is used for example by the Office of the Comptroller of the Currency (OCC) in their Quarterly Report on Bank Derivatives Activities. See https://www.occ.treas.gov/topics/capital-markets/financial-markets/derivatives/index-derivatives.html

where they are the most relevant.

Going back to our model, the core with high collateral is less constraint by regulation and values opacity more to maintain private insurance benefits. The insurance buyers in the core do not clear their exposures whereas insurance buyers in the periphery do. This asymmetric response reduces bilateral netting between the core and the periphery. In turn, the CCP becomes heavily exposed to the core; more than the corresponding pre-regulation OTC exposures of the periphery to core. Additionally, exposures within the core are unaffected as the core has or can raise sufficient capital to remain unconstrained. Consequently the cycles in the core which are the triggers of coordination failures persist, despite being the most important target for regulation. Additionally, the exposures to the core increase, primarily by transforming the exposures of the periphery into exposures of the CCP on the extensive margin and increasing these exposure on the intensive margin due to relaxed regulation of cleared exposures. The former effect means that coordination failures are not triggered less frequently, highlighting a redundancy of regulation, and the latter means that coordination failures spread more frequently, highlighting an adverse consequence of regulation.

Related Literature:

The aftermath of the financial crisis witnessed the flourishing of a rich literature studying the functioning and the fragility of OTC markets, partly initiated by a search-theoretic approach applied to asset markets, such as Duffie et al. (2005) and Lagos and Rocheteau (2009). Afonso and Lagos (2015), for instance, study the functioning of federal fund markets applying a search model to study how two banks get together and bargain bilaterally. Following this tradition, Atkeson et al. (2015) introduce entry and exit in an OTC derivative markets and study the characteristics of the ensuing network. Even more recently, Hugonnier et al. (2020 and 2022) study the role of heterogeneity and of search and bargaining frictions in these markets. Our main goal is not to understand the intricacies of OTC markets operations but instead the impact of new regulations on those operations.

The imposition of new regulations in the U.S. and Europe trying to reduce the influence of OTC derivative markets through incentivizing the use of CCPs have also induced a renewed literature on their effects.[4] This literature has focused on different relevant aspects. Duffie et al. (2015) discuss how CCPs affect collateral demand in the system (given the heterogeneity of margin requirements), which may have important distributional consequences across intermediaries. Cont and Kokholm (2014) highlight that CCPs may reduce counterparty risk, but at the cost of reducing netting across asset classes. Part of this literature is also concerned about the resolution protocols of CCPs in distress and their potential systemic consequences, such as Duffie (2015), Bignon and Vuillemey (2019), Kuong and Maurin (2021), and Capponi et al. (2019).

Our focus is different. We explore a novel trade off behind regulations that encourage the use of CCPs, and show the current form of regulation is at best redundant. Low CCP risk weights create a tradeoff between bilateral and multilateral netting between the core and the periphery. Transparency makes the core avoid clearing of core-core exposures. The closest to our insight regarding transparency is highlighted in Spatt (2017), who concludes that transparency should consider liquidity needs and should not increase trading costs. This is the precise channel in our paper through which regulation makes itself redundant due to its failure to move core banks to clearing. But we also highlight that the simultaneous "success" in moving the periphery to

[4] A recent legal literature, such as McBride (2010) and Allen (2012), have also studied the effects of CCPs and their regulation.

clearing creates adverse unintended consequences in terms of systemic risk by making the CCP heavily exposed to the core, even in the hypothetical absence of a need to manage and govern CCPs' risks.

The literature on the role of transparency of CCPs, the lack thereof in OTC markets, is however, scarcer. Babus and Kondor (2018) discuss how information flows through the network in OTC markets and how it affects trading, while Glode and Opp (2019) show that OTC markets can be rationalized in spite of larger frictions than centralized markets when traders' expertise is endogenous. In contrast to this literature, here we focus on the transparency of the contracts and its potential to reveal information about traders' types and assets' types. This is more in line with the positive view of opacity highlighted in Dang et al. (2017).

Finally, our paper is also a contribution to the recent literature on the unforeseen effects of government regulations and interventions to financial networks, such as Erol and Ordonez (2017) in terms of capital regulations and Anderson et al. (2019) in terms of public liquidity provision.

Section 2 describes the model. Section 3 lays out details of contagion and coordination failures. Section 4 solves the benchmark economy in the absence of capital requirements. Section 5 introduces capital requirements and solves the general model. Section 6 investigates the effects of regulation on coordination failures through intensive margins and quantifies the efficacy of regulation in mitigation coordination failures. Section 7 focuses on regulation that mimics changes to clearing and transparency brought forth by the Dodd-Frank Act, and highlights adverse stability consequences of the regulation. Section 8 executes a positive welfare analysis. Section 9 is the empirical section. Section 10 concludes.

2 Model

In what follows, we maintain the following notation and exposition choices. All random variables are independent unless noted otherwise. Parametric assumptions made in text are maintained from the point they are stated. Assumptions made inside results only apply to those results. When there is no risk of confusion subscripts and superscripts are dropped to highlight the variables of interest and to reduce clutter.

Agency structure. There is a finite set of *banks*. Each bank's equity is owned by its representative *shareholder*, who can borrow from a representative *creditor* and hold its own *projects*. Each bank houses a mass of *bankers*. Each banker manages one of the projects, and also obtains, through his bank, exclusive access to an *investor* to undertake an *investment* as a joint venture.

Investments are subject to idiosyncratic shock and so insurable, but they are non-pledgeable and so investors and insurance counterparties require collateral. Projects are subject to an *aggregate shock* and so uninsurable, but are pledgeable so can be used as *collateral* by bankers to insure against the shocks to investments. This insurance takes place though *(derivative) insurance contracts* between two bankers of different banks randomly matched. Bankers sign investment and insurance contracts on behalf of their banks. Bankers are compensated as a fraction of the profits they generate for their banks.

A regulator concerned with financial stability enforces *capital requirements* on banks. Banks regulate their bankers' activities via *internal regulation* to ensure regulatory compliance.[5] There

[5]This is typically done by risk divisions of banks. Ensuring regulatory compliance by limiting trader behavior is usually the main task of risk divisions in practice.

is a *central clearing counterparty (CCP)* that *novates* insurance contracts if the insured bankers choose to sign those insurance contracts through CCPs.

Banks and bankers. The set of banks is finite, denoted B. Bank $u \in B$ has μ_u mass of projects and a sufficient mass of bankers. The *caliber* of u is c_u reflecting the potential returns from its projects. The caliber c_u also reflects the scale of *collateral* available to its bankers. For a banker i, b_i denotes i's bank. Banker i has random *quality* $q_i \in \{0,1\}$. The probability of $q_i = 1$, *good* quality, is γ_i.

Projects. The creditor has deep pockets and *lends* to u at a market rate. Each project requires m' lending, which is promised m in return. Each project requires also a banker's management for maturity. For a project managed by banker $i \in u$, the net rate of return to the bank is $(\alpha + \zeta_i)c_u - m$ where $\alpha \sim U[\underline{\alpha}, \overline{\alpha}]$ is the *aggregate shock* to project returns across the economy, $\zeta_i \sim U[-Z, Z]$ is an idiosyncratic shock to returns capturing the effect of i's management,[6] and m is the debt to the creditor. If a project is not managed, it does not mature. The fair value of projects serve as *collateral* for bankers.

Investments. Each banker i has access to an investor, n_i, and an investment opportunity. The investor n_i has 1 unit of funds (perishable for simplicity), or liquid assets, available to invest in one of two options. The first is a self-investment opportunity that pays a random return w_i. The utility is denoted $\omega_i := V_I(w_i)$, called the *outside option* for n_i, where V_I is the investors' utility function. The outside option is assumed to be uniform $\omega_i \sim U[0, \overline{\omega}]$ for some $\overline{\omega} > 0$.[7] The second option is to fund i who accepts funding and channels the funds to his investment all on behalf of the bank. When indifferent, n_i uses his outside option.

If n_i funds i, $s \in (0,1)$ *share* of the investment returns are promised to n_i as the outcome of the joint venture. If financed, i's investment yields a random return depending on the quality of i. We denote the investment *return* $r_i \in \{0, r\}$.[8] The investment succeeds ($r_i = r$) with *success probability* $\sigma_i = \sigma_{i0} + q_i(\sigma_{i1} - \sigma_{i0})$ and fails ($r_i = 0$) with probability $1 - \sigma_i$ where $\sigma_{i1} > \sigma_{i0} > 0$ are constants.[9] This reflects the idea that good bankers monitor markets better and pick better investments than bad bankers. We assume $\omega^* := V_I(sr) < \overline{\omega}$ for simplicity.

Funding and investment contracts are signed on behalf of the bank. Out of returns from investments, $s' < 1 - s$ share is accounted towards the banker i, and the remainder $1 - s - s'$ share is retained by the bank.

Insurance. Each banker has utility function $V_B(x) = x + \theta \min\{\beta, x\}$ where $\theta, \beta > 0$ are constants. This utility function displays global risk aversion around the "*breaking point*" β and local risk neutrality.[10] Risk aversion creates incentives for diversification, up to an extent determined by the *steepness* θ which can also be seen as a measure of risk aversion. Under this utility function, there are potential insurance gains if a banker has less than β return and another banker has more than β. We assume $rs' > 2\beta$ so that returns to two bankers from one

[6]The distribution of ζ_i can have non-zero mean, and it can depend on banker's identity and quality. This would represent quality's impact on management effects and various other banker-specific heterogeneities. We fix the distribution and assume 0 mean only to reduce notation.

[7]The corresponding distribution of w_i has CDF $F_w(w_i) = V_I(w_i)\overline{\omega}^{-1}$ for all $w_i \in [0, V_I^{-1}(\overline{\omega})]$.

[8]This can be generalized without any change to our results. The low return to investment can be positive instead of 0. Both high and low returns on investments can depend on the banker's identity, not only quality. We assume these generalizations away only to reduce notation.

[9]The base success probability σ_{i0} and the improved success probability σ_{i1} are characteristics of the type of investment opportunity that i has access to. Accordingly, these are known by n_i. However n_i knows neither the quality of i nor the unrealized rate of return r_i at the time of funding.

[10]The advantages of this specification to study insurance are discussed by Dang et al. (2017).

successful investment is sufficient to give both β with a suitable insurance contract.

Some pairs of bankers are matched bilaterally for an opportunity to insure each other. The matching protocol is described in Section 4.2.2. The insurance contracts are signed on behalf of the banks and secured by the collateral of the banks. A (*derivative*) *insurance contract* (d_{ij}, d_{ji}) between two bankers i and j is contingent on the outcomes of investments of i and j. The value $d_{ij}(\tilde{r}_i, \tilde{r}_j)$ describes the liability of b_j and the asset of b_i as a function of investment returns $(\tilde{r}_i, \tilde{r}_j)$. A fraction s'' of the final return from the insurance contracts are accounted towards the bankers who signed the contract. The remaining share $1 - s''$ is retained by the bank. If the pair does not have a contract, we denote this with $(d_{ij}, d_{ji}) \equiv \mathbf{0}$. As bankers aim to achieve β but their share from insurance contracts is s'', a banker with no return from his investment would need a payment β/s''. This appear appears frequently throughout the *contracts* so we denote $\kappa = \beta/s''$.

Each banker in a matched pair decides to insure or not. If both bankers decide to insure, they sign an *optimal contract* which is defined as a feasible contract maximizes the sum of the pair's expected utilities subject to individual rationality.

Collateral. Each banker has the capacity to manage at most one project and he must post collateral for his investment contracts and insurance contracts. First, bankers get randomly matched with investors. If a banker can secure *provisional funding* from his investor, the bank borrows m' from the creditor, initiates a project with m', and allocates the project to the banker for management. Then the banker uses the project he manages as collateral, and the funding from the investor is finalized.

But the bank has μ_u mass of projects. Thus the original set of bankers are "served" collateral on a first-come-first-serve basis, up to the mass of projects μ_u. At the background, investors arrive at random times and bankers who receive their investors earlier than others are *early-on-the-line*, with a priority for collateral. Bankers who fail to bring provisional funding from their investors do not receive collateral even if they are early-on-the-line. Bankers can not have insurance contracts without investments. So bankers without (finalized) funding become *inactive*. Bankers that have funding, and so collateral, are called *active*. Inactive bankers are assumed to leave the bank without loss of generality, and we denote an active banker $i \in u$. To save space, a banker refers to an active banker going forward, and so the mass of bankers in u is μ_u. We call the initial large set of bankers in u the *provisional bankers* to clarify the distinction when needed. All of this is simply a mechanical module to discipline the mass of bankers in the bank, similar to an entry condition.[11,12]

Liabilities in each contract must be fully collateralized. The fair value of unposted collateral earns the banker $\xi\theta s''$ utils of private gain per dollar of unposted collateral. We call ξ (normalized opportunity) *cost of collateral*.[13]

CCP and Novation. There is a central clearing counterparty (*CCP* or C) in the economy. A pair of bankers who have signed an insurance contract can *novate* their contract through

[11] The bank does not know the qualities of bankers. But the bank could still prioritize the bankers whose "success distribution" $(\sigma_{i0}, \sigma_{i1})$ FOSD dominates the others. This does not make any change to our results other than adding some notation. We simplify notation by assuming a first-come-first-serve basis.

[12] Alternatively one can take banks to have a sufficient mass of projects and a fixed number of bankers. Results are nearly identical with few differences. The level of financing in the system becomes endogenous and the welfare analysis changes slightly.

[13] The private gains are utils to simplify the contracts. This can be seen as management returns materializing at a different date. See the appendix for a detailed microfoundation which describes ξ in terms of the utility function V_B.

the CCP. Novation means that the contract (d_{ij}, d_{ji}) is replaced with two identical contracts, $(d_{iC}, d_{Ci}) \equiv (d_{ij}, d_{ji})$ between b_i and the CCP, and $(d_{Cj}, d_{jC}) \equiv (d_{ij}, d_{ji})$ between the CCP and b_j. The original contract (d_{ij}, d_{ji}) is annulled. Note that the contracts with the CCP are still contingent on the success of investments of i and j. The CCP does not have investments. The CCP simply inserts itself as the counterparty to both of the original counterparties.

Roughly speaking, when a large number of contracts are novated, the CCP can "clear" complex exposures that would arise across banks simply in its own balance sheet. Hence novated contracts are sometimes called cleared contracts. We use the term *novated* for contracts between bankers and the term *cleared* for *exposures* which are aggregated positions between banks that stem from the novated contracts of bankers signed on behalf of the banks. All contracts are *over-the-counter* (*OTC* or *O*) when signed. If a contract is not novated after signing, we say the contract is *kept OTC*, and we use *OTC exposures* for the corresponding exposures between banks.

Note that the CCP is not a bank. We refer to a *(financial) institution* $f \in B \cup \{C\}$ as either a bank or the CCP. We refer to exposures between all institutions simply with interbank assets and liabilities.

Investor information. Some information about the insurance contracts can be inferred by the market depending on the market microstructure. However, parties to an insurance contract can be aware of the extent of potential inference by the market. The parties can also learn about the underpinnings and the development of the process by which some agents "figure out" the information, before the information starts to diffuse into the market. Accordingly, the counterparties of the contract can revise their insurance decision to conceal the information before it is "leaked."

Formally, after two matched bankers i and j sign a contract, nature determines *signals* $(\iota_{ij}^C, \iota_{ij}^O) \in \{0,1\}^2$ and $(\iota_{ji}^C, \iota_{ji}^O) \in \{0,1\}^2$, capturing the information that can potentially be inferred by investors. The signal ι_{ij}^C is about i's quality if the contract is novated through the CCP and ι_{ji}^C is about i's quality if the contract is kept OTC. In particular, the signal $(\iota_{ij}^C, \iota_{ij}^O)$ is (q_i, q_i) with probability τ_{ij}^O , and $(q_i, 1)$ with probability $\tau_{ij}^C - \tau_{ij}^O > 0$. Otherwise it is $(1, 1)$. Note that the signal can never be $(1, 0)$ capturing the idea that monitoring and transparency attached to novation through a CCP results in superior information discovery for the market. For a given platform $P \in \{C, O\}$, τ^P reflects the level of *transparency* implied by the use of the platform.

The pair i and j both observe $(\iota_{ij}^C, \iota_{ij}^O)$ and $(\iota_{ji}^C, \iota_{ji}^O)$. After observing the signals the pair either novates the contract through the CCP, keeps the contract OTC, or annuls the contract.[14] If the contract is novated, n_i observes $\iota_{ij} = \iota_{ij}^C$. If the contract is kept OTC, n_i observes $\iota_{ij} = \iota_{ij}^O$. If the contract is annulled, or there was no contract to begin with, n_i observes $\iota_{ij} = 1$. We call (the observed signal) ι_{ij} the *investor information* regarding i. The investor n_i does not observe anything regarding j's identity, b_j's identity, or ι_{ji}. Each investor can withdraw his funding

[14]The only role of assuming that bankers observe signals before the market is to rule out bad bankers taking on non-zero early liquidation risk on the path of play, hoping that the signals favor them and misleads investors into maintaining their funding. Yet, such liquidations could have additional costs which we do not model for simplicity. Moreover, incentives to conceal information are prevalent in our model regardless of this assumption, as long as there is market information. This assumption simplifies and unifies an otherwise case-by-case analysis without causing any loss of insight in so far as opacity, transparency, and concealing information are the foci. Another consequence of the assumption is that the level of transparency does not affect the level of financing in the system. This is also desirable as it puts the focus on the effect of transparency on interbank relations without any second order distortions.

without cost after observing his investor information and updating his belief about investment returns. If an investor withdraws his funding, the banker is forced to liquidate his investment early, recover the original investment 1, repay the investor 1, and his insurance contract is annulled if there was one.[15]

We use the term *funding* for initial lending from an investor to a banker. As explained, funding can be withdrawn. Funding that is not withdrawn is called *financing*. A contract that has not been annulled is called *implemented*. If a contract is kept OTC and implemented, we call this *implemented on OTC*. If a contract is novated and implemented we call this *implemented on CCP*.

Payouts absent defaults. Absent defaults, n_i gets paid $r_i s$ or w_i, and achieves utility ω^* or ω_i, depending his choice between financing and the outside option. Denote i^* the realized match of i and p_i the payment i is owed by his bank due to i's activities. If the pair i and i^* have implemented a contract, i gets paid $p_i = s'r_i + s''(d_{ii^*}(r_i, r_{i^*}) - d_{i^*i}(r_{i^*}, r_i))$. If i does not have insurance but has financing, he gets paid $p_i = s'r_i$. If he suffered a withdrawal of funding, $p_i = 0$. His utility net of his management gains is $V_B(p_i)$ less the cost of collateral $\xi\theta s''(r + \max_{(\tilde{r}_i, \tilde{r}_{i^*})}\{d_{i^*i}(\tilde{r}_i^*, \tilde{r}_i)\})$.

The creditor gets paid $m-m'$ per unit of project funded. The shareholder of u retains earnings $(\alpha + \zeta_i)c_u - m + r_i(1-s) - p_i$ integrated over all bankers. The creditor and the shareholder are mechanical parts of the model, so we specify their utility functions only when we study welfare.

Consolidation and netting. Each bank consolidates its on and off-balance sheet positions, accurately up to a yet unrealized aggregate shock. These are projects, investments, liabilities to creditors and investors, and derivative insurance contracts.

Bank u's projects have asset value $\int_u (\alpha + \zeta_i)c_u \mathtt{d}i = \alpha\mu_u c_u$.[16] We denote $A_u = \mu_u c_u$. Then bank u's projects create liability $L'_u = m\mu_u$ to the creditor. The total returns from investments is $R_u = \int_{u_R} r_i \mathtt{d}i$ where u_R is the set of financed bankers in u. The total promised share of return to the investors is $L''_u = sR_u$. These are the *senior liabilities*, adding up to $L_u = L'_u + L''_u$. With some abuse of language, we call $\alpha A_u + R_u$ *senior assets*.

Similar integration identifies interbank assets and liabilities. Denote $i \in u_{Ov}$ if $i \in u$, $i^* \in v$, and the pair implemented a contract on OTC. Then $b_{i^*}//b_i$ must fulfill the payment of $d_{ii^*}(r_i, r_{i^*})//d_{i^*i}(r_{i^*}, r_i)$ directly to $b_i//b_{i^*}$. Denote $i \in u_{Cv}$ if the pair implemented a contract on CCP. Then $b_{i^*}//b_i$ must fulfill the payment of $d_{ii^*}(r_i, r_{i^*})//d_{i^*i}(r_{i^*}, r_i)$ to the CCP, and the CCP must fulfill the payment of the same amount to $b_i//b_{i^*}$. The total expected payment promise to b_i and by b_i are

$$D_{ii^*} = \mathbb{E}_{(\tilde{r}_i, \tilde{r}_i^*)}[d_{ii^*}(\tilde{r}_i, \tilde{r}_{i^*})], \quad D_{i^*i} = \mathbb{E}_{(\tilde{r}_{i^*}, \tilde{r}_i)}[d_{i^*i}(\tilde{r}_{i^*}, \tilde{r}_i)]$$

The gross interbank asset arising out of contracts between their bankers are called *exposures*. The gross *OTC exposure* of u to v is E_{uv} and the gross *cleared exposure* of u to v is E_{uCv}, given by[17]

$$E_{uv} = \int_{O_{uv}} D_{ii^*}\mathtt{d}i, \quad E_{uCv} = \int_{u_{Cv}} D_{ii^*}\mathtt{d}i$$

The gross exposure of u to the CCP is then $E_{uC} = \sum_v E_{uCv}$. The gross exposure of the CCP to u is $E_{Cu} = \sum_v E_{vCu}$. We assume without loss that bankers within the same bank do not get

[15] Insurance contracts are contingent on returns from investments. Hence there can be no execution of the contract if the investment is no more.

[16] Note that ζ_i is not correlated with i's financing.

[17] In fact, $E_{uv} = \int_{u_{Ov}} d_{ii^*}^{r_i r_i^*}\mathtt{d}i$. Under some regularity conditions this is equal to $\int_{u_{Ov}} D_{ii^*}\mathtt{d}i$. We assume such regularity throughout the paper.

matched and so $E_{ff} = E_{fCf} = 0$ for every institution $f \in B \cup \{C\}$.

Institutions can have two sided exposures with each other. Opposing two sided exposures between two given counterparties are eliminated via *bilateral netting* via a master netting agreement between the institutions. Bilateral netting results in *net exposures*: the net exposure of f to f' is

$$E'_{ff'} := \langle E_{ff'} - E_{f'f} \rangle$$

where the notation $\langle \cdot \rangle$ is the positive part of a number:

$$\langle \cdot \rangle = \max\{0, \cdot\}$$

Note that netting does not affect equity as $x_1 - x_2 = \langle x_1 - x_2 \rangle - \langle x_2 - x_1 \rangle$ for any x_1, x_2. Also note that $\min\{E'_{ff'}, E'_{f'f}\} = 0$. This is, after netting, there are no two-sided exposures left in the system.

The collection of these aggregate values with bilaterally netted exposures across all banks is called the *system S:*

$$S = (A_u, R_u, L_u, (E'_{uC}, E'_{Cu}), (E'_{uv})_{v \in B})_{u \in B}$$

Contagion. We follow Acemoglu et al. (2015) and Eisenberg and Noe (2001) for the modality of financial contagion with appropriate additions necessitated by our model. Details and resulting payoffs are described in Section 3.1 but we present a brief summary here. The aggregate shock α alters the value of projects across the economy. Depending on the system and the level of the aggregate shock, a bank may not be able to repay its debt if it receives less return to projects than expected and less assets than it was promised in the interbank system. This forces (late) *liquidation* of projects and investment, as in fire sales, reducing their value to fractions $\lambda_A < 1$ and $\lambda_R < 1$ respectively.[18] Then the bank can become insolvent and so unable to fulfill its interbank liabilities. Defaults cascade in this manner. If a bank defaults, liabilities to the creditor and the investors have the highest seniority. Then comes interbank liabilities. After interbank liabilities, bankers of the defaulting bank get payments as employees. The remaining equity belongs to the shareholder. Within each group of seniority, each agent recovers a payment proportional to its original net asset value.

Regulation. The regulator is concerned with financial stability and enforces capital requirements during the implementation of insurance contracts. Each banker needs to follow internal regulation imposed by his bank that ensures the bank's capital adequacy. We describe capital requirements and the implied internal regulation in Section 5.1. In a nutshell, capital requirements are imposed on the aggregate positions, which is the aggregation of the contracts, and so internal regulation is the "parallel" constraint on the infinitesimal positions created by a banker's contract. Capital requirements are more lenient for cleared exposures than for OTC exposures, which influences bankers' novation decisions through the parallel internal regulation. This way, capital requirements induce banker level constraints that promote novation.

Timing.

Stage 1 - Funding and lending: Investor outside options and banker qualities are drawn. Each banker gets matched with an investor. Each banker observes his investor's outside option. Then investors decide whether to provisionally fund their bankers. Then creditors lend to banks, banks initiate projects, and distribute projects to provisionally funded bankers for management and collateral. Then funding is finalized.

[18]Creditors demand liquidation of investments and investors demand liquidation of projects simultaneously. Creditors and investors can not coordinate.

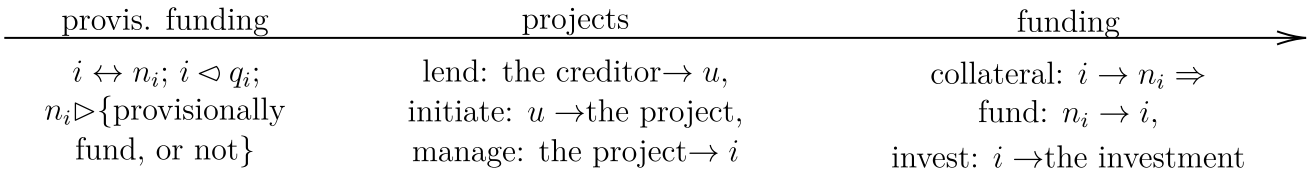


Figure 1: Funding and lending stage

"$\lhd$" indicates observing information. "$\rhd$" indicates choosing an action.

"$\rightarrow$" indicates mechanical components (with possibly trivial incentives at the background).

Stage 2 - Insurance and information: Bankers are matched. Matched bankers observe each others' quality. Then each pair of matched bankers decide to insure or not. If bankers in a pair both decide to insure, they sign an optimal contract. Then nature determines signals, which are observed by the corresponding pairs. Then each pair decides whether to novate their contract, keep it OTC, or annul it. Then investors observe their investor information. Then each investor chooses to withdraw his funds or not. If an investor demands withdrawal, the corresponding banker liquidates the investment, repays the investor, and the banker's insurance contract is annulled. Then financing is finalized and any investor who has not financed his banker uses his outside option.

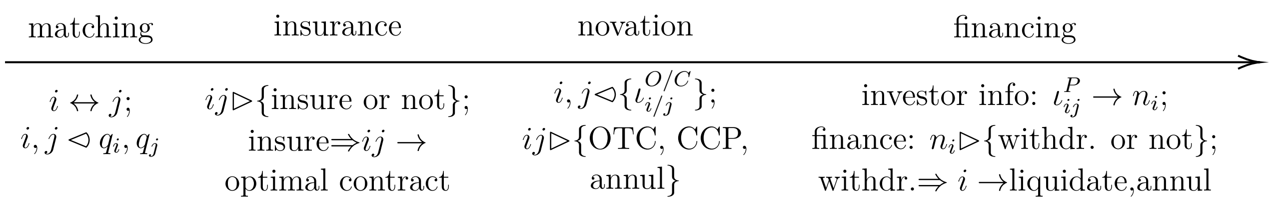


Figure 2: Insurance and information stage

Stage 3 - Consolidation and contagion: Banks consolidate their positions. Then bilateral netting is executed. Then aggregate shock is realized. Then liquidations, maturity, and contagion materialize simultaneously as in Acemoglu et al. (2015) and Eisenberg and Noe (2001). Payments to agents are made as per contractual promises, using seniority and proportional sharing rules.

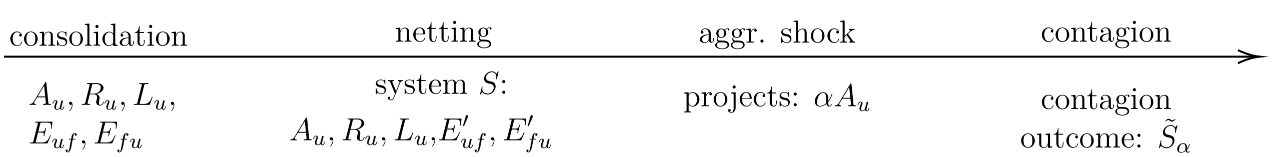


Figure 3: Consolidation and contagion stage

3 Contagion stage and coordination failures

3.1 Model of contagion

Here we revisit Acemoglu et al. (2015) and Eisenberg and Noe (2001), and introduce the modifications we make. Let $E^{\rightarrow}_f$ be total exposures to institution $f \in B \cup \{C\}$ which are the interbank liabilities of f. Similarly, $E_f^{\leftarrow}$ is the total exposures of f which are the interbank assets of f:

$$E_f^{\rightarrow} = \sum_{f' \in B \cup \{C\}} E'_{f'f}, \qquad E_f^{\leftarrow} = \sum_{f' \in B \cup \{C\}} E'_{ff'}$$

Notice $E_C^{\rightarrow} = E_C^{\leftarrow}$ since a novated contract induces the same exposure to and from the CCP. After the consolidation, netting, and the realization of the aggregate shock, absent any defaults, bank u's equity would be given by

$$Q_{u,\alpha} = \alpha A_u + R_u + E_u^{\leftarrow} - L_u - E_u^{\rightarrow}$$

When there are defaults, the recovered assets and returned liabilities can be less than the original amounts. These are determined as a solution to a long system of equations so it is helpful to introduce definitions and notation in an intuitive way first.

The *recovered assets* of u, denoted $\mathrm{RA}_{u,\alpha}$, can be less than the original assets $\alpha A_u + R_u + E_u^{\leftarrow}$ due to liquidations of projects and investments, as well as due to the counterparty defaults that reduce recovered interbank assets. In turn, the *returned liabilities* of u, denoted $\mathrm{RL}_{u,\alpha}$ can be less than the original liabilities $L_u + E_u^{\rightarrow}$ which can push the bank to a *default*. Recovered assets and returned liabilities are determined simultaneously "during" contagion. Accordingly, we define *"intra-contagion" assets and liabilities* (variables with tildes below) through the endogenous *recovery and return rates* (rr). Recovered assets from senior assets after liquidation or maturity are $\tilde{A}_{u,\alpha} = \mathrm{rr}^A_{u,\alpha} A_u$ and $\tilde{R}_{u,\alpha} = \mathrm{rr}^R_{u,\alpha} A_u$. Recovered interbank assets of u are $\tilde{E}'_{uf} = \mathrm{rr}^E_{f,\alpha} E'_{uf}$ and returned interbank liabilities of u are $\tilde{E}'_{fu} = \mathrm{rr}^E_{u,\alpha} E'_{fu}$. The total recovered interbank assets are $\tilde{E}_u^{\leftarrow} = \sum_f \tilde{E}'_{uf}$ and total returned interbank liabilities are $\tilde{E}_u^{\rightarrow} = \sum_f \tilde{E}'_{fu}$. Returned senior liabilities to the creditor and investors are $\tilde{L}_{u,\alpha} = \mathrm{rr}^L_{u,\alpha} L_{u,\alpha}$. Then $\mathrm{RA}_{u,\alpha} = \alpha \tilde{A}_{u,\alpha} + \tilde{R}_{u,\alpha} + \tilde{E}^{\leftarrow}_{u,\alpha}$ and $\mathrm{RL}_{u,\alpha} = \tilde{L}_{u,\alpha} + \tilde{E}^{\rightarrow}_{u,\alpha}$. When there are no defaults, all recovery and return rates are equal to 1.

Defaults are triggered by bad aggregate shocks and low interbank asset recovery. Formally, bank u is said to *default* if

$$0 > Q^{\mathrm{def}}_{u,\alpha} \coloneqq \alpha A_u + R_u + \tilde{E}^{\leftarrow}_{u,\alpha} - L_u - E_u^{\rightarrow} \tag{1}$$

Importantly, the senior assets αA_u and R_u are not liquidated "before" default, reflected by defining default condition in equation (1) with original senior assets $\alpha A_u + R_u$ rather than recovered senior assets $\alpha \tilde{A}_{u,\alpha} + \tilde{R}_u$. It is possible that the original senior assets are larger than original interbank liabilities net of recovered interbank assets, $L_u + E^{\rightarrow}_{u,\alpha} - \tilde{E}^{\leftarrow}_{u,\alpha}$, and the latter is larger than liquidated senior assets. If this is the case, there can be two solutions to the "default condition" of a bank keeping all else fixed. This is, u can default simply because it defaults. This is akin to a bank-run. We aim to study banks defaulting because of each other. We rule out "self-defaults" by defining a default through the maximum payment u can make if it were not to default, rather than through the maximum payment it could make if it were to default. Therefore, we focus on self-fulfilling contagion rather than self-fulfilling bank-runs. In future work, we study the interactions between the two using the tractability of our model.

The default condition uses the original values of liabilities and all assets other than interbank assets. It is assumed that liabilities are not renegotiated in response to contagion. The exposures are already bilaterally netted and $\min\{E'_{uv}, E'_{vu}\} = 0$, and so a pair of banks can not further reduce their default probability by further bilateral arrangements without involving other banks. Also note that failure to fulfill payments to employed bankers do not cause default as bankers are *internal agents* of the bank. Only failure to repay *external liabilities* $L_u + E_u^{\rightarrow}$ to *external agents* result in default.

Defaulting banks are forced to liquidate their projects and investments before maturity, reducing their price to fractions λ_A and λ_R.

$$(\mathrm{rr}^A_{u,\alpha}, \mathrm{rr}^R_{u,\alpha}) = \begin{cases} (1,1) & \text{if } u \text{ does not default } (Q^{\mathrm{def}}_{u,\alpha} \geq 0) \\ (\lambda_A, \lambda_R) & \text{if } u \text{ defaults } (Q^{\mathrm{def}}_{u,\alpha} < 0) \end{cases}$$

As investors and ex-ante creditors have seniority over other agents, they are paid first, up to the total assets:

$$\tilde{L}_{u,\alpha} = \min \{L_u, \mathrm{RA}_{u,\alpha}\}$$

Out of this aggregated amount $\tilde{L}_{u,\alpha}$, each investor and ex-ante creditor gets proportional payments: $\mathrm{rr}^L_{u,\alpha}$ fraction of the original liability. In particular, n_i is owed $r_i s$ and gets payment $\mathrm{rr}^L_{u,\alpha} r_i s$.

Institutions are second in seniority, and pay each other proportional to how much each is owed up to their remaining funds:

$$\mathrm{rr}^E_{u,\alpha} = \min \left\{ 1, \frac{\mathrm{RA}_{u,\alpha} - \tilde{L}_{u,\alpha}}{E_u^{\rightarrow}} \right\}, \qquad \mathrm{rr}^E_{C,\alpha} = \frac{\tilde{E}^{\leftarrow}_{C,\alpha}}{E^{\leftarrow}_{C,\alpha}}$$

(Note $\tilde{E}_C^{\rightarrow} = \tilde{E}_C^{\leftarrow}$.) After these more senior liabilities are fulfilled (perhaps partially), the bank has $\mathrm{RA}_{u,\alpha} - \mathrm{RL}_{u,\alpha}$. Bankers as employees have contracts with the bank, with less seniority than external agents, and with "more seniority" than the shareholders. Bankers are distributed the amounts promised to them $R_u s' + (E_u^{\leftarrow} - E_u^{\rightarrow})s''$, up to the remaining funds in the bank $\mathrm{RA}_{u,\alpha} - \mathrm{RL}_{u,\alpha}$, and each banker gets a proportional share. So the banker i gets paid $p_i \min\{1, \frac{\mathrm{RA}_{u,\alpha} - \mathrm{RL}_{u,\alpha}}{R_u s' + (E_u^{\leftarrow} - E_u^{\rightarrow})s''}\}$. What remains is the equity of the bank.

In principle, the CCP and the banks can have different seniorities. The CCP can follow a non-proportional sharing rule. Shareholders and bankers can have same or different seniorities. As it will become clear later, these are not consequential in our model as only investors and ex-ante creditors receive positive payments from a bank when the bank defaults.

This completes the description of the contagion. Given the system S and a shock α on S, for a solution to the system above, the resulting vector of corresponding components of the system is called a *contagion outcome*:

$$\tilde{S}_\alpha = (\tilde{A}_{u,\alpha}, \tilde{R}_{u,\alpha}, \tilde{L}_{u,\alpha}, (\tilde{E}'_{uC,\alpha}, \tilde{E}'_{Cu,\alpha}), (\tilde{E}'_{uv,\alpha})_{v \in B})_{u \in B}$$

3.2 Coordination failures and cycles of exposures

Multilateral netting. Multilateral netting among multiple banks could further reduce OTC exposures across banks. For example, suppose u_1 owes u_2 a dollar, u_2 owes u_3 a dollar, and u_3 owes u_1 a dollar. Bilateral netting does not change these exposures. If all three banks netted these exposures multilaterally among each other, all banks would have had zero exposure as they each owe a dollar and each are owed a dollar. In general, it is not clear what extent of coordination is plausible among a large group of banks. We consider the case wherein banks can not execute any multilateral netting except bilateral. A virtue of a CCP is the implicit multilateral netting. In the previous example, if all the underlying contracts were novated, the outcome would have been each bank owing CCP a dollar and the CCP owing each bank a dollar, in gross terms. After bilateral netting with the CCP, banks and the CCP would end up with zero exposures. That is, bilateral netting with the CCP would implement multilateral netting. In general, after bilaterally netting their exposures with a CCP, each bank ends up with the total exposures that they would have had under multilateral netting as if all banks participated in netting. We call this concept the *clearinghouse effect* of a CCP.

This cycle of exposures and self-fulfilling failures of repayment brings us to coordination failures. As mandated clearing is not enforced, or not enforcable, the regulator uses incentivizes novation through capital requirements. We study the efficacy of regulation in Sections 6 and 7, and discuss welfare implications in Section 8. We start with a formal example of what we mean by a coordination failure.

Example 1. Consider the following hypothetical situation as portrayed in Figure 4. There are three banks u_1, u_2, u_3, and no contracts are novated. Banks have senior assets $\alpha A_u + R_u \equiv 4$ and senior liabilities $L_u \equiv 3$. Exposures are cyclic: $E_{u_2u_1} = E_{u_3u_2} = E_{u_1u_3} = 2$ and $E_{uv} = 0$ otherwise. Suppose that liquidation costs are large enough that $\lambda_A = \lambda_R < 0.75$. If u_3 actually pays 2 to u_1, then u_1 does not liquidate, fulfills senior liabilities $L_{u_1} = 3$, and fulfills interbank liabilities $E_{u_2u_1} = 2$ to u_2, and ends up with equity 1. Cyclically, all banks pay all debt, and all have equity 1. On the other hand, if u_3 pays 0 to u_1, then u_1's assets are 4 and liabilities are 5. Then u_1 is forced to liquidation, and its senior assets lose value down to $4\lambda < 3$. Then u_1 returns $\max\{4\lambda, L_{u_1}\} = 4\lambda$ towards senior liabilities, and has nothing left to pay u_2. Then cyclically, all banks pay 0 to each other and all banks default with 0 equity. We call such a situation a coordination failure which we define formally next. Notice that if all the underlying contracts were novated, banks would have had 0 exposures. The CCP would eliminate cycles of exposures thereby eliminating the possibility of coordination failures.

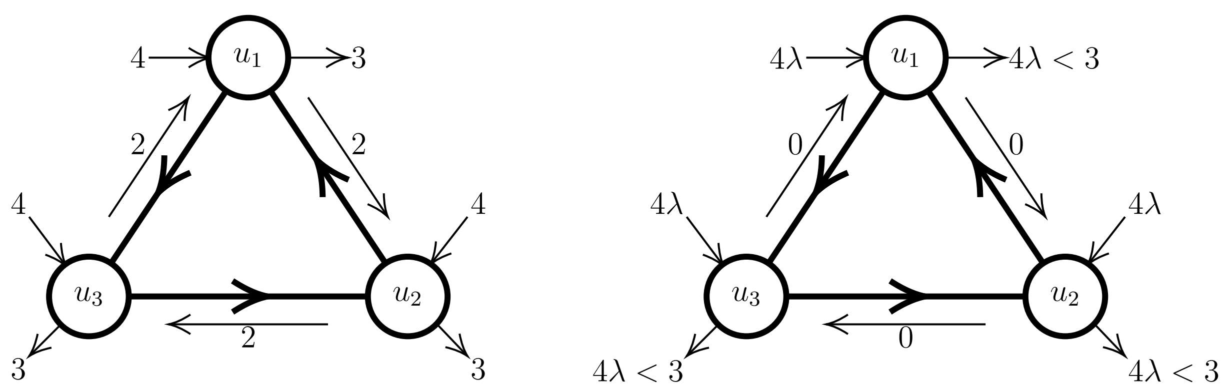


Figure 4: Example 1, a coordination failure

Definition. A system with a realized aggregate shock is said to have a *weak coordination failure* if both of -no bank defaults- and -all banks default- are featured in separate contagion outcomes of the system. In other words, (S, α) has a weak coordination failure if there are two contagion outcomes $\tilde{S}_{\alpha,1}, \tilde{S}_{\alpha,2}$ such that $\tilde{Q}^{\text{def}}_{u,\alpha,1} < 0 \leq \tilde{Q}^{\text{def}}_{u,\alpha,2}$ for all banks u.

When there is a coordination failure, we select the contagion outcome that involves all banks defaulting. Although weak coordination failure is formally the co-existence of no-default and all-default outcomes, we will sometimes refer to the all-default outcome itself as a weak coordination failure, when there is no risk of confusion.

The definition of a weak coordination failure does not immediately appear to imply any specific structure for the network. It rather appears to be about the sizes of exposures. This is not accurate:

Theorem 1. *If there exists a weak coordination failure, then the exposure network has a directed cycle. Moreover, each bank is indirectly exposed to a cycle: the bank is either on a cycle, or exposed to bank on a directed cycle, or exposed to a bank that is exposed to bank on a directed cycle, or exposed to a bank that is exposed to a bank that is exposed to a bank on a directed cycle, and so on.*

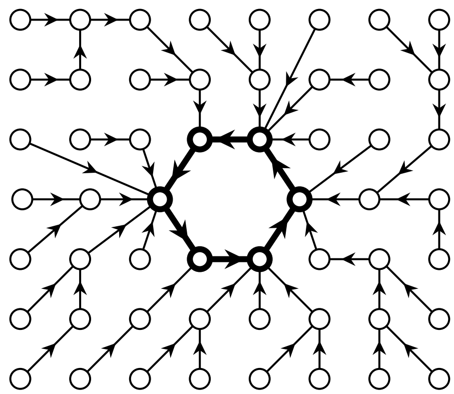


Figure 5: A cycle-rooted tree subgraph. Forest of cycle-rooted trees is a necessary condition for coordination failures.

Figure 5 portrays the topological implication of a coordination failure. All banks must be a on a subnetwork that is a cycle-rooted tree. This result is simple but it illuminates the nature of a coordination failure. Banks along directed cycles default in a jointly-self-fulfilling fashion (as in the earlier example with three banks). Then cascading defaults spread outward from such cycles.

The cyclic clearing effect. This brings us to the netting benefits of CCPs. One may think the netting benefit of a CCP is reducing exposures. But it is not immediately clear why simply clearing exposures is important beyond accounting or regulatory compliance. Equity is invariant to netting. We find that the effect of the CCP on the topology of the network, in particular cycles on the network, is an essential channel through which CCP's netting aspect impacts coordination failures. In order to explain this better, fix a level for the aggregate shock α and consider a directed cycle of exposures $E'_{21}, E'_{32}, ..., E'_{z,z-1}, E'_{1,z} > 0$. Clear an amount x out of all gross exposures $E_{z'+1,z'}$ along the cycle (do not change $E_{z',z'+1}$) through the CCP. The exposures of none of the banks to/from the CCP change as each clears the same amount of exposure to and from itself; $x - x = 0$. Then the net exposures along the cycle have been reduced to $(E_{z'+1,z'} - x) - E_{z',z'+1} = E'_{z'+1,z'} - x$, and everything else has been kept fixed, in particular, the exposure to and from the CCP. We call this *the cyclic clearing effect*, as exemplified in Figure 6. The exposures can be reduced while keeping all else fixed precisely because the banks are along a cycle. Keep clearing exposures along the cycle this way until the cycle breaks at its weakest link $E'_{z'+1,z'} = \min_{z''}\{E_{z''+1,z''}\}$ (mod z). Keep doing this for other cycles as long as there is a cycle on the network. Note that clearing a cycle among banks does create new cycles, except possibly creating cycles that involve the CCP. Then at the end, clear all cycles involving the CCP. Now there are no cycles left in the entire system and there are no coordination failures. Note that this can be done in all possible networks of gross exposures down to the point of completely eliminating cycles and coordination failures.

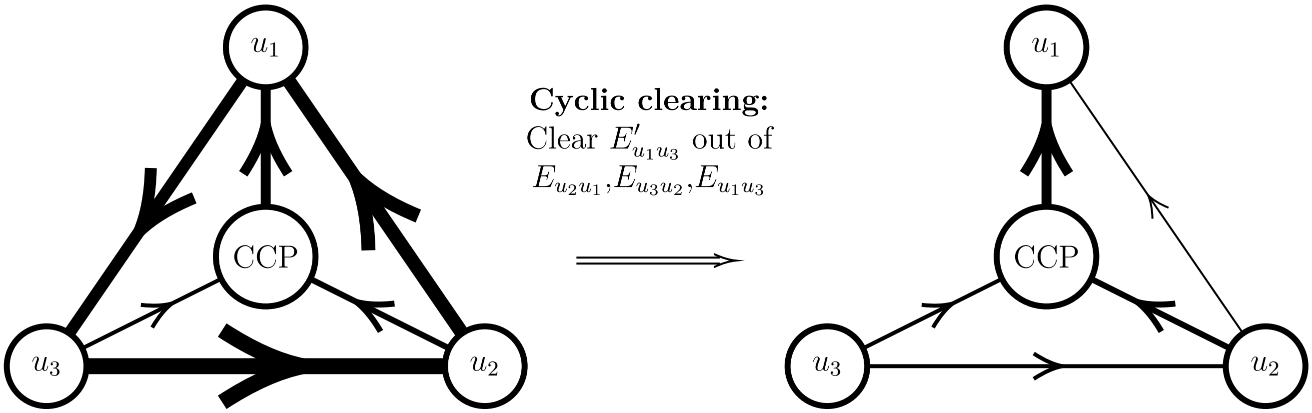


Figure 6: Cyclic clearing reduces net exposures on cycles, keeping all else fixed, including net exposures to/from the CCP

Corollary 1. *If there are no directed cycles in the system (of exposures) then there are no weak coordination failures. If exposures on all directed cycles are iteratively cleared, all weak coordination failures are eliminated.*

In principle a critical set of exposures can be identified and cleared to mitigate weak coordination failures, if at all implementable. One advantage of the cyclic clearing effect compared to targeting individual exposures lies in its feature that relevant exposures are reduced while all else is kept fixed. In particular, the exposures to and from the CCP remain fixed. In our main model the CCP does not have exogenous risks of default and the CCP's default does not result in additional losses such as liquidation costs. The CCP simply serves as a device to provide clearing.

3.3 Simplifications

We are interested primarily in the probability of a self-fulfilling financial collapse: a weak coordination failure. The actual payments made between banks in a weak coordination failure are highly complicated objects to identify in closed form, which also complicate identifying the probability of a coordination failure in closed form. Additionally, banker level incentives underlie the exposures and bankers' payoffs can be equally complicated objects when a bank is close to default but does not default. In this case, the bank can not fulfill all payments to bankers, but this does not mean that the bank defaults as bankers are internal agents. We introduce a few *tricks* to make sure the model has a simple closed form solution. We believe these tricks can be helpful in other models of OTC markets and financial contagion.

Trick for coordination failures. In studying a non-trivial probability of a weak coordination failure and how it reacts to regulation, it is more tractable to work with a refined notion.

Definition. A system with a realized aggregated shock is said to have a *coordination failure* if both of -no banks default- and -all banks default and pay 0 to each other- are featured in separate contagion outcomes of the system. In other words, (S, α) has a coordination failure if there are two contagion outcomes $\tilde{S}_{\alpha,1}, \tilde{S}_{\alpha,2}$ such that $\tilde{Q}^{\text{def}}_{u,\alpha,1} < 0 \leq \tilde{Q}^{\text{def}}_{u,\alpha,2}$ and $\tilde{E}^{\rightarrow}_{u,\alpha,1} = 0$ for all banks u.

The difference between a weak coordination failure and a coordination failure is that in the latter banks make 0 payments to each other. A coordination failure is always a weak coordination failure but not vice-versa. It is easy to identify conditions for a coordination failure:

$$\begin{aligned} E^{\rightarrow}_u > \alpha A_u + R_u - L_u \geq E^{\rightarrow}_u - E^{\leftarrow}_u \\ 0 > \alpha \lambda_A A_u + \lambda_R R_u - L_u \end{aligned} \tag{2}$$

On the left hand side, the first condition with $E^{\rightarrow}_u$ requires that a bank that receives no payments from other institutions defaults. The second condition on the left hand side requires that a bank that receives no payments from other institutions and defaults can not make any payments to other institutions. These make sure that -all banks default and pay 0 to each other- is a contagion outcome. The right hand side means that no banks defaulting is a contagion outcome.

Going forward we assume $\lambda_R < \max\{s\,,\,1 - s'/s''\}$. This is a suitable assumption in that it means liquidation of investments is a risk for the bank as it may turn investments into net liabilities

Proposition 1. *Suppose that S arises endogenously. All weak coordination failures are coordination failures, and vice-versa.*

The maximal interbank liability $E^{\rightarrow}_u$ is formed for insurance against investments, and so it is endogenously smaller than a fraction investment returns. This is, $E^{\rightarrow}_u < R_u \max\{1 - s, s'/s''\}$.[19] Then in an arbitrary contagion outcome where a bank u is on the margin of default with non-default-equity 0 would suffer the discontinuous asset losses at least $(1 - \lambda_R)R_u$ from liquidation, which is larger than the interbank liabilities $E^{\rightarrow}_u$. But interbank liabilities are junior liabilities and so once the default margin is passed, other banks recover 0 from u. This is, any defaulting bank in any contagion outcome makes 0 payment to other banks. (This is a powerful trick that can be used to identify the set of contagion outcomes which we leave to future work.) Therefore, all weak coordination failures are coordination failures. Depending on whether there is a coordination failure or not, interbank recovery and return rates are either all 0 or all 1, and return rates for senior liabilities are $(\text{rr}^L_{u,\alpha})_{u \in B} = \left(\frac{\alpha \lambda_A A_u + \lambda_R R_u}{L_u}\right)_{u \in B}$ or $(1)_{u \in B}$. We can use this to identify the (probability of weak) coordination failures tractably.

Proposition 2. *There exists a (weak) coordination failure if and only if $E^{\rightarrow}_u > \alpha A_u + R_u - L_u \geq E^{\rightarrow}_u - E^{\leftarrow}_u$. Denoting*

$$\begin{aligned} \phi_u &:= \frac{E^{\rightarrow}_u + L_u - R_u}{A_u} \\ \phi'_u &:= \frac{E^{\rightarrow}_u - E^{\leftarrow}_u + L_u - R_u}{A_u} \end{aligned} \tag{3}$$

[19] The exposures are formed by the contracts of bankers. During the contracting stage, banks do not allow the bankers to make insurance promises more than the maximum amount their investments can yield. Then $E^{\rightarrow}_u < (1 - s)R_u$. Additionally, bankers would not promise a contractual payment d such that their return falls below zero, so $ds'' < rs'$. Then $s''E^{\rightarrow}_u < s'R_u$.

the coordination failure cutoffs of bank, there exists a coordination failure if and only if

$$\phi := \min_u \phi_u > \alpha \geq \max_v \phi'_v =: \phi' \tag{4}$$

Denoting $\Phi_u = F_\alpha(\phi_u) - F_\alpha(\phi')$*, the probability of a coordination failure is* $\Phi = \min_u \Phi_u$*.*

The coordination failure cutoffs ϕ and ϕ', and multiplicity of contagion outcomes are portrayed in Figure 7.

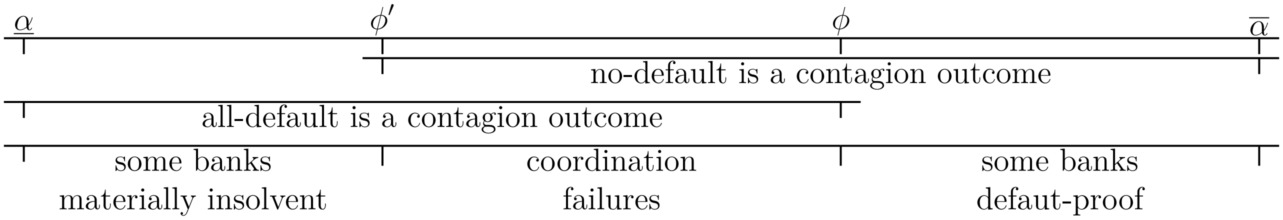


Figure 7: Probability of coordination failures

Normative simplification for lower cutoff. Note that ϕ'_u is invariant to netting so the lower bound on the right hand side of coordination failure condition in inequality (4) is invariant to netting. This makes it an object of less interest for us. Under various parametric restrictions on fundamentals, $\underline{\alpha} \geq \phi'$ in all endogenous systems. If so, $F_\alpha(\phi') = 0$, and we can neglect the heterogeneity in ϕ'_u, which is already invariant to netting. We describe the required assumptions on the fundamentals as we describe the solution of the model, which is not possible before we describe the matching structure. For now, we state this property as a condition which amounts to aggregate shocks that can never be too low, and a bank that receives all interbank payments can fulfill all payments.

Condition 1. Bank u does not default if it receives all interbank payments in any contagion outcome: $\underline{\alpha} A_u + R_u - L_u + E^{\leftarrow}_u - E^{\rightarrow}_u \geq 0$. Equivalently, $\phi'_u < \underline{\alpha}$.

Lemma 1. *The probability that there is a contagion outcome in which all banks default is given by* $F_\alpha(\phi)$*. If Condition (1) holds for all banks,* $\Phi = F_\alpha(\phi)$*.*

We can completely drop Condition (1) and our results would still be about financial stability rather than having a focus on coordination failures. Our results are explicitly about $F_\alpha(\phi)$, which is the probability that all banks default in the worst[20] contagion outcome even if Condition (1) does not hold for some banks. When Condition (1) holds for all banks, we do not need to make a distinction.

When Condition (1) holds for all banks, the aggregate shock poses a risk only through its capacity to enable and trigger coordination failures. The shock itself does not cause any material defaults. If Condition (1) does not hold for any banks, the unique outcome is that all banks default, which are all material defaults outside of boundary coordination failures. If Condition (1) holds for some banks and not others, the latter group always defaults materially, which alters the condition describing material vs. self-fulfilling default for the former group. The set of banks that default in one contagion outcome and not default in another is derived as a fixed point of

[20] Worst equilibrium is well-defined due to supermodularity. See Jackson and Pernoud (2020) for more on multiplicity of equilibria.

a complicated system of equations. The size of this self-fulfillingly defaulting subset of banks and the resulting losses can be very large or very small, which would require taking a normative stance on what extent of losses constitutes financial instability in the context of coordination failures. We study this case in future work and focus on Condition (1), ensuring that no such normative definition is required: banks do not default without a coordination failure, and all banks default in a coordination failure. Following the description of the matching structure in Section 4.2.2, we present the parametric assumption that yields Condition (1). In a nutshell the condition requires sufficiently high interconnectedness in the matching structure that translates into a sufficiently high interconnectedness in the system as well. Until this is formalized in Section 4.2.3 wherein the equilibrium system is identified, we work under Condition (1) for all banks.

Trick for insurance contracts. Another intractability with a complicated contagion model with endogenous exposures is the conditional incentives on the margin of default. When the aggregate shock is below the coordination failure cutoff ϕ, any given bank defaults, its equity hits zero, so there are no payments to bankers to be distributed. If the aggregate shock is well above the cutoff ϕ, the equity is well above the promises to bankers, and all bankers get paid in full. When the aggregate shock is good, but close to the coordination failure cutoff ϕ, banks who are close to the margin of default may be unable to repay all their bankers after fulfilling the external liabilities to investors, to the creditor, and to other institutions. This complicates bankers' incentives by involving very fine details of the network to appear in expected payoffs.

Condition 2. Interbank assets are larger than internal liabilities: $E_u^{\leftarrow} \geq s' R_u + s''(E_u^{\leftarrow} - E_u^{\rightarrow})$.

Lemma 2. *Under a coordination failure, all bankers get* 0 *payment from their banks. If Condition (2) holds for bank u, all bankers of u get full payment from u whenever there is no coordination failure.*

If the aggregate shocks is around the coordination failure cutoff, say reduced from $\phi + \epsilon$ to $\phi - \epsilon$, banks suffer discontinuous losses above and beyond the liquidations. The entire notion of a coordination failure is based on this loss: $E_u^{\leftarrow}$. When the aggregate shock is above the cutoff ϕ, no banks default and they all receive their full interbank assets $E_u^{\leftarrow}$, but just below ϕ, all banks lose all their interbank assets in addition to liquidations they suffer. If these interbank assets are larger than the internal liabilities to the bankers, $s' R_u + s''(E_u^{\leftarrow} - E_u^{\rightarrow})$, then moving α up from the default margin ϕ earns the bank all its interbank liabilities $E_u^{\leftarrow}$, carrying its non-default-equity from at least 0 to at least all its internal liabilities, meaning all bankers can be paid in full. This way, bankers payoffs are simplified to no payment or full payment, depending solely on whether there is a coordination failure or not. Coordination failure probability simply scales bankers' payoffs. Then we can identify the optimal contracts tractably by virtue of also the continuum assumption, which ensures that single pairs of bankers can not influence aggregate outcomes.[21]

Just like Condition (1), we can not state the assumptions on fundamentals that lead to Condition (2) before we introduce the matching structure. We work under Condition (2) until we describe the solution of the model before which we describe the corresponding parametric restriction.

[21]Note that taking the private management benefits of bankers to be in utils does not help in terms of tractability of the solution of the general model. It only simplifies expressions by making sure collateral does not appear directly in contracts. This can be justified simply by the timing of consumption.

We believe that these tricks we introduce can be extremely helpful for models of financial contagion that aim to incorporate endogenous formation of interbank links and study systemic events. These tricks can be applied to a broader set of interactions between banks, not just insurance.

3.4 Co-movement necessity and cyclic clearing necessity

Clearing exposures simply for the sake of reducing exposures does not necessarily reduce the probability of a coordination failure. In fact, it can even increase the probability of a coordination failure.

Proposition 3. *Take two banks banks u, v such that u has gross exposure to v: $E_{uv} > 0$. Consider clearing small amounts of exposures between u and v, with $\varepsilon > 0$ more out of E_{uv} than out of E_{vu}.*

If $E'_{uC}, E'_{vu} > 0$, ϕ_u strictly increases. If $E'_{Cu}, E'_{uv} > 0$, ϕ_u strictly decreases.

If $E'_{Cv}, E'_{vu} > 0$, ϕ_v strictly increases. If $E'_{vC}, E'_{uv} > 0$, ϕ_v strictly decreases.

Otherwise, ϕ_u and ϕ_v do not change.

If bank u has some of its exposures to v cleared, the CCP owes more to u and u is owed less by other banks. This increases the bilaterally netted exposures of other banks to u if they were positive, but the bilaterally netted exposure of CCP to u does not get reduced if it was already 0. In this case, the sum of netted exposures to u strictly increase (E'_{vu}), increasing ϕ_u, which weakly increases the probability of a coordination failure. The change is strict if u has the binding coordination failure cutoff $\phi_u \geq \phi_{u'}$ for all u'. In some sense, there is a *tradeoff between bilateral netting and multilateral netting*, resulting in adverse consequences. Similar logic applies for v. In the case of v, ϕ_v increases because E'_{Cv} increases but E'_{uv} does not get reduced. Notice that these adverse consequences arise out conditions $E'_{Cv}, E'_{vu} > 0$ or $E'_{vu}, E'_{uC} > 0$ reflecting a net exposure direction as a subset of $C \to v \to u \to C$ whereas the cleared exposure is in the opposite direction $u \to v$. The result implies that clearing arbitrary exposures can have adverse consequences particularly when the cleared exposure is in the opposite direction of the net exposures of the banks and the CCP. For beneficial clearing, clearing of gross exposures must result in a net exposure change in the specific direction of bilaterally netted exposure between the pair and the CCP. We call this concept the *co-movement necessity* for clearing. Clearing//novation done in the right direction, the direction of the net exposure, is called *pro-clearing//pro-novation*, and the adverse direction called *counter-clearing//counter-novation*. These are portrayed in Figures 8 and 9. Notice that coordination failure probability is determined by the interbank liabilities of banks, $E_u^{\rightarrow}$. It depends directly on neither the interbank assets, $E_u^{\leftarrow}$, nor the assets and liabilities of the CCP. The relevant net exposures are circled in Figure 8 and irrelevant net exposures are dashed in Figure 9.

The co-movement necessity highlights some key insights for policy. Incentives for novation are ultimately implemented at the contract level and novation takes places soon after undersigning. Conditioning banker-level incentives on the yet-unrealized and often dynamic direction of the netted bank-level exposures which is to be determined after some master netting agreement is executed between two banks requires infeasible levels of foresight and coordination. As novation incentives can not be practically conditioned on the direction of bank-level exposures, the effect of the incentives remain ambiguous for a policymaker. Then the remaining solution is to consider clearing as a systemic endeavor, creating incentives that induce novation broadly in the direction

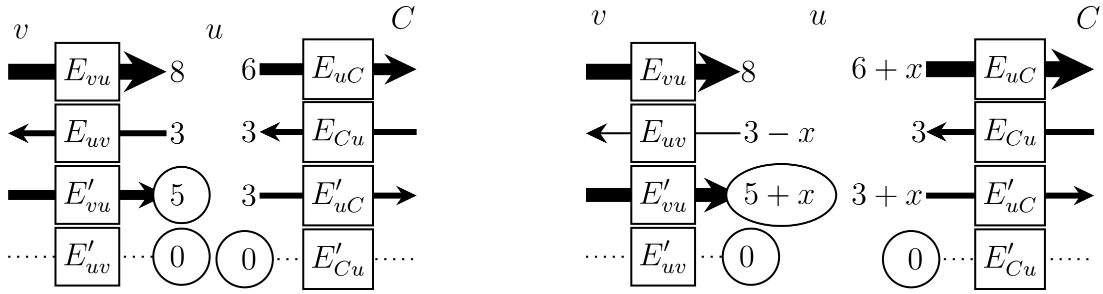


Figure 8: Example: novating x in the counter direction of the net flow increases exposures to u and ϕ_u, which can increase coordination failure probability

of netted exposures. Indirect restrictions on contracts via heterogenous capital constraints for cleared and uncleared exposures is a reasonable candidate a-priori.

The co-movement necessity and the cyclic clearing effect are somewhat independent forces at the first sight. If the direction of exposures along cycles are unknown, co-movement necessity applies for the cyclic clearing effect as well. If exposures along a cycle are cleared in the opposite direction, clearing the cycle can increase the probability of a coordination failure. This helps us understand the cyclic clearing effect better. It is important to clear exposures along directed cycles consistent with the direction of the cycle, not exposures on arbitrary undirected cycles with arbitrary directions of exposures along the cycle. In this sense, co-movement necessity seems to be the primary goal to achieve in reducing probability of coordination failures compared to utilizing the cyclic clearing effect. But this hinges on the specific and extreme notion of a coordination failure that we have adopted. Going back to Proposition 1 and Figure 5, think of the cycle and the "branches" of the cycle consisting of banks that are indirectly exposed to the cycle. Clearing an exposure on a path from a "branch" bank u to the cycle can reduce the probability of coordination failure to 0, since the coordination failure requires all banks to default. However, clearing this exposure only saves the banks that are exposed to the cycle through u, this is, the remainder of the branch of the tree. A "coordination failure" can still start at the cycle, result in the default all banks, except those few that were previously exposed to the cycle through u in the remainder of the branch that was "cut." Due to the apparent importance of cycles as highlighted by Proposition 1 and illustrated by Figure 5, we think of cyclic clearing as a necessity as well.

In fact, financial networks are known to exhibit core-periphery structures. These networks consist of a group of core banks and a group of periphery banks such that the core is connected densely in itself, the periphery is connected to the core, but the periphery has only infrequent connections in itself. Reflecting this on to Figure 5, the cycle-rooted tree would become a cycle-centered star: a cycle of exposure(in the core), and all other banks (periphery) are *directly* exposed to the cycle. This implies that regulation *must* target the cycle to mitigate coordination failures. Breaking an exposure between the core and the periphery saves only one bank from a "coordination failure."

For a more formal argument in favor of cyclic clearing being a necessity in a theoretically broader class of networks, we study broader notions of coordination failures in future work. A weaker notion of coordination failures that factors in a large numbers of self-fulfilling defaults rather than the entire system's self-fulfilling default would clearly require a particular focus on the cycle in Figure 5.

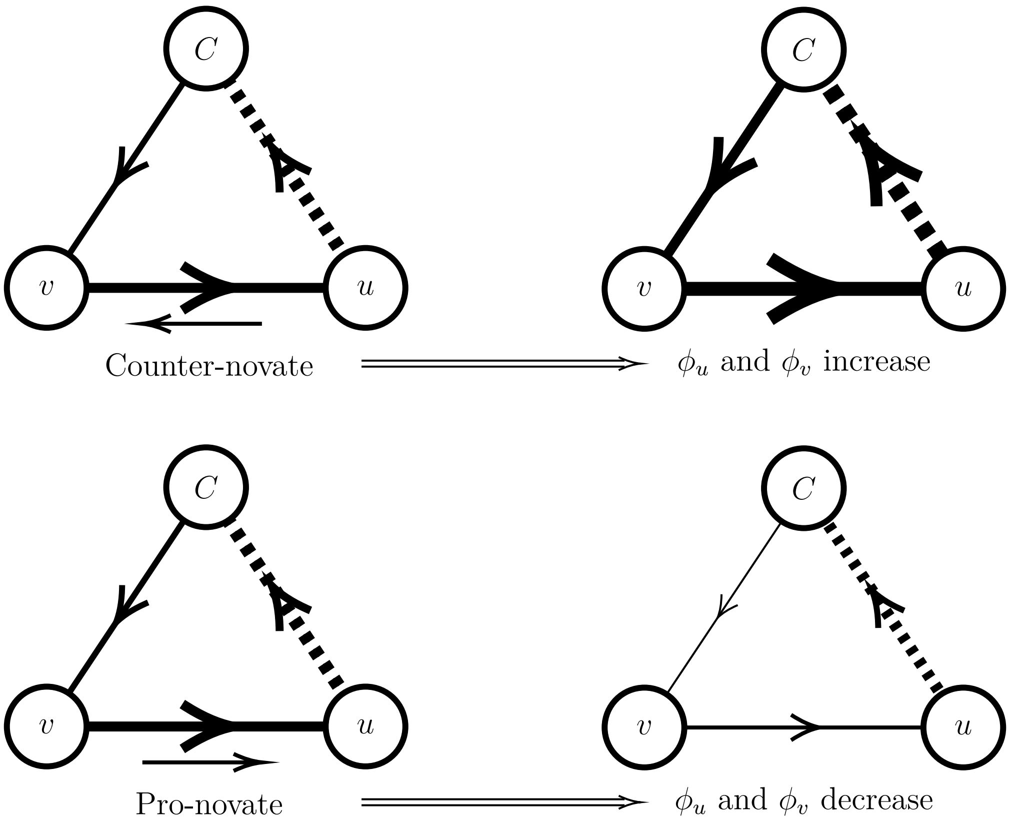


Figure 9: Counter-novation increases coordination failure probability. Pro-novation decreases coordination failure probability.

In these senses, achieving co-movement necessity and cyclic clearing are jointly important factors for policy. Cycles must be targeted to prevent the triggering of coordination failures that will otherwise spread to other parts of the network, but the clearing on the cycle must be done in the correct direction. Otherwise the result is the exact opposite of the intent. Probability of coordination failures increase when co-movement necessity is violated on the cycle. Clearing is ineffective when it does not target the cycle. These two insights turns out to to have central importance once we study the effects of novation incentives induced by capital requirements.

In future work we consider the exogenous risks to CCPs, which make the interplay between co-movement necessity and the cyclic clearing effect further important. When exposures are cleared for a specific pair as in Proposition 1, the exposure to and from the CCP change, whereas clearing exposures along cycles keep the exposures to and from the CCP constant. After Dodd-Frank Act, the balance sheets of CCPs grew significantly and so this question has become relevant.

4 Benchmark: the unregulated economy

4.1 Bankers' contracts

4.1.1 Model of insurance and novation

Capital constraints. In general, capital requirements depend on whether exposures are cleared or not. So prospective novation and the implied constraints need to be considered at the stage of signing a contract. This will be explored in Section 5 when we formalize capital requirements. For now we assume away capital requirements to provide a benchmark and to understand the other forces better.

Insurance. If both bankers in a pair decide to insure, they sign an optimal contract. Since individual rationality is satisfied, no banker is worse-off by insurance. We select the Pareto optimal Nash equilibrium. This is, if at least one banker is strictly better off by insuring, they insure. If both bankers are indifferent, they do not insure.[22]

Novation. If the pair i, j has signed a contract, they both observe the signals $\iota_{ij/ji}^{O/C}$ and decide whether to novate the contract, keep it OTC, or annul it. The contract is fixed at this point.

Two (or one) of these options Pareto dominate the other(s). Accordingly, we assume that bankers pick a Pareto dominant option among the three options. When multiple options are Pareto optimal bankers follow priorities for tie breaking. Their first priority is annulment for robustness against costs of early liquidation, which can be potentially large, but this is off-path regardless. Their second priority is keeping OTC for robustness against small unverifiable costs of novation such as increased monitoring and agency by the CCP.

4.1.2 Financing and novation

Each investor knows the characteristics of the investment that he will finance through his banker, yet he does not know the quality of his banker. An investor who is willing to finance an average banker still faces the risk of financing a bad banker. The investor compares his outside option with his financing payoff against risk of financing a bad banker. Once investor information is revealed, the investor reassesses the likelihood of a successful investment.

If n_i believes that his banker $i \in u$ is a good banker with probability $\tilde{\gamma}_i$, then n_i believes that the investment will succeed with probability $\sigma_{i0} + \tilde{\gamma}_i (\sigma_{i1} - \sigma_{i0})$, in which case he is owed rs. Otherwise the investment fails, $r_i = 0$, and he is owed $r_i s = 0$. But n_i understands that there can be coordination failures, which would reduce his actual payment to a fraction $\mathrm{rr}_{u,\alpha}^{L} rs$ even if the investment succeeds. Recalling the notation $\omega^* = V(sr)$, the investor's expected payoff from financing is $(\sigma_{i0} + \tilde{\gamma}_i (\sigma_{i1} - \sigma_{i0}))\Omega_u \omega^*$ where

$$\Omega_u := (1 - \Phi) + (1/\omega^*)\Phi \mathbb{E}_\alpha \left[V_I \left(\mathrm{rr}_{u,\alpha}^{L} sr \right) \Big| \; \alpha < \phi \right] \tag{5}$$

Here $\Omega_u \omega^*$ is the investor's expected payoff from financing conditional on a successful investment. This is less than $\omega^* = V_I(sr)$ due to the possibility of coordination failures. In a sense, Ω_u is the recovery rate of utility for an investor that lends to a banker in u. Denote

$$\sigma_{i\gamma} = \sigma_{i0} + \gamma_i(\sigma_{i1} - \sigma_{i0})$$

the unconditional success probability of i. This is also the prior belief of n_i that the investment of i succeeds.

Definition. We say n_i has *low outside option* if $\omega_i < \sigma_{i0}\Omega_u\omega^*$, *moderate outside option* if $\sigma_{i0}\Omega_u\omega^* < \omega_i < \sigma_{i\gamma}\Omega_u\omega^*$, and *high outside option* if $\sigma_{i\gamma}\Omega_u\omega^* < \omega_i$.

We call $P \in \{O, C\}$ *pursuable for* i if n_i has moderate outside option and $\iota_{ij}^{P} = 1$, or n_i has low outside option. We call $P \in \{O, C\}$ *pursuable for* $\{i, j\}$ if P is pursuable for i and pursuable for j.

[22] The only case in which both bankers are indifferent is when the optimal contract entails no payments in any state. So it is without loss that they prefer not to insure in this case. Additionally, this is off-the-path of play.

Proposition 4. *Consider matched pair of bankers who are both funded, and have an insurance contract. Suppose that the contract is individually rational and yields positive total expected surplus to the pair.*

The pair keeps the contract OTC if OTC is pursuable for the pair. Otherwise the pair annuls the contract.

Off-the-path of play, n_i withdraws if and only if n_i has moderate outside option and he observes $\iota_{ij} = 0$, or n_i has high outside option.

For low and high outside options, investor information is irrelevant. For low outside option it is strictly dominant for the investor to finance. For high outside option, it is strictly dominant to withdraw. For moderate outside option, investor information is relevant. In particular, the outside option is low enough that the investor strictly prefers not to finance a bad banker, but high enough that he strictly prefers to finance an average banker. Investor information $\iota_{ij} = 0$ is perfectly informative about i being a bad banker. So withdrawal is strictly dominant if $\iota_{ij} = 0$. Bankers understand this. So if $\iota_{ij}^P = 0$ for some $P \in \{O, C\}$, i strictly prefers to annul the contract over choosing P in order to maintain financing. Notice j is indifferent to this early annulment. If P is chosen, investor information observed by n_i would be $\iota_{ij} = \iota_{ij}^P$, n_i would withdraw, i would have to liquidate, and the contract would be automatically annulled, as there can not be a contract contingent on investment return if there is no investment. Therefore, annulment Pareto dominates P if $\iota_{ij}^P = 0$. As CCP information is superior, $\iota_{ij}^O = 0$ implies $\iota_{ij}^C = 0$. Thus, annulment is uniquely Pareto dominant if $\iota_{ij}^O = 0$. This implies that n_i never observes $\iota_{ij} = 0$ on the path of play, as bankers would conceal the information by annulling the contract. Then n_i can never update his beliefs on the path of play. His outside option remains moderate also with respect to his posterior belief, which is equal to his prior belief. Combining this with the cases of low and high outside options, we find that conditional on $P \in \{O, C\}$, n_i withdraws if and only P is not pursuable for i. All of these apply also for banker j. Hence, the pair maintain financing and insurance by choosing P if and only P is pursuable for the pair. As the contract is individually rational and yields positive total expected surplus, choosing P Pareto dominates annulment when P is pursuable for the pair. When P is not pursuable for the pair, annulment Pareto dominates P as at least one banker loses financing and the other is at best indifferent. Finally, notice that if $P = C$ is pursuable for the pair, then so is $P = O$ because $\iota_{ij}^C \leq \iota_{ij}^O$. Then by the priority ranking (CCP entails a small additional cost due to increased monitoring and agency), $P = C$ is irrelevant. The pair chooses $P = O$ if and only if $P = O$ is pursuable for the pair. Otherwise they annul the contract. Note that when we introduce capital requirements $P = C$ will be chosen on the path of play.

4.1.3 Funding

Investors can withdraw their funding without cost. So in principle they can always fund bankers and withdraw later. In order to discipline redundant funding, we assume that investors who are certain of withdrawal do not fund for robustness against a negligibly small costs of withdrawing or a negligibly small transaction cost.

Proposition 5. *A provisional banker receives provisional funding if and only if his investor has low or moderate outside option. All bankers face investors with low or moderate outside option, and obtain and finalize funding. A pair of matched bankers implement an insurance contract if and only if OTC is pursuable for the pair. All implemented contracts are implemented on OTC.*

Investors with high outside option are certain to withdraw. So they do not fund in the first place. Investors with low or moderate outside option have higher expected payoff from financing than their outside options in the continuation game. So they provisionally fund their bankers. Then a random μ_u mass of provisional bankers receive projects and finalize funding.

Figure 10 shows, for a bad provisional banker who is early-on-the-line, the regions of his investor's outside option that leads to specific financing and insurance (conditional on having a match with financing) outcomes. For good bankers, the middle region is included into the first region of financing and insurance as good bankers never get bad signals. Figure 11 shows, for two bad bankers, the regions of their investors' outside options that lead to specific insurance probabilities. When one is good banker, the corresponding separation disappears and the good banker's transparency does not impact the insurance probabilities.

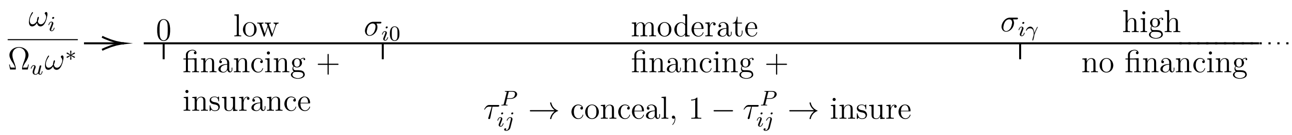


Figure 10: Financing, insurance, and concealing regions of investor outside option for a bad provisional banker early-on-the-line

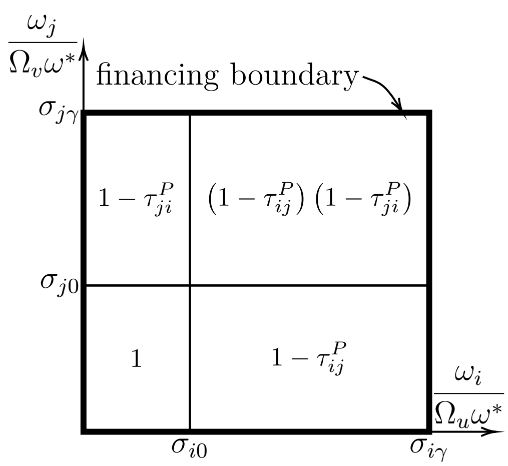


Figure 11: Ex-ante insurance probability between two bad bankers conditional on obtaining funding and getting matched, as a function their investors' outside options

4.1.4 Optimal contract and insurance

As it has become clear, investor information does not influence the optimality of the positions in the contract. In finding the optimal positions in a contract conditional on a joint decision to insure, a pair of bankers need to consider the aggregate outcomes, as they get proportional shares out of the aggregate outcomes in case of default. However, actions of infinitesimal investors and bankers have no effect on the system S. Each investor and each banker take as given the potential contagion outcomes for each α and the resulting probability of a coordination failure Φ. If there is no coordination failure, there are no defaults and all bankers get paid in full as per their contracts. If there is a coordination failure, bankers get 0. These jointly imply that the optimality of positions in a contract disregards the aggregate outcomes, investor information, and novation. Novation decision influences the optimality of contracts when there are capital requirements, which are assumed away for now.

For a matched pair, there are insurance gains only in two states of the world; when one investment succeeds and one fails. Individual rationality can require payments to be made in the state where both investments succeed, but there can not be any payments in the state when both investments fail since bankers have nothing to promise. As our focus is clearing and contagion rather than details of contracts we relegate the general case to the appendix and assume $\theta(\sigma_{ji} - \xi) > \sigma_j - \sigma_i$ for all i, j. This way unconstrained optimal contracts are strictly individually rational and no payments are necessary under the state in which both investments succeed. Note that this condition also implies $\xi < \min\{\sigma_{ij}, \sigma_{ji}\}$, so that collateral costs do not prevent insurance. As there are payments only in states wherein one project succeeds and one fails and there are positive costs of collateral, all components of the contracts other than $d_{ij}(r, 0)$ and $d_{ji}(r, 0)$ are equal to 0. So we abuse notation and denote $d_{ij} = d_{ij}(r, 0) \in \mathbb{R}$ and $d_{ji} = d_{ji}(r, 0) \in \mathbb{R}$, and find the optimal contract $(d_{ij}, d_{ji}) \in \mathbb{R}^2$.

The utility function is $V_B(x) = x + \theta \min\{\beta, x\}$. Recall $rs' > 2\beta$ so that when one investments succeeds and one fails, the returns from the successful investment can give both bankers β. This way bankers can ensure β in both of the relevant states, maximizing insurance gains. This is for simplicity and the general case is relegated to the appendix.

To describe the optimal contract denote

$$\sigma_{ij} = (1 - \sigma_i)\sigma_j, \quad \sigma_{ji} = (1 - \sigma_j)\sigma_i$$

Here σ_{ij} is the probability that i is "exposed" to j, or j is "liable" to i. This happens when i's investment fails and j's investment succeeds. Then conditional on no annulment, the expected payoff of banker i who is matched with banker j, with whom he signed a contract (d_{ij}, d_{ji}) is given by

$$\begin{aligned}
&\Phi\left(\sigma_{ji} V(s'r - s''d_{ij}) + \sigma_{ij} V(s''d_{ij}) + \xi\theta s''(c_u(\mathbb{E}[\alpha|\alpha > \phi] + \zeta_i) - d_{ji})\right) \\
\propto &\underbrace{\sigma_{ij}(s''d_{ij} + \theta \min\{s''d_{ij}, \beta\}) - \sigma_{ji}s''d_{ji}}_{\text{insurance gain}} + \theta \min\{rs' - s''d_{ij}, \beta\}) - \underbrace{\xi\theta s''d_{ij}}_{\text{coll. cost}} \\
\propto &\sigma_{ij} \min\{d_{ij}, \kappa\} + \sigma_{ji} \min\{rs'/s'' - d_{ji}, \kappa\}) - d_{ji}\xi + (\sigma_{ij}d_{ij} - \sigma_{ji}d_{ji})/\theta
\end{aligned}$$

Proposition 6. *The unique optimal contract is given by $d_{ij} = d_{ji} = \kappa$. Total expected contracting gain is $(\sigma_{ij} + \sigma_{ji} - 2\xi)\beta\theta$.*

Consider the state when i's investment fails and j's investment succeeds. Beside the $\xi\theta s''$ utility the cost of collateral, by promising d_{ij}, j incurs utility cost $d_{ij}s''$ out of his insurance gain. On the other hand, the utility gain to i is $s''d_{ij} + \theta \min\{\beta, s''d_{ij}\}$. The total insurance gain is $\theta \min\{\beta, s''d_{ij}\}$ which is maximized by setting $d_{ij} \geq \kappa$. Similarly, $d_{ji} \geq \kappa$ is payoff maximizing. The cost of collateral ξ is less than both σ_{ij} and σ_{ji}, which guarantees that the logic applies generally for contracting gains. If individual rationality holds at the unconstrained optimal contract (κ, κ), $\xi > 0$ prevents additional payments and the optimal contract is (κ, κ). See Figure 12 for indifference curves (for sum of expected payoffs), individual rationality constraints, and the optimal contract.

Individual rationality can be violated when success probabilities are significantly uneven. For example, if $\sigma_{ij} - \sigma_{ji} = \sigma_j - \sigma_i$ is sufficiently large, the expected transfer to j is significantly smaller than the expected transfer to i. This is explored in the appendix.

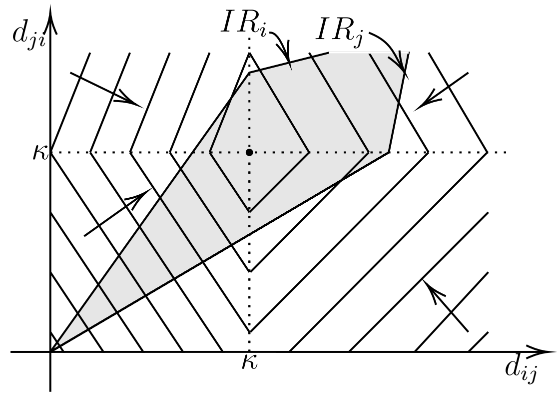


Figure 12: Indifference curves for the sum of expected payoffs and IR constraints

As investment success probabilities are less than one but sufficiently larger than cost of collateral, and low investment returns are less than κ, there are insurance gains between all pairs of bankers. As individual rationality is satisfied by definition, insurance Pareto dominates no insurance outcomes for all bankers.

4.2 Consolidation and the equilibrium system

4.2.1 Ex-ante financing and insurance probabilities

Next we find aggregate exposures resulting from contracting. To this end we factor in probability of pursuability, and outside options. Remember that $i \in u$ means i has funding. Conditional on being "early-on-the-line" to match with an investor on the first-come-first-serve collateral allocation, a provisional banker i has ex-ante probability $\sigma_{i0}+\gamma_i(\sigma_{i1}-\sigma_{i0})$ of $i \in u$ by Proposition 5. Regarding the system S, outside options of bankers must be conditioned on the fact that they obtained funding. The *pursuance rate* π_i is describes the conditional ex-ante probability of pursuing a contract, defined as

$$\pi_i(\cdot) := \frac{\sigma_{i0} + (1-\cdot)\gamma_i(\sigma_{i1}-\sigma_{i0})}{\sigma_{i0} + \gamma_i(\sigma_{i1}-\sigma_{i0})}$$

Notice that $\pi_i(\tau_{ij}^P)$ is the ex-ante probability that P is pursuable for i conditional on $q_i = 0$, $i \in u$, and $j = i^*$ (Recall that i^* denotes i's match). Similarly, $\pi_i(0) = 1$ is the ex-ante probability that i has financing as well as the ex-ante probability that P is pursuable for i, both conditional on $q_i = 0$, $i \in u$, and $j = i^*$. Succinctly, $\pi_i((1-q_i)\tau_{ij}^P)$ is the ex-ante pursuance rate of P for i conditional on $i \in u$ and $j = i^*$. Denote

$$\pi_{Pij} := \pi_i((1-q_i)\tau_{ij}^P) \times \pi_j((1-q_j)\tau_{ij}^P)$$

Proposition 7. *The ex-ante probability of an implemented insurance contract between i and j conditional on being funded and matched is* π_{Oij}.

4.2.2 Model of banker matching

After borrowing from investors, a mass of pairs of bankers from different banks match with each other that gives them an opportunity to insure each other. We assume away matching inside a single bank for simplicity and focus on the network structure. As we work with matching between continuums of bankers, it improves readability to define the masses of actually matched bankers directly, rather than defining matching probabilities that would generate the corresponding masses of matched bankers. Our method is akin to stochastic block models and graphons, adapted to one-to-one matchings. See Erol et al. (2020) for details.

Recall that γ_i is the probability that banker i is a good banker. Denote $\gamma_{iq} = 1 - \gamma_i + 2q\gamma_i$ the probability that i has quality q and $\gamma_{uq} = \mu_u^{-1}\int_u \gamma_{iq}\mathtt{d}i$ the probability that a random banker in u has quality q. Note $\gamma_{u0} + \gamma_{u1} = 1$. These are given outside of the matching structure.

Definition. A *matching structure* is a vector of non-negative numbers $M = ((\mu_{uv}^{qq'})_{v,q,q'}, (\mu_{u0}^q)_q)_u$ that satisfies

- (*Measure Preservation*) $\mu_{uv}^{qq'} = \mu_{vu}^{q'q}$ for all u, v, q, q', and
- (*Consistency*) $\mu_{u0}^q = \gamma_{uq}\mu_u - \sum_{v'}\sum_{q''}\mu_{uv'}^{qq''}$ for all u, q.

A *matching* drawn ex-ante from M is a one-to-one measure preserving mapping between bankers such that for all u, v, q, q', there is $\mu_{uv}^{qq'}$ mass of bankers in u with quality q that are matched with a banker in v with quality q', and there is μ_{u0}^q mass of unmatched bankers of quality q in bank u.

There is $\mu_{uv}^{qq'}$ mass of bankers in u with quality q that are matched with a banker in v with quality q'. If this is counted from the side of bank v, the mass of bankers in v with quality q' that are matched with a banker in u with quality q is $\mu_{vu}^{q'q}$. The first condition $\mu_{uv}^{qq'} = \mu_{vu}^{q'q}$ ensures that the resulting one-to-one matching between these bankers in u with quality q and in v with quality v' is a measure preserving mapping. The mass of bankers in u with quality q that have a match is then given by $\sum_{v'}\sum_{q''}\mu_{uv'}^{qq''}$. The remaining bankers in u with quality q are unmatched, which has a mass $\gamma_{uq}\mu_u - \sum_{v'}\sum_{q''}\mu_{uv'}^{qq''}$. The consistency condition simply means that $\mu_{u0}^q \geq 0$ represents the mass of unmatched bankers in u who have quality q.

It is helpful to understand the matching protocol that generates a matching. Given the a matching structure $M = ((\mu_{uv}^{qq'})_{v,q,q'}, (\mu_{u0}^q)_q)_u$, the following process generates a matching drawn from M wherein each banker's match is determined independently of his identity.

The protocol. The process takes each of $\gamma_{uq}\mu_u$ mass of bankers in u with quality q and distribute them to "matching categories." The process assigns each banker among this $\gamma_{uq}\mu_u$ mass independently to the *matching category* $\{(q, u), (q', v)\}$ with probability $\mu_{uv}^{qq'}(\mu_u\gamma_{uq})^{-1}$, and to the matching category Null with the residual probability $1 - \sum_v \sum \mu_{uv}^{qq'}(\mu_u\gamma_{uq})_{q'}^{-1}$. By the Consistency property of M, the probability of being assigned to Null is equal to $\mu_u^{-1}\mu_{u0}^q$. Once all allocations to matching categories are made, consider each category $\{(q, u), (q', v)\}$. The mass of bankers from u who are allocated to category $\{(q, u), (q', v)\}$ is $(\mu_u\gamma_{uq})\,\mu_{uv}^{qq'}\,(\mu_u\gamma_{uq})^{-1} = \mu_{uv}^{qq'}$. Note that by construction all of these bankers have quality q. Similarly the mass of bankers from v who are allocated to category $\{(q, u), (q', v)\}$ is $\mu_{vu}^{q'q}$. These bankers have quality q'. By the Measure Preservation property of M, $\mu_{uv}^{qq'} = \mu_{vu}^{q'q}$, and so there are equal masses of bankers from u and v in category $\{(q, u), (q', v)\}$. Take each banker in the category from bank u and allocate an index drawn i.i.d. from uniform $U[0, \mu_{uv}^{qq'}]$. Do the same for bankers in the category from v. Then, match bankers on two sides that have the same index. Finally, leave all bankers in category Null unmatched. As being assigned to Null has probability $\mu_u^{-1}\mu_{u0}^q$, the mass of unmatched bankers of quality q in u is μ_{u0}^q. Notice that banker indices do not appear in the process and the resulting matching is measure preserving since there are finitely many categories.

Notice that the identity of banker i influences his match only through his bank's characteristics and his realized quality, not the name i in and of itself. Then according to the process, for any two bankers $i \in u$ and $j \in v$ of quality q and q', the probability density of i and j getting matched is

$$\tilde{\mu}_{uv}^{qq'} := \frac{\mu_{uv}^{qq'}}{\mu_u \gamma_{uq}} \frac{\mu_{uv}^{qq'}}{\mu_v \gamma_{vq'}} \frac{1}{\mu_{uv}^{qq'}} = \frac{\mu_{uv}^{qq'}}{\mu_u \gamma_{uq} \mu_v \gamma_{vq'}}$$

The aggregate matching structure is considered a bank characteristic jointly. Thus bankers' insurance opportunities are determined by the banks' identities. This captures the idea that banks serve as hubs of communication across bankers in the economy and reduce search and matching frictions.

4.2.3 Consolidation and equilibrium

In finding the resulting system we aggregate the variables that we have identified so far. Optimal contracts have been stated for given success probabilities σ_i, σ_j in Proposition 6 but σ_i, σ_j depend on banker qualities. In finding aggregate exposures we need to take into account the dependence of success probabilities on the random banker quality and the probability of qualities. Accordingly index all relevant variables and functions with banker quality.

Denote $\pi_u^0 = \int_u \pi_i(d) \mathtt{d}i$ the average success probability of bankers in u. Also denote the *exposure scaler* e_{uv}^*:[23]

$$e_{uv}^* = \int_{i \in u} \int_{j \in v} \sum_{q,q'} \gamma_{iq} \gamma_{jq'} \tilde{\mu}_{uv}^{qq'} \pi_{Oij}^{qq'} (\sigma_{jq'} - \sigma_{iq}) \kappa \mathtt{d}j \mathtt{d}i$$

The exposure scaler e_{uv}^* reflects the critical ingredients of the model except the novation decisions, which are to be explored further after capital regulation is introduced. For a pair of bankers i, j from banks u, v, their qualities are drawn first. Then they get matched with each other with probability mass $\tilde{\mu}_{uv}^{qq'}$. There is $\pi_{Oij}^{qq'}$ probability that they implement a contract. The contracting probability is influenced by the level of transparency and the bankers' ex-ante success probabilities. The banker qualities affect the pursuance rate because good bankers are not concerned with investor information and do not conceal information. Finally, the term $(\sigma_{jq'} - \sigma_{iq})\kappa = (\sigma_{ij}^{qq'} - \sigma_{ji}^{q'q})\kappa = D_{ij}^{qq'} - D_{ji}^{q'q}$ is the expected infinitesimal net liability of v to u due to the contract between i and j. Once all of these factors are integrated over all banker pairs, the resulting gross liability of v to u is determined.

Proposition 8. *The equilibrium system S^* is given by*[24]

$$E'_{uv} = \langle e_{uv}^* \rangle, \quad E'_{vu} = \langle e_{vu}^* \rangle, \quad E'_{uC} = E'_{Cu} = 0$$
$$A_u = \mu_u c_u, \quad R_u = \mu_u \pi_u^0 r_u, \quad L_u = \mu_u (s \pi_u^0 r_u + m)$$

The equilibrium coordination failure cutoff is

$$\phi^* = \min_u c_u^{-1} \Big(\mu_u^{-1} \sum_v \langle e_{vu}^* \rangle + m^* \Big)$$
$$\textit{where } m_u^* = m - \pi_u^0 (1-s) r$$

[23]To guarantee Condition 1 and 2 for all following results, we assume $\underline{\alpha} c_u < \frac{1}{\mu_v} \sum_v e_{vu}^* + m - (1-s)\pi_u^0 r$ and $s' \pi_u^0 r + s'' \sum_v e_{vu}^* \leq \sum_v \langle e_{uv}^* \rangle$.

[24]Notice that $e_{uv}^* + e_{vu}^* = 0$.

Going forward we assume $m_u^* > 0$ to signify the risky component of projects and their role in triggering coordination failures. Low m^* can mean that the coordination failure cutoff is never crossed regardless of aggregate shock. Then higher size collateral (c_u) and higher investment returns ($\pi_u^0 r$) reduce the probability of coordination failures by providing more assets as buffer. Higher interbank exposure (e_{uv}^*), higher payments to investors (s), higher payments to creditors (m) increase the probability by increasing liabilities.

Regarding the effect of transparency on the probability of a coordination failure, the only terms that depend on level of transparency are exposure scalers e_{uv}^*, through the pursuance rate π_{Oij}. This is decreasing in transparency vector $(\tau_{ij}^O)_{i,j}$. However, as the net liability $D_{ij}^{q_i q_j} - D_{ji}^{q_j q_i}$ can be positive or negative, the net effect is ambiguous. To fix ideas, if one assumes that all bankers are ex-ante identical, then some algebra shows that $e_{uv}^* = (\eta_{uv} - \eta_{vu})\pi_O^{01}$. Total exposures to u are $\propto \sum_v \langle \eta_{uv} - \eta_{vu} \rangle \pi_O^{01}$ which is decreasing in transparency $\tau_{ij}^O \equiv \tau^O$. This is, unless there are large asymmetries is banker quality probabilities and success probabilities of bankers across different banks, exposures are decreasing in transparency, which reduces the probability of a coordination failure.

The effect of netting is also observable here. Denote

$$e_u^{\rightarrow} = \sum_v \langle e_{vu}^* \rangle , \quad e_u^{\leftarrow} = \sum_v \langle e_{uv}^* \rangle$$

Note that $e_{uv}^* + e_{vu}^* = 0$, and so $e_u^{\rightarrow} - e_u^{\leftarrow} = \sum_v e_{vu}^*$. When there is a coordination failure, the exposure to u increases from $\sum_v e_{vu}^*$ to $e_u^{\rightarrow}$ as the interbank assets $e_u^{\leftarrow}$ are wiped in a coordination failure, reducing the self-fulfilling contagion cutoff to ϕ^*. In a mechanical sense, if there is more netting keeping gross exposures fixed, $e_u^{\rightarrow}$ and $e_u^{\leftarrow}$ would decrease while keeping $e_u^{\rightarrow} - e_u^{\leftarrow}$ fixed. This would reduce interbank asset cost of coordination failures ($e_u^{\leftarrow}$) and self-fulfillingly make the coordination failures less likely ($e_u^{\rightarrow}$).

5 Capital requirements

5.1 Model of capital requirements

We highlighted the role of cyclic clearing necessity and co-movement necessity earlier. Next we described the main ingredients of the model while deriving the solution to an unregulated system. Now we study regulation and how successful it is in reducing probability of coordination failures. In particular, are cyclic clearing and co-movement necessities satisfied?

It is not clear what type of regulation can implement novation along cycles in the correct direction. Bank-specific network-prudential regulation depending on the detailed structure of the system of exposures, such as cycles, does not seem plausible or practical for various reasons. In practice, following the Dodd-Frank Act, capital requirements for cleared exposures have been reduced and for OTC exposures have been increased, partly to promote clearing. An important question to address is then to figure out the effective target of such regulation. Which contracts have moved to novation in response to capital regulation? How does the implicit transparency of CCPs play a role in this potential shift?

Capital requirements. Capital adequacy is required after insurance before consolidation. Each bank must maintain a capital adequacy ratio, defined as the ratio of their regulatory capital to risk weighted assets. See Consolidated Reports of Condition and Income for a Bank with Domestic and Foreign Offices—FFIEC 031 form for details on how regulatory capital and risk weighted assets are calculated.[25]

In our model, financing and insurance contracts have been determined at the time of regulation but the aggregate shock and investment returns have not. The regulatory capital REG_u at the time of regulation is given by

$$\text{REG}_u = \int_u (c_u(\zeta_i + \mathbb{E}[\alpha]) - m)\mathtt{d}i + (1-s)r\int_{u_R} \sigma_i \mathtt{d}i$$

The insurance contracts do not go into regulatory capital as they are off-balance sheet items.

The asset classes are publicly known ex-ante: projects face risk α, investments of each banker faces $(\sigma_{i0}, \sigma_{i1})$ risk, and contractual interbank exposures face $(\sigma_{i0}, \sigma_{i1}, \sigma_{j0}, \sigma_{j1})$ risk. Accordingly, risk weights are given by RW_A for projects, RW_R^i for i's investment class, $\text{RW}_{C/O}^{ij}$ for the class of insurance contract that insures against returns from investments classes of i and j, for example an exotic derivative. The regulation differentiates between cleared and OTC exposures, so RW_C^{ij} applies to cleared exposures and RW_O^{ij} applies OTC exposures, where $\text{RW}_O^{ij} \geq \text{RW}_C^{ij}$. It is important to note that risk weights for (derivative) insurance contracts apply to net asset contracts, not the net liability contracts.[26]

Recall the random variable d_{ii^*}, the payment to be made from i^* to i after investment returns. Let u_O be the set of insured bankers in u that kept contracts OTC, and u_C be those that novated. Then the risk weighted assets RWA_u of bank u at the time regulation is given by

$$\begin{aligned}\text{RWA}_u = \text{RW}_u c_u \int_{u_R} (\zeta_i + \mathbb{E}[\alpha])\mathtt{d}i + r\int_{u_R} \text{RW}_R^i \sigma_i \mathtt{d}i \\ + \int_{u_O} \text{RW}_O^{ii^*} \langle \mathbb{E}\left[d_{ii^*} - d_{ii^*}\right]\rangle \mathtt{d}i + \int_{u_C} \text{RW}_C^{ii^*} \langle \mathbb{E}\left[d_{ii^*} - d_{ii^*}\right]\rangle \mathtt{d}i\end{aligned}$$

The capital requirements require a certain capital adequacy ratio, CAR_u. This is, the regulatory capital of u must be at least CAR_u fraction of the risk weighted assets of u:

$$\text{REG}_u \geq \text{CAR}_u \times \text{RWA}_u$$

The bank must ensure its capital adequacy by internally regulating its (infinitesimal) bankers. This is typically done by risk divisions of banks by putting restrictions on traders through automated algorithms. In our framework, bank u imposes every banker $i \in u_O \cup u_C$ to uphold an *internal capital constraint* that is the parallel reduction of the capital requirement to individual bankers. We call this the *internal regulation.* For a banker i who wants to implement an insurance contract, internal capital constraint is

$$(\zeta_i + \mathbb{E}[\alpha])\, c_u - m + (1-s)r\sigma_i \geq \text{CAR}_u \left(\text{RW}_A(\zeta_i + \mathbb{E}[\alpha])c_u + \text{RW}_R^i r\sigma_i + \text{RW}_{O/C}^{ii^*} \langle \mathbb{E}\left[d_{ii^*} - d_{ii^*}\right]\rangle\right)$$

Here $\text{RW}_{O/C}^{ii^*}$ depends on whether the pair i, i^* decide to novate their contract or not.

[25] Available at https://www.ffiec.gov/pdf/FFIEC_forms/FFIEC031_202112_f.pdf

[26] See Consolidated Reports of Condition and Income for a Bank with Domestic and Foreign Offices—FFIEC 031 form (at https://www.ffiec.gov/pdf/FFIEC_forms/FFIEC031_202112_f.pdf). Pages 78 items 20 and 21 require reporting the positive part of the fair value of cleared and OTC derivatives in risk weighted assets.

For an arbitrary banker i, denote $\psi_A^i = 1 - \mathrm{CAR}_{b_i}\mathrm{RW}_A$, $\psi_R^i = 1 - s - \mathrm{CAR}_{b_i}\mathrm{RW}_R^i$, and $\rho_{O/C}^{ij} = \mathrm{CAR}_{b_i}\mathrm{RW}_{O/C}^{ij}$. The *net regulatory capital* of banker i is defined as

$$k_i = \psi_R^i \sigma_i r + \left(\psi_A^i(\zeta_i + \mathbb{E}[\alpha])\right) c_{b_i} - m$$

Then the internal capital constraint that banker i faces is $k_i \geq \rho_{O/C}^{ii^*} \langle D_{ii^*} - D_{i^*i}\rangle$. We assume $\psi_R^i \sigma_{i0} r + (\psi_A^i(-Z + \mathbb{E}[\alpha]))\, c_{b_i} - m \geq 0$, so that k_i is always positive.[27] The internal capital constraint that i faces is then given by

$$k_i \geq \rho_{O/C}^{ii^*}(D_{ii^*} - D_{i^*i}) \tag{6}$$

Finally, $\rho_O^{ii^*} \geq \rho_C^{ii^*}$ meaning the OTC regulation is tighter than CCP regulation.

Novation and insurance under capital constraints. The contracts must uphold the capital adequacy constraint for the chosen platform. Given a contract, we say the choice $P \in \{O, C\}$ is *adequate* if the contract respects inequality (6) for the platform P. Given a contract, the pair either annuls the contract, or chooses an adequate option. As before, they are assumed to pick the Pareto dominant option, with the same priority ranking in case of equivalence.

Given this continuation regarding novation, optimal contracts are defined as before: individually rational expected payoff maximizing contracts. As before, banker play the Pareto optimal Nash equilibrium.

5.2 Optimal contract

Capital regulation differs across platforms, so there are two contracts to consider: OTC-optimal and CCP-optimal which differ by constraint they are subjected to. Recall that CCP capital regulation is more lenient. Then if bankers sign an OTC-optimal contract, their insurance gains are smaller as the OTC capital regulation (if binding) results in more constraint contracts. But the pursuance rate is higher since OTC platform is more opaque. If bankers sign a CCP-optimal contract, their insurance gains are larger but the pursuance rate is smaller due to transparency of the CCP platform. Whichever contract yields higher expected payoff in resolving this tradeoff is the optimal contract.

Earlier we had assumed $\theta(\sigma_{ji} - \xi) > \sigma_j - \sigma_i$ that made sure IR holds at the unconstrained solution. Now we have capital constraints as well, which interacts with the IR constraint in a way influenced by the cost of collateral. Denote

$$\xi_{ij}^* = \frac{\sigma_{ij}\sigma_{ji}}{\sigma_{ij} + \sigma_{ji}}$$

Proposition 9. *Consider a matched pair $i \in u$, $j \in v$. The unique P-optimal contract for $P \in \{O, C\}$ is given as follows.*

If cost of collateral is low, $\xi < \xi_{ij}^*$, then

$$D_{Pij} = \sigma_{ij} d_{Pij} = \max\left\{\kappa\sigma_{ij}\, ,\, \kappa\sigma_{ji} - k_j \big/ \rho_P^{ji}\right\}$$

and $D_{Pji} = \sigma_{ji} d_{Pji}$ vice-versa. If cost of collateral is high, $\xi < \xi_{ij}^*$, then

$$D_{Pij} = \sigma_{ij} d_{Pij} = \min\left\{\kappa\sigma_{ij}\, ,\, \kappa\sigma_{ji} + k_i \big/ \rho_P^{ji}\right\}$$

and D_{Pij} vice-versa.

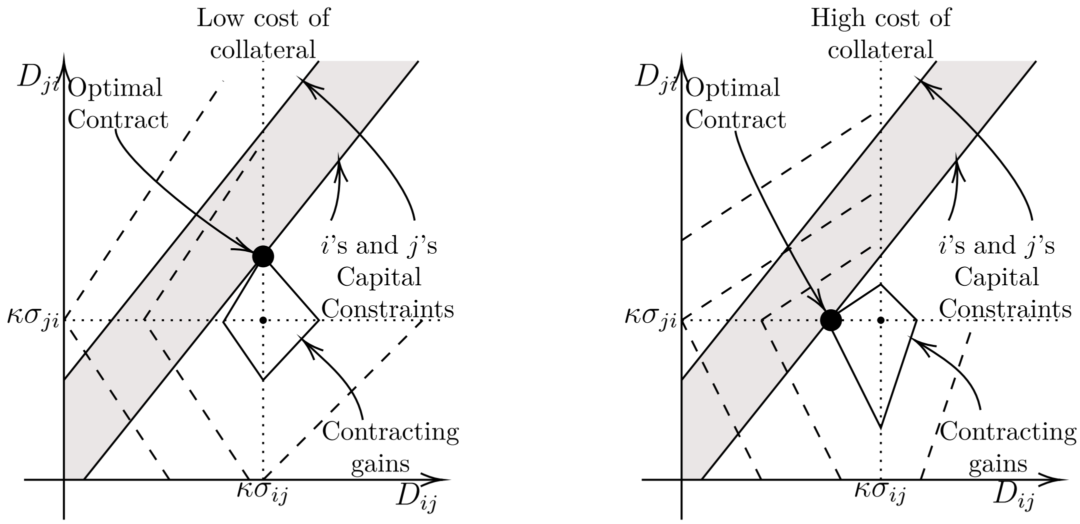


Figure 13: Optimal contract when capital constraint binds

We explain Proposition 9 using Figure 13. Without loss, suppose that $\sigma_{ji} \leq \sigma_{ij}$. Equivalently $\sigma_i \leq \sigma_j$. In the unconstraint optimal contract (κ, κ), the banker with lower success probability, i, gets paid more often. He brings his bank positive expected payout, which must be less than his net regulatory capital k_i. If $\kappa\sigma_{ij} - \kappa\sigma_{ji} > k_i/\rho^{ij}$, i does not have adequate regulatory capital for the unconstraint optimal contract. Then i must pay j further in the contract, reducing the assets of i down to a compliant level, or i must be paid less by j to achieve the same. Which option is optimal depends on the cost of collateral. If i pays more, this addition keeps insurance gains at the maximum level by making $D_{ij} = \kappa\sigma_{ij}$ and $D_{ji} = \kappa\sigma_{ij} - k_i/\rho^{ij} > \kappa\sigma_{ji}$, but comes at the cost of additional cost of collateral. This is optimal when the cost of collateral is low. If i gets paid less, this reduction reduces insurance gains but saves on costs of collateral by making $D_{ij} = \kappa\sigma_{ji} + k_i/\rho^{ij} < \kappa\sigma_{ij}$ and $D_{ji} = \kappa\sigma_{ji}$. This is optimal when the cost of collateral is high. Proposition 9 states these jointly for both cases of $\sigma_{ji} \leq \sigma_{ij}$ and $\sigma_{ji} \geq \sigma_{ij}$. Note that the described contracts do not violate the incentive constraints because the rate of substitution between expected payments to satisfy capital constraints is 1, whereas the same rate for incentive constraint is distorted by costs of collateral making it larger than 1.

In what follows we assume low cost of collateral $\xi < \xi^*_{ij}$ for simplicity. Total insurance gains are maximal but collateral costs are varied. The internal regulation for the banker with lower success probability is the potentially binding constraint for the pair.

5.3 Novation and ex-ante probabilities of insurance and financing

As capital constraints are more binding for OTC platform compared to CCP platform, total contracting gains of the OTC-optimal contract is weakly smaller than that of the CCP-optimal contract. If the OTC-optimal contract is non-binding, i.e. $d_O \equiv \kappa$, then $D_O = D_C = (\kappa\sigma_{ij}, \kappa\sigma_{ji})$, and so total contracting gains are the same. In this case, bankers sign $d \equiv \kappa$ and keep it OTC. When the OTC constraint is binding, i.e. $d_O \not\equiv \kappa$, then OTC is not adequate for the CCP-optimal contract. So d_C can be implemented only on CCP, when CCP is pursuable.

[27]The internal capital constraint for bankers without insurance contracts is $k_i \geq 0$, so $k_i < 0$ would prevent investment.

As OTC is not adequate for the CCP-optimal contract, the CCP optimal contract can be pursued with probability π_{Cij}. On the other hand, the OTC-optimal contract can be pursued on either platform, which has probability π_{Oij}. Bankers compare the expected gains in determining whether OTC-optimal or CCP-optimal contract is the optimal contract.

Definition. The *value of opacity* for i and j is the difference in expected total insurance gain between the OTC-optimal contract that is kept OTC and the CCP-optimal contract that is novated.

Lemma 3. *Consider a matched pair $i \in u$, $j \in v$. The value of opacity for the pair is $\Theta_{ij}\theta$ where*

$$\begin{aligned}\Theta_{ij} &= \overbrace{(\pi_{Oij})\left(\beta(\sigma_{ij}+\sigma_{ji}) - \xi s''\left(d_{Oij}+d_{Oji}\right)\right)}^{\text{OTC contracting gains}} - \overbrace{\pi_{Cij}\left(\beta(\sigma_{ij}+\sigma_{ji}) - \xi s''\left(d_{Cij}+d_{Cji}\right)\right)}^{\text{CCP contracting gains}} \\ &= \underbrace{(\pi_{Oij}-\pi_{Cij})(\sigma_{ij}+\sigma_{ji})\beta}_{\text{insurance gains}} - \underbrace{\xi s''\left(\pi_{Oij}\left(d_{Oij}+d_{Oji}\right) - \pi_{Cij}\left(d_{Cij}+d_{Cji}\right)\right)}_{\text{cost of collateral}}\end{aligned}$$

Conditional on signing a contract, the pair signs the OTC-optimal contract if the value of opacity is positive, and the CCP-optimal contract if the value of opacity is negative.

When there is no risk of confusion, we call Θ_{ij} as well as $\Theta_{ij}\theta$ the value of opacity. The only relevant part of the value of opacity is its sign.

Proposition 10. *Consider a matched pair $i \in u$, $j \in v$.*

A CCP-optimal contract is implemented on CCP if and only if CCP is pursuable for the pair and the value of opacity is negative.

An OTC-optimal contract is implemented on OTC if and only if OTC is pursuable for the pair and the value of opacity is positive

Otherwise there no contract is implemented.

Conditional on i and j getting matched and value of opacity being negative, the ex-ante probability that the CCP-optimal contract implemented (on CCP) is π_{Cij}.

Conditional on i and j getting matched and value of opacity being positive, the ex-ante probability that the OTC-optimal contract implemented (on OTC) is π_{Oij}.

5.4 Collateral and the value of opacity

The sign of the value of opacity for a pair is the sole determinant of whether the pair chooses to novate or not, conditional on pursuability and adequacy. In trying to shift exposures to central clearing, the regulator's tool is to use capital constraints to shift the value of opacity from positive to negative. Define $\widetilde{N}_{ij}$ the *upper novation threshold* and $\underset{\sim}{N}_{ij}$ the *lower novation threshold*, given by

$$\begin{aligned}\widetilde{N}_{ij} &:= \frac{\rho_O^{ij}}{\pi_{Oij}}\left(\pi_{Cij}(\sigma_{ij}-\sigma_{ji}) - (\pi_{Oij}-\pi_{Cij})(\sigma_{ij}+\sigma_{ji})\left(\frac{\sigma_{ji}}{\xi}-1\right)\right)\kappa \\ \underset{\sim}{N}_{ij} &:= \max\left\{0, \frac{\pi_{Cij}}{\rho_C^{ij}} - \frac{\pi_{Oij}}{\rho_O^{ij}}\right\}^{-1}(\pi_{Oij}-\pi_{Cij})(\sigma_{ij}+\sigma_{ji})\left(\frac{\sigma_{ji}}{\xi}-1\right)\kappa\end{aligned}$$

Definition. Take a matched pair i, j and let i be the one with lower success probability: $\sigma_i \leq \sigma_j$. The pair is said to have *high collateral* if $\rho_O^{ij}(\sigma_j-\sigma_i)\kappa < k_i$, *medium collateral* if $\rho_C^{ij}(\sigma_j-\sigma_i)\kappa < k_i < \rho_O^{ij}(\sigma_j-\sigma_i)\kappa$, and *low collateral* if $k_i < \rho_C^{ij}(\sigma_j-\sigma_i)\kappa$.

Proposition 11. *Consider a matched pair i, j and suppose that both platforms are pursuable for the pair. Without loss take $\sigma_i \le \sigma_j$. Then $D_{Pij} = \kappa\sigma_{ij}$ for both $P \in \{O, C\}$.*

If the pair has high collateral, then neither OTC nor CCP constraints bind, $D_{Oji} = \kappa\sigma_{ji}$, and $D_{Cji} = \kappa\sigma_{ji}$. The contract is not novated as $\Theta_{ij} > 0$.

If the pair has medium collateral, OTC constraint binds, CCP constraint does not, $D_{Oji} = \kappa\sigma_{ij} - k_i/\rho_O^{ij}$, and $D_{Cji} = \kappa\sigma_{ji}$. Value of opacity has $k_i < \widetilde{N}_{ij} \iff \Theta_{ij} < 0$, and so the contract is novated if and only if $k_i < \widetilde{N}_{ij}$.

If the pair has low collateral, then both OTC and CCP constraints bind, $D_{Oji} = \kappa\sigma_{ij} - k_i/\rho_O^{ij}$, and $D_{Cji} = \kappa\sigma_{ij} - k_i/\rho_C^{ij}$. Value of opacity has $k_i > \underset{\sim}{N}_{ij} \iff \Theta_{ij} < 0$, and so the contract is novated if and only if $k_i > \underset{\sim}{N}_{ij}$.

By $\sigma_i \le \sigma_j$, $D_{Pij} = \kappa\sigma_{ij}$ regardless of regulation or platform. On the other hand, $D_{Pji} = \max\{\kappa\sigma_{ji}, \kappa\sigma_{ij} - k_i(\rho_P^{ij})^{-1}\}$. As CCP constraint is more lenient than OTC constraint, if OTC asset constraint does not bind (high collateral), then CCP asset constraint does not bind either. Then $d \equiv \kappa$. In this case, the pair uses OTC regardless, and regulation is ineffective in shifting exposures. They keep the contract OTC to save on small costs of CCP.

In the case of medium collateral, the pair entertains switching from a constraint OTC-optimal contract with high opacity to a novated unconstrained optimal contract with high transparency. The banker with low success probability, i, must compensate the other, j, with additional payments on top of the unconstrained optimal contract so that i can uphold his capital constraint. If i's collateral is increased, he needs to pay less compensation, meaning that he needs to incur less cost of collateral. Therefore, the total contractual gains from switching to novation is lower if i has higher collateral, all else fixed. This is, the value of opacity is larger when i has more collateral. The novation condition $k_i < \tilde{N}_{ij}$ is harder to satisfy if i has more collateral (larger k_i). Hence conditional on a region of medium collateral, as regulation gets tighter, bankers with higher collateral among the medium collateral bankers are the last to switch to CCP as they have the highest value of opacity.

In the case of small collateral, both CCP and OTC regulation bind. In this case bankers compare the OTC-optimal optimal contract under high opacity with the CCP-optimal contract under high transparency. The gains from relaxed regulation is limited by ρ_C. If this limit is too low, which is $\pi_{ijC}^{q_i q_j}(\rho_C^{ij})^{-1} < \pi_{ijO}^{q_i q_j}(\rho_O^{ij})^{-1}$, the pair does not novate regardless of collateral. The transparency is too large to be compensated by the limited relaxed regulation despite low collateral. In this case, value of opacity is positive, and without loss the novation cutoff is infinity. The savings on the cost of collateral per unit of collateral due to novation is positive, which increases with collateral. Thus larger collateral increases savings and decreases the value of opacity. The novation condition $k_i > \underset{\sim}{N}_{ij}$ is harder to satisfy if i has less collateral (smaller k_i). Bankers with low collateral among the low collateral banks switch last to novation.

5.5 Equilibrium system

Denote $\{\{\cdot\}\}$ the Iverson bracket. This is, $\{\{x\}\} = 1$ if x holds and $\{\{x\}\} = 0$ otherwise. Out of the contract between i and j, the resulting (infinitesimal) gross exposure of u to v is $D_{Oij}\{\{\Theta_{ij} > 0\}\}$. The resulting gross exposure of u to CCP is $D_{Cij}\{\{\Theta_{ij} < 0\}\}$. As before we find the financing and insurance probabilities and aggregate them to find equilibrium values. So index all relevant variables and functions by the quality of bankers.

Proposition 12. *The equilibrium system is given by*

$$E'^*_{vu} = \langle e^{**}_{vu} \rangle\,, \;\; E'^*_{uv} = \langle e^{**}_{uv} \rangle\,, \;\; E'^*_{Cu} = \langle \sum_v e^{**}_{vCu} \rangle, \;\; E'^*_{uC} = \langle \sum_v e^{**}_{uCv} \rangle$$
$$A_u = \mu_u c_u, \;\; R_u = \mu_u \pi^0_u r_u, \;\; L_u = \mu_u (s\pi^0_u r_u + m)$$

where

$$e^{**}_{uv} \coloneqq \sum_{q,q'} \int_{i\in u} \int_{j\in v} \pi^{qq'}_{ijO} (D^{qq'}_{Oij} - D^{q'q}_{Oji}) \{\{\Theta^{q_i q_j}_{ij} > 0\}\} \gamma_{iq} \gamma_{jq'} \tilde{\mu}^{qq'}_{uv} \mathtt{d}j \mathtt{d}i$$
$$e^{**}_{uCv} \coloneqq \sum_{q,q'} \int_{i\in u} \int_{j\in v} \pi^{qq'}_{ijC} (D^{qq'}_{Cij} - D^{q'q}_{Cji}) \{\{\Theta^{q_i q_j}_{ij} < 0\}\} \gamma_{iq} \gamma_{jq'} \tilde{\mu}^{qq'}_{uv} \mathtt{d}j \mathtt{d}i$$

for all u, v. Define exposure-to-u scaler as

$$e^{\Rightarrow}_u = \sum_v \langle e^{**}_{vu} \rangle + \langle \sum_v e^{**}_{vCu} \rangle$$

The equilibrium probability of a coordination failure is $\Phi^* = F_\alpha(\phi^*)$ where

$$\phi^* = \min_u c_u^{-1} \Big(\mu_u^{-1} e^{\Rightarrow}_u + m^*_u \Big)$$

One can substitute D in Proposition 9 and $\{\{\Theta^{q_i q_j}_{ij} > 0\}\}$ in Proposition 11 into Proposition 12 to write e^{**}_{uv}, e^{**}_{uCv}, and ultimately Φ^* in closed form.

6 Intensive margins: broad effects of regulation on coordination failures

6.1 The novation gap and the opacity gap

As we move on to applications we assume that all bankers are identical to simplify expressions. This means $\sigma_{i0}, \sigma_{i1}, \gamma_i, \tau^O_{ij}, \tau^C_{ij}, RW^i_R, RW^i_A, RW^{ij}_{O/C}$ are identical across all bankers and pairs. For simplicity we also assume that banks have the same capital adequacy ratio CAR_u. Thus the heterogeneity is the matching structure M and the collateral structure (c_u, μ_u).

Since bankers are ex-ante identical, $\sigma_{ij} = \sigma_{ji}$ whenever $q_i = q_j$. Hence capital constraints do not bind and the pair signs (κ, κ). This results in $D_{Pij} - D_{Pji} = 0$ contribution to bilaterally netted exposures between banks. The bilaterally netted exposures stem from contracts between good and bad bankers. Accordingly, the relevant variables for the coordination failure are those that relate to pairs of bankers of opposite quality. We drop banker indices, refine notation, introduce some simplfying definitions for brevity and easier interpretation of the following results. Denote[28]

$$\Delta \coloneqq (\sigma_1 + \sigma_0 - 2\sigma_0\sigma_1)\,(\sigma_0(1-\sigma_1)/\xi - 1)\,\kappa, \qquad \delta \coloneqq (\sigma_1 - \sigma_0)\kappa$$
$$\overline{k}_u \coloneqq \psi_R \sigma_0 + (\psi_A(\mathbb{E}[\alpha] + Z) - m) c_u, \qquad \underline{k}_u \coloneqq \psi_R \sigma_0 + (\psi_A(\mathbb{E}[\alpha] - Z) - m) c_u$$

[28]Recalling net regulatory capital of i, $k_i = \psi^i_R \sigma_i + \big(\psi^i_A(\zeta_i + \mathbb{E}[\alpha]) - m\big)\, c_{b_i}$, $\overline{k}_u$ and $\underline{k}_u$ the largest and smallest net regulatory capital for a bad banker in u. The purpose of the idiosyncratic component ζ_i is to generate heterogenous preferences within a bank and so we can study intensive margins.

Definition. We call Γ_{OP} the *opacity gap,* Γ_{CR} the *(capital) regulation gap, given by*

$$\Gamma_{OP} = 1 - \frac{\pi(\tau^C)}{\pi(\tau^O)}, \qquad \Gamma_{CR} = 1 - \frac{\rho_C}{\rho_O}$$

We call $\overline{N}$ the *upper novation cutoff* and $\underline{N}$ lower novation cutoff, given by[29]

$$\overline{N} = \rho_O \left(\delta - \Gamma_{\text{OP}}(\Delta + \delta)\right), \qquad \underline{N} = \rho_C \max\left\{0, \Gamma_{\text{CR}} - \Gamma_{\text{OP}}\right\}^{-1} \Gamma_{\text{OP}}\Delta$$

We call $\mathcal{N}$ the *novation gap* and $\mathcal{N}_u$ the *novation gap towards* u, given by

$$\mathcal{N} = \left(\underline{N}, \overline{N}\right), \qquad \mathcal{N}_u = \mathcal{N} \cap [\underline{k}_u, \overline{k}_u]$$

For a pair i, j that implements an insurance contract, we say i *sells insurance* to j and j *buys insurance* from i if i is a good banker and j is a bad baker.

We denote η_{uv} the mass of bankers in u that buy insurance from a banker in v, and denote π_P the pursuance rate for buying and selling insurance on $P \in \{O, C\}$:

$$\eta_{uv} := \mu_{uv}^{01}, \quad \eta_{vu} := \mu_{vu}^{01}, \quad \pi_O := \pi_O^{01} = \pi(\tau^O), \quad \pi_C := \pi_C^{01} = \pi(\tau^C)$$

Lemma 4. *The extensive margins are described by the novation gaps. If banker i buys insurance from j, they novate their contract if and only if $k_i \in \mathcal{N}$.*[30]

Additionally, $\underline{N} < \rho_C\delta$ if and only if $\frac{\Gamma_{OP}}{\Gamma_{CR}} < \frac{\delta}{\Delta+\delta}$ if and only if $\overline{N} > \rho_C\delta$. Accordingly, the novation gap is empty if and only if $\frac{\Gamma_{OP}}{\Gamma_{CR}} > \frac{\delta}{\Delta+\delta}$

The novation gap depends significantly on the opacity gap Γ_{OP} and regulation gap Γ_{CR}. As ρ_C increases up from 0 to ρ_O, $\underline{N}$ increases from 0 to ∞, with an asymptote at $\Gamma_{\text{CR}} \leq \Gamma_{\text{OP}}$. When the pair is constraint both on the OTC and the CCP, they never choose CCP if CCP transparency and CCP regulation are too high as a combination. Below this threshold, conditional on choosing CCP, the contract is constraint by the CCP regulation, which affects collateral costs. Lower CCP regulation induces lower cost of collateral per unit of collateral, which is a stronger incentive for bankers with low collateral. Denote

$$[\![\cdot]\!]_u := \min\{\overline{k}_u, \max\{\underline{k}_u, \cdot\}\}$$

Definition. The *average OTC net position towards u* is

$$\begin{aligned}\mathcal{O}_u =&(\overline{k}_u - \underline{k}_u)^{-1}\Big(\delta\left\langle \overline{k}_u - [\![\rho_O\delta]\!]_u\right\rangle + (2\rho_O)^{-1}\left\langle [\![\rho_O\delta]\!]_u^2 - [\![\max\{\overline{N}, \rho_C\delta\}]\!]_u^2\right\rangle \\ &+ (2\rho_O)^{-1}\left\langle [\![\min\{\underline{N}, \rho_C\delta\}]\!]_u^2 - \underline{k}_u^2\right\rangle\Big)\end{aligned}$$

The *average cleared net position towards u is*

$$\mathcal{C}_u =(\overline{k}_u - \underline{k}_u)^{-1}\Big(\delta\langle[\![\overline{N}]\!]_u - [\![\rho_C\delta]\!]_u\rangle + (2\rho_C)^{-1}\langle[\![\rho_C\delta]\!]_u^2 - [\![\underline{N}]\!]_u^2\rangle\Big)$$

[29] Notice $\tilde{N}_{ij} = \overline{N}$ and $\underset{\sim}{N}_{ij} = \underline{N}$ when $q_i = 0, q_j = 1$.

[30] If $\underline{N} > \overline{N}$, then $\left(\underline{N}, \overline{N}\right) = \emptyset$.

Lemma 5. *The intensive margins are described by the average OTC and cleared net positions. Equilibrium exposure scalers are given in closed form as*

$$e_{uv}^{**} = \pi_O \left(\eta_{uv}\mathcal{O}_u - \eta_{vu}\mathcal{O}_v\right)$$
$$e_{uCv}^{**} = \pi_C \left(\eta_{uv}\mathcal{C}_u - \eta_{vu}\mathcal{C}_v\right)$$

Exposure-to-u scaler is

$$e_u^{\Rightarrow} = \pi_O \sum_v \overbrace{\langle \eta_{vu}\mathcal{O}_v - \eta_{uv}\mathcal{O}_u \rangle}^{\textit{bilaterally netted}} + \pi_C \overbrace{\langle \sum_v (\eta_{vu}\mathcal{C}_v - \eta_{uv}\mathcal{C}_u) \rangle}^{\textit{"multilaterally" netted via CCP}}$$

We have $\overline{k}_u - \underline{k}_u = 2Z\psi_A c_u$ for all u. The bilaterally netted exposures and so the net expected positions in contracts determine the intensive margins. Here $\mathcal{O}_u$ is the average net position of OTC insurance sellers to buyer in u, averaged by the mass of all insurance buying bankers in u. The counterpart for novated contracts is $\mathcal{C}_u$.

As a corollary of the expression of $\mathcal{C}_u$ we see that a contract between a good banker and a bad banker $i \in u$ whose net collateral is in a middle range from $[\![\min\{\underline{N}, \rho_C\delta\}]\!]_u$ to $[\![\max\{\overline{N}, \rho_C\delta\}]\!]_u$ are novated. This pins down the novation gap. As $\underline{N} < \rho_C\delta$ and $\overline{N} > \rho_C\delta$ are equivalent, the novation gap is $([\![\underline{N}]\!]_u, [\![\overline{N}]\!]_u)$. The remaining contracts are kept OTC.

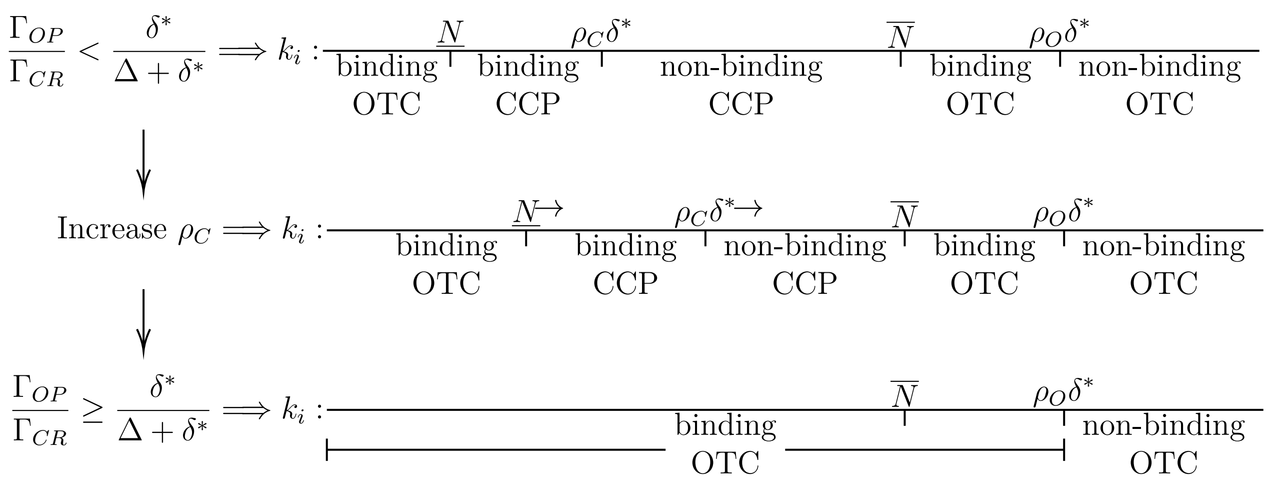


Figure 14: Novation gap as ρ_C increases

The novation gap can be used to describe the changes in the network on the *extensive margin* as it identifies which contracts move from OTC to novation in response to regulation. Lemma 5 can be used to describe the changes in the network on the *intensive margin* through the values of $\mathcal{O}_u$ and $\mathcal{C}_u$ that reflect contract sizes. Within and outside the novation gap, insurance contracts are still affected by regulation on the intensive margin, depending on whether the corresponding regulation binds or not. Inside $\mathcal{O}_u$, unconstrained contracts yield the linear term $\delta\left(\overline{k}_u - [\![\rho_O\delta]\!]_u\right)$. The constrained contracts are on the two sides of the novation gap, captured by the remaining quadratic terms. Similarly, non-binding and binding novated contracts appear inside $\mathcal{C}_u$ as the linear and quadratic terms.

Figure 14 describes the extensive margins through the novation gap, and intensive margins by the corresponding binding constraint. Note that $\overline{N}$ does not depend on ρ_C. This is because the novation decision between a pair who is constraint on the OTC but not on the CCP is independent on the CCP-regulation level. Also, $\overline{N}$ is increasing in Γ_{OP} and $\underline{N}$ is decreasing in Γ_{OP}. In fact, the novation thresholds are the sole channel through which opacity impacts extensive margins. An implication is, the more opaque the CCP is, the more it is adopted.

Corollary 2. *The CCP adoption (i.e. the novation gap $\mathcal{N}$), is decreasing in the transparency of the CCP (via increasing the opacity gap Γ_{OP}), down to no adoption (i.e. $\mathcal{N} = \emptyset$) when opacity gap becomes too high relative to regulation gap (i.e. $\Gamma_{OP} \geq \Gamma_{CR}\frac{\delta}{\Delta+\delta}$).*

CCPs come with the added transparency on top of the implicit multilateral netting. An opaque clearinghouse who provides netting without increasing transparency would achieve higher rate of adoption. The opacity gap would be 0, and all bankers would adopt the clearinghouse. In a sense, regulation aimed to promote clearing and increase transparency via reduced risk weights for CCP novation makes itself redundant. We explore this concept in more details in Section 7.2.

Then it is helpful to put recent regulation in perspective along these lines. Consider a hypothetical regulator who can choose risk weights as well as the transparency of the CCP, τ^C. Let the primary objective of this hypothetical regulator would be complete financial stability by way of reducing coordination failure probability to 0, while a secondary objective is to maximize transparency for non-modeled reasons. This regulator could maximize the opacity gap, subject to complete CCP adoption, as complete CCP adoption eliminates coordination failures.

Corollary 3. *All exposures of bank u are completely cleared regardless of the matching structure if and only if*

$$\Gamma_{OP} \geq \max\left\{\frac{\Delta + \frac{\overline{k}_u}{\rho_O}}{\Delta+\delta}, \frac{\Delta + \underline{k}_u\frac{1}{\rho_O}}{\Delta + \underline{k}_u\frac{1}{\rho_C}}\right\}$$

Corollary 3 implies that that higher ρ_O and lower ρ_C enable lower Γ_{OP} that achieves complete CCP adoption. This is consistent with the Dodd-Frank Act which explicitly aims to increase transparency (lower Γ_{OP}), and, in practice, increases ρ_O and lowers ρ_C.

Transparency can not be controlled in simple ways. So we take τ^O and τ^C as given, determined by non-modeled market micro-structure. Next we illustrate challenges to the efficacy of incentivizing clearing through imposing capital regulation.

6.2 Collateral and the efficacy of regulation

We first study intensive margins in a systemic way. We follow up on the dependence on the level of collateral as outlined in Section 5.4. We illustrate the effects on a simple and minimal matching structure that does not preclude coordination failures by default.

Definition. Call a matching structure *out-regular* if there is some η and g such that the following hold. For all u, v, $\eta_{uv} \in \{0, \eta\}$ and for all v $|\{u : (\eta_{uv}, \eta_{vu}) = (\eta, 0)\}| = g$.

When $\eta_{uv} = \eta_{vu}$, u and v do not have exposures to each other. When $(\eta_{uv}, \eta_{vu}) = (0, \eta)$, v is exposed to u. Under an out-regular matching structure, bank v can be exposed to any number of banks. The out-regularity condition means that the number of banks exposed to v is given by g, same for all v. This is, each bank sells insurance to the same number of banks. The number of banks that a given bank buys insurance from is not directly limited by out-regularity, but only indirectly, as the number of insurance sellers and buyers must always add up to the same amount.

Proposition 13. *Suppose that all banks have the same collateral structure (i.e. same mass and caliber). Assume that the matching structure is out-regular with η and g. Then $\phi^* = (\mathcal{O}\frac{1}{\mu}\pi_O g\eta + m^*)/c$.*

Since the total exposures to and from the CCPs are equal, there is at least one bank that does not expose the CCP. This bank's total outgoing OTC exposures, which is fixed by regularity, determines the probability of coordination failures. Hence, the average conditional exposure $\mathcal{O}$ is a sufficient statistic for the efficacy of regulation in reducing coordination failures.

We measure the efficacy via the average net position of OTC contracts by insurance buying bankers in u averaged by the mass of OTC insurance buying bankers in u

$$\tilde{\mathcal{O}} = \frac{\mathcal{O}}{\text{OTC prob.}} = \frac{\overline{k} - \underline{k}}{(\overline{k} - \underline{k}) - ([\![\overline{N}]\!] - [\![\underline{N}]\!])}\mathcal{O}$$

The marginal efficacy of increasing ρ_O and decreasing ρ_C is the elasticity of $\tilde{\mathcal{O}}$, defined as

$$\text{Eff}_O = -\frac{\mathrm{d}\tilde{\mathcal{O}}}{\mathrm{d}\rho_O}\frac{\rho_O}{\tilde{\mathcal{O}}} \qquad\qquad \text{Eff}_C = \frac{\mathrm{d}\tilde{\mathcal{O}}}{\mathrm{d}\rho_C}\frac{\rho_C}{\tilde{\mathcal{O}}}$$

Corollary 4. *(High collateral) In addition to Proposition 13, assume $\underline{k} > \rho_O\delta$. Then there is no novation, contracts are unconstrained, and $\mathcal{O} = \delta$. Regulation is ineffective:*

$$\mathit{Eff}_O = 0 \qquad\qquad \mathit{Eff}_C = 0$$

Fixing the extensive margins by assuming $\underline{k} > \rho_O\delta$, we see that the regulation does not bind banks that have high collateral. Novation gap is empty. All contracts are kept OTC and the probability of coordination failures do not depend on regulation on the intensive margin.

Albeit being obvious, this is relevant for the post-Dodd-Frank Era. When there is heterogeneity, high collateral banks are more likely to be the determinants of the probability of coordination failures, since Φ^* is decreasing in c. It is possible that these determinant banks with high enough collateral do not react to regulation. We explore this further later in Section 7.

Corollary 5. *(Medium collateral) In addition to Proposition 13, assume $\rho_O\delta > \overline{k} > \underline{k} > \rho_C\delta$. Then $\mathcal{O} = (4\rho_O Z\psi_A)^{-1}\left\langle \overline{k}^2 - [\![\overline{N}]\!]^2\right\rangle$.[31] For $\underline{k} < \overline{N} < \overline{k}$, all OTC contracts are constraint, but larger contracts are kept OTC whereas smaller contracts are novated. Regulation admits inefficacies:*

$$\mathit{Eff}_O = \frac{\overline{k}}{\overline{k} + \overline{N}} \in (\frac{1}{2}, 1) \qquad\qquad \mathit{Eff}_C = 0$$

The inefficacy stems from the fact that high collateral pairs have high value of opacity and are last to switch no novation as regulation gets tighter. Formally, when the random net regulatory capital is between and $[\![\overline{N}]\!]$ and $\overline{k}$, the value of opacity is positive and the pair keeps the contract OTC. These contracts are constraint by the OTC capital regulation, reflected in the ρ_O^{-1} term in $\mathcal{O}$, which makes regulation effective, but the effectiveness is hindered by the fact that the average exposure stemming from these contracts is proportional to $\frac{\overline{k}^2 - [\![\overline{N}]\!]^2}{\overline{k} - [\![\overline{N}]\!]} = \overline{k} + [\![\overline{N}]\!]$ which is increasing in ρ_O.

[31]For $\overline{N} > \overline{k}$, all contracts are novated. There is no coordination failure and efficacy is not well-defined. For $\overline{N} < \underline{k}$, there is no novation and OTC capital constraints bind all contracts. $\text{Eff}_O = 1$, $\text{Eff}_C = 0$.

Corollary 6. *(Low collateral) In addition to Proposition 13, assume* $\rho_C\delta > \overline{k}$. *Then* $\mathcal{O} = (4\rho_O Z\psi_A)^{-1}\left\langle [\![\underline{N}]\!]^2 - \underline{k}^2\right\rangle$.[32] *For* $\underline{k} < \underline{N} < \overline{k}$, *all OTC contracts are constraint, and larger contracts are novated whereas smaler contracts are kept OTC. Regulation is very effective.*

$$\mathit{Eff}_O = \frac{\underline{N}}{\underline{N}+\underline{k}}\frac{1-\Gamma_{CR}}{\Gamma_{CR}-\Gamma_{OP}} + 1 > \frac{3}{2} \qquad \mathit{Eff}_C = \frac{\underline{N}}{\underline{N}+\underline{k}}\frac{1-\Gamma_{OP}}{\Gamma_{CR}-\Gamma_{OP}} > \frac{1}{2}$$

As in the case of medium collateral, contracts are constraint by OTC regulation reflected in the ρ_O^{-1} term in $\mathcal{O}$. This makes regulation effective. Additionally, contracts with larger net positions move to novation first. The average exposure stemming from contracts that are kept OTC is $\frac{\underline{N}^2-\underline{k}^2}{\underline{N}-\underline{k}} = \underline{N} + \underline{k}$ which is decreasing in ρ_O. This adds efficacy to regulation, making it very effective.

In summary, the efficacy of regulation depends critically on the size of collateral. Regulation is more effective when the insurance buyers have less collateral. When there is heterogeneity, regulation can potentially be less effective in segments of the network that is highly collateralized. If there is a positive correlation between high collateral and interconnectedness, it is possible that parts of the network with cycles, which are the more important targets for regulation, are the least likely to react to regulation. In fact, our data also shows that post-regulation, OTC exposures in the core of the network is backed by high collateral and the core is highly interconnected with cyclic exposures.

7 Extensive margins: Dodd-Frank Act and its adverse consequences

7.1 Pre-regulation and post-regulation regimes

Having illustrated the broader forces at play on the intensive margin, we move on to a more systemic analysis on the extensive margin. Guided by the regulatory changes to capital adequacy for cleared and OTC derivative exposures implemented after the Dodd-Frank Act, we study two regimes. Pre-regulation, capital adequacy did not differ for cleared or OTC derivatives. So pre-regulation regimes involves a medium level for $\rho_O = \rho_C$. Post-regulation, regulation was made tighter for OTC exposures and made very loose for cleared contracts. So post-regulation regime involves a high ρ_O and low ρ_C. Formally, the first regime is *pre-regulation* : $\rho_O = \rho_C = \rho'$. The second regime is *post-regulation*: $\rho_O = \rho''$, $\rho_C = 0$ where $\rho'' \geq \rho'$. We compare pre-regulation with post-regulation. It is not critical that we consider $\rho_C = 0$; small enough ρ_C is sufficient for our insights. We index relevant variables with prime for pre-regulation and double prime for post-regulation.

In the light of our earlier results that highlight the significant role of collateral and of our data that shows how OTC contracts are more secured than novated contracts post-regulation, we assume there are two types of banks, $t \in \{h, l\}$, referring to high caliber/collateral and low caliber/collateral. Bank $u \in t \in \{h, l\}$ has caliber c_t, forming the basis for the collateral for each of its bankers. Bank characteristics except for matching structure is determined by their type. Replace bank indices with types except in matching structure.

[32] For $\underline{N} < \underline{k}$, all contracts are novated. There is no coordination failure and efficacy is not well-defined. For $\underline{N} > \overline{k}$, there is no novation and OTC capital constraints bind all contracts. $\text{Eff}_O = 1$, $\text{Eff}_C = 0$.

We assume $\underline{k}_h \geq \overline{N}' \geq \overline{k}_l$. This reflects the idea that h banks have more collateral. This also means that we focus on levels of regulation that is not too constraining for banks with highest collateral. After all, one could theoretically set $\rho' = \infty$, effectively banning OTC, and ensure that all net exposures are cleared.

Lemma 6. *The changes on the extensive margin are described by the novation gap as follows. Pre-regulation, the novation gap is empty towards both h and l: $\mathcal{N}'_t = \emptyset$. Post-regulation, novation gap towards $t \in \{l, h\}$ is $\mathcal{N}''_t = (\underline{k}_t, [\![\overline{N}'']\!]_t)$. In particular, all contracts in which a banker in an l bank buys insurance are novated: $\mathcal{N}''_l = [\underline{k}_l, \overline{k}_l]$. All contracts in which a banker in an h bank buys insurance are kept OTC: $\mathcal{N}''_h = \emptyset$.*

The changes on the intensive margin are described by the average net positions as follows. Cleared exposures have $\mathcal{C}'_t = 0$ and $\mathcal{C}''_t \equiv \delta$. The latter means that novated contracts by low collateral bankers generate large net positions post-regulation. OTC exposures have $\delta \geq \mathcal{O}'_h \geq \mathcal{O}''_h > 0$, $\mathcal{O}'_h > \mathcal{O}'_l > 0$, and $\mathcal{O}''_l = 0$. In particular, high collateral insurance buyers generate weakly smaller net positions post-regulation than pre-regulation. Low collateral insurance buyers generate strictly smaller net positions than high collateral buyers pre-regulation. Additionally, if $\underline{k}_h > \delta\rho'$, then $\mathcal{O}'_h = \mathcal{O}''_h = \delta > \mathcal{O}'_l$. This means that if high collateral bankers have sufficiently large collateral, their pre-regulation and post-regulation OTC contracts are identical with large net positions.

Pre-regulation and and post-regulation exposure-to-v for $v \in h$ are

$$
\begin{aligned}
e'^{\Rightarrow}_{v\in h} &:= \pi_O \mathcal{O}'_h \sum_{u\in h} \langle \eta_{uv} - \eta_{vu} \rangle + \pi_O \sum_{u \in l} \langle \mathcal{O}'_l \eta_{uv} - \mathcal{O}'_h \eta_{vu} \rangle \\
e''^{\Rightarrow}_{v\in h} &:= \pi_O \mathcal{O}''_h \sum_{u\in h} \langle \eta_{uv} - \eta_{vu} \rangle + \pi_C \sum_{u \in l} \delta \eta_{uv}
\end{aligned}
$$

Pre-regulation and post-regulation exposure-to-v scalers for $v \in l$ are

$$
\begin{aligned}
e'^{\Rightarrow}_{v\in l} &:= \pi_O \mathcal{O}'_l \sum_{u\in l} \langle \eta_{uv} - \eta_{vu} \rangle + \pi_O \sum_{u \in h} \langle \mathcal{O}'_h \eta_{uv} - \mathcal{O}'_l \eta_{vu} \rangle \\
e''^{\Rightarrow}_{v\in l} &:= \pi_C \delta \Big\langle \sum_{u\in l} (\eta_{uv} - \eta_{vu}) - \sum_{u\in h} \eta_{vu} \Big\rangle + \pi_O \sum_{u\in h} \mathcal{O}''_h \eta_{uv}
\end{aligned}
$$

7.2 Co-movement necessity between core and periphery

Pre-regulation, exposures between h banks and l banks are OTC, and all are bilaterally netted. Post-regulation, gross exposures between h and l banks wherein h bank is a buyer remains OTC, but the gross exposures wherein l bank is a buyer is novated. Therefore, these contracts and corresponding exposures are *de-coupled* and exposures are *not bilaterally netted anymore*. Then h insurance sellers expose the CCP instead of exposing l insurance buyers, and l insurance sellers expose h insurance buyers in gross terms instead of netted terms. Exposures to h increase by the shift of l insurance buyers to novation, which substitute gross exposures of l buyers to h with net exposures of CCP to h. Exposures of h to l increase by the same de-coupling.

The former is reflected in the change from $\sum_{u\in l} \langle \mathcal{O}'_l \eta_{uv} - \mathcal{O}'_h \eta_{vu} \rangle$ in $e'^{\Rightarrow}_{v\in h}$ to $\sum_{u\in l} \delta \eta_{uv}$ in $e''^{\Rightarrow}_{v\in h}$. In addition to increase in exposures to h due to the *de-coupling*, the exposures to h that are shifted from OTC to CCP increase average contract size $\mathcal{O}'_l$ to δ but decrease in pursuance rate from π_O to π_C. We can show $\pi_C \delta > \pi_O \mathcal{O}'_l$, meaning that the CCP becomes *heavily exposed* to h with large assets, without receving the corresponding de-coupled liabilities to its balance sheet, as h insurance buyers do not clear exposures as they highly value their opacity. But these liabilities do remain in the system.

The latter is reflected in the change from $\pi_O \sum_{u\in h} \langle \mathcal{O}'_h \eta_{uv} - \mathcal{O}'_l \eta_{vu} \rangle$ in $e'^{\Rightarrow}_{v\in h}$ to $\pi_O \sum_{u\in h} \mathcal{O}''_h \eta_{uv}$ in $e''^{\Rightarrow}_{v\in h}$. There is an increase on the extensive margin due to the same de-coupling, but it is reduced on the intensive margin through the change from $\mathcal{O}'_h$ to $\mathcal{O}''_h$. Which effect dominates is ambiguous.

The de-couping is precisely due to a violation of co-movement necessity. There is a *tradeoff between multilateral netting and bilateral netting.* The probability of a coordination failure can potentially increase. We call this *the unintended consequence.* Notice that this is a consequence of reducing CCP risk weights, not increasing OTC risk weights. We highlight the co-movement necessity between h and l banks in a systemic way next and flesh out the unintended consequence.

Guided by the financial networks observed in practice and our empirical findings, we focus on the so called "core-periphery networks." In these networks, loosely speaking, the core banks are densely connected to each other whereas the periphery banks are loosely connected to each other but relatively more connected to core banks.

Definition. The matching structure is *uniformly peripheral* if $\eta_{uv} = \eta_{vu}$ for all $u, v \in l$.

This is, l bankers match each other at similar rates. A uniformly peripheral matching structure induces a network that is a split graph, generically.[33] Then in the induced system there is a link between every pair of banks, except pairs of l banks. This is loosely a necessary condition for a core-periphery network wherein h would be the core banks and l would be the periphery banks.[34]

Definition. The matching structure is *cross-connected* if $\sum_{u\in l} \eta_{uv} > 0$ for all $v \in h$, $\sum_{u\in h} \eta_{uv} > 0$ for all $v \in l$, and $\sum_{u\in h} \eta_{uv}\eta_{vu} > 0$ for all $v \in l$.

Cross-connected means that each h bank sells insurance to at least one l bank and each l bank sells insurance to at least one h bank.

Theorem 2. ***(Unintended consequence)***

Suppose that $\rho = \rho'$. If the matching structure is uniformly peripheral, then $\phi^*_{pre} \leq \phi^*_{pos}$. If additionally the matching structure is cross-connected, $\phi^*_{pre} < \phi^*_{pos}$.

Reducing CCP risk weights in a core-periphery network violates co-movement necessity in the clearance of exposures between the core and the periphery. The probability of coordination failures increase as a consequence.

In core-periphery networks which emerge from uniformly peripheral matching structures, there are no cycles among periphery (l) banks and so all cycles of exposures must primarily involve core (h) banks. Cycles are a prerequisite for coordination failures and coordination failure probability increases with regulation. This naturally puts core banks at the center of attention.

[33] A split graph is one which one group of nodes form a clique, and within the remaining set of nodes there are no links. There can be links between the two group of nodes.

[34] For our results what matters is that $\max_{u,v\in l} |\eta_{uv} - \eta_{vu}|$ is small enough. Exact equality is not essential. Notice that if $\max_{u,v\in l} \eta_{vu}$ is small, then so is $\max_{u,v\in l} |\eta_{uv} - \eta_{vu}| \leq \max_{u,v\in l} \eta_{vu}$. In terms of the relationship of uniformly peripheral matching structure to core-periphery, a small enough $\max_{u,v\in l} |\eta_{uv} - \eta_{vu}|$ means there are some (weak) links across "periphery" l banks, which does not impact our results.

On the empirical side, it is usually thought that so called core banks are systemically important and pose the major contagion threat to financial stability. After Dodd-Frank Act, OTC risk weights were increased, but at the same CCP risk weights were lowered. We took $\rho = \rho'$ in this proposition to highlight the primary reason behind the unintended consequence. The de-coupling of exposures between the core and the periphery and the violation of co-movement necessity is because CCP risk weights are reduced, not because OTC risk weights are increaesed. OTC risk weights can hypothetically cover for the damage done by the reduction in CCP risk weights, but this does not happen in core-periphery networks with a high-collateral core:

Theorem 3. ***(Collateral adjustment)*** *If the matching structure is uniformly peripheral and* $\underline{k}_h > \rho'\delta$*, then* $\phi^*_{pre} \leq \phi^*_{pos}$*. If additionally the matching structure cross-connected,* $\phi^*_{pre} < \phi^*_{pos}$*.*

If the network is core-periphery and the core banks already have sufficiently high collateral (or can adjust their collateral to sufficiently high levels), the regulation increases the probability of coordination failures through the unintended consequence (which is the violation of co-movement necessity for the exposures between the core and the periphery by reducing CCP risk weights), regardless of the magnitude of tightening in OTC capital regulation.

In order to focus more on extensive margins, we assume $\underline{k}_h > \rho''\delta$ in the remainder. This is, high collateral banks have (or can raise) enough capital so that capital requirements do not bind their OTC exposures.

7.3 Co-movement necessity and cyclic clearing in the core

Two key properties of the extensive margins underlie the unintended adverse consequence. First, the periphery banks have low or close matching rates so that multilateral netting does not generate significantly more benefits than bilateral netting. Second, some bankers in a given periphery bank can buy from and sell insurance to bankers in a given core bank, meaning there is room for bilateral netting between the core and the periphery. Pre-regulation these contracts would bilaterally net out. Post-regulation, this benefit of bilateral netting is removed and the systemic exposures to core increases. Since periphery l banks' exposure to each other already net out due to having close matching rates, moving the exposures of the periphery to the core from OTC to clearing does not reduce the exposure of the CCP to the periphery. So multilateral netting does not provide any benefit.

The former property that periphery banks have close-by matching rates to each other is implied by a commonly held view that periphery banks are not major trading counterparties of each other, i.e. periphery-to-periphery matching rates are small. The latter property is unclear. So for the sake of robustness we remove the second property by considering the more general cases of trading patterns between the core and the periphery:

Definition. A bank v is a *downstreamer* if $\eta_{uv} = 0$ whenever $u \in h, v \in l$, or if $\eta_{vu} = 0$ whenever $u \in l, v \in h$. It is an *upstreamer* if $\eta_{uv} = 0$ whenever $u \in l, v \in h$, or if $\eta_{vu} = 0$ whenever $u \in h, v \in l$. It is a *streamer* if it is a downstreamer or an upstreamer.

A matching structure is *downstreamed* if all banks are downstreamers: $\eta_{uv} = 0$ for all $u \in h, v \in l$. It is *upstreamed* if all banks are upstreamers: $\eta_{uv} = 0$ for all $u \in l, v \in h$. It is *streamed* if all banks are streamers: for any $v \in t \in \{h, l\}$ and $t' \in \{h, l\} \backslash \{t\}$, either $\sum_{u \in t'} \eta_{uv} = 0$ or $\sum_{u \in t'} \eta_{vu} = 0$.

Downstreamer l banks do not sell insurance to h banks and downstreamer h banks do not buy insurance from l banks. Upstreamer h banks do not sell insurance to l banks and upstreamer l banks do not buy insurance from h banks. In a downstreamed matching structure, the l banks do not sell insurance to h banks. In an upstreamed matching structure, h banks do not sell insurance to l banks. In a streamed matching structure, each bank either never buys insurance from the other type, or never sells insurance to the other type. Notice that a streamed matching structure is never cross-connected.

A downstreamed//upstreamed uniformly peripheral matching structure generates a core-periphery structure wherein the core//periphery sells insurance to the periphery//core, but not vice-versa.

Theorem 4. ***(Redundancy without the unintended consequence)*** *Suppose the matching structure is uniformly peripheral and streamed. Then $\phi^*_{pre} \leq \phi^*_{pos}$. Additionally, if the matching structure is upstreamed, $\phi^*_{pre} = \phi^*_{pos}$.*

In core-periphery networks where the core banks have (or can raise) sufficiently high collateral, regulation fails to achieve cyclic clearing in the core, even when the network does not require pro-clearing outside the core. Hence regulation does not reduce the probability of coordination failures, regardless of the tightening in OTC risk weights.

The unintended consequence of Theorem 2 is shut down in Theorem 4. A streamed matching structure is never cross-connected. There is no bilateral netting of bought and sold OTC insurance between the core and the periphery when the matching structure is streamed. The OTC exposures of $v \in h$ to l banks on the extensive margin does not get reduced by the fact that l banks shift their insurance purchases from h banks to central clearing. Bank v is either an explicit seller of insurance to l, or an explicit buyer of insurance from l. Hence the gross total exposures to v stemming from buying from and selling insurance to v is equal to the bilaterally netted exposure on the extensive margin.[35]

Following along these lines, in a "streamed" core-periphery, periphery do not have links with each other, and each bank either explicitly sells insurance to or buys insurance from the other side of the network. Thus, the only cycles are inside the core. Moreover, co-movement necessity is reduced down to only the exposures within the core. The net exposures between the core and the periphery are equal to the underlying gross exposure due the streamed structure. Hence there is no co-movement necessity for the exposures between the core and the periphery. The contracts between bankers of the same type are effectively unregulated and unconstraint, and do not react to any regulation. So co-movement necessity can not be violated between bankers of the same quality. The gross exposures within the periphery can not violate the co-movement necessity either. As periphery banks have the same type l and are ex-ante symmetric, $\eta_{uv} = \eta_{vu}$ ensures that their gross exposures to each other always cancel out. Even if a gross exposure is cleared in the wrong direction, an identical gross exposure is cleared in the right direction in response to regulation. The initial violation of co-movement necessity is canceled out. In this sense, bi-stream and uniformly peripheral matching structures generate core-periphery networks wherein co-movement necessity applies only to exposure within the core, and the "unintended consequence" is shut down. Consequently the focus on core banks: cycles are in the core and co-movement is a necessity is only for exposures inside the core.

Nevertheless, the core has high collateral, and reacts poorly to regulation for reasons described in Section 6.2. So the only relevant target of regulation on the network topology that makes

[35] This is, $\sum_{u \in l} \langle x\eta_{uv} - x'\eta_{vu} \rangle = \sum_{u \in l} x\eta_{uv}$ for any $x, x' > 0$.

central clearing a necessity in the first place (the core) is the part that reacts the least (high collateral). This insight is primarily about the extensive margins, so we have highlighted it by taking $\underline{k}_h > \rho''\delta$, which implies that the average net positions of OTC contracts, $\mathcal{O}''_h$ and $\mathcal{O}'_h$ are equal to δ. Then there is no change on the intensive margin of OTC exposures to the core. The intensive margins of exposures of the periphery to the core bank v change via the change from $\pi_O \sum_{u\in l}\langle \mathcal{O}'_l \eta_{uv} - \mathcal{O}'_h \eta_{vu}\rangle$ on OTC to $\pi_C \delta \sum_{u\in l} \eta_{uv}$ on CCP. In this change, the effect of contract size is dominant over pursuance: $\pi_C\delta > \pi_O \mathcal{O}'_l$ holds. So if v is a downstreamer, exposures to v increase strictly. If v is an upstreamer, exposures to v do not change as $\sum_{u\in l}\eta_{uv} = 0$. Therefore, at the "best" case, which is when the matching structure is upstream, the contagion cutoffs do not change and the probability of a coordination failure is unchanged, despite large amounts of novation.

7.4 General redundancy

So far we have compared pre-regulation $(\rho_O, \rho_C) = (\rho', \rho')$ with post-regulation $(\rho_O, \rho_C) = (\rho'', 0)$. Now think of a hypothetical alternative-regulation. Define a "clearinghouse" (CLH) as a hypothetical CCP with the same level of transparency with the OTC. This means, for the clearinghouse CLH, the opacity gap is $\Gamma'''_{\mathrm{OP}} = 0$. The risk weights are $(\rho_O, \rho_C) = (\rho'''_O, \rho'''_C)$. OTC contracts are subject to ρ'''_O and clearinghouse contracts are subject to ρ'''_C. This can be any arbitrary level of risk weights between pre-regulation and post-regulation, with the only requirement that OTC regulation is tighter than CCP regulation. Formally, $\rho'''_O \in [\rho', \rho'']$, $\rho'''_C \in [0, \rho']$, and $\rho'''_O > \rho'''_C$. Notice that this allows for $\rho'''_O = \rho' + \epsilon$, $\rho'''_C = \rho'$, and $\rho'''_O = \rho'$, $\rho'''_C = \rho' - \epsilon$, which are arbitrarily close regulation levels to pre-regulation. Using the alternative-regulation regime we formalize the notion of redundancy.

Definition. We say that the regulation is *(weakly redundant) // (redundant) // (strictly redundant)* if alternative-regulation coordination failure cutoff is (equal to) // (weakly smaller than) // (strictly smaller than) the post-regulation coordination failure cutoff. We say that the regulation is *strongly redundant* if it is strictly redundant and alternative-regulation coordination failure cutoff is strictly smaller than pre-regulation coordination failure cutoff.

Theorem 5. ***(General redundancy)*** *The system under post-regulation and alternative-regulation are identical except for average net positions towards low collateral insurance buyers: $\mathcal{C}''_l = \delta \geq \mathcal{C}'''_l$. Thus, regulation is redundant.*

If $\rho'''_C < \underline{k}_l/\delta$, the post-regulation and alternative-regulation systems are identical: $S'' = S'''$. Thus the regulation is weakly redundant.

If clearing would not entail more transparency, a small change[36] *in the regulation gap by increasing OTC risk weights or decreasing CCP risk weights in the pre-regulation regime would achieve the post-regulation regime's outcome. The regulation makes itself redundant as the opacity gap between OTC and CCP cancels out the regulatory gap between two regimes.*

On the extensive margin, whatever the current regulation "achieves" can be achieved by CLH under arbitrary risk weights lying in-between pre-regulation and post-regulation. Increased transparency and adjusted risk-weights is a redundant combination. One undoes the other.

[36] Just enough to compensate the additional costs of clearing with CCPs, such as agency, monitoring, default fund contributions,.. which are assumed to be negligible in our model. Since these costs are assumed to be negligible, the condition is as stark as $\Gamma_{\mathrm{CR}} > 0$.

The lower novation threshold $\underline{N} = \rho_C \max\{0, \Gamma_{\text{CR}} - \Gamma_{\text{OP}}\}^{-1} \Gamma_{\text{OP}}\Delta$, which controls the extensive margins for low collateral insurance buyers, is increasing in Γ_{OP}, decreasing in Γ_{CR}, and decreasing in ρ_C. The upper novation threshold $\overline{N} = \rho_O (\delta(1 - \Gamma_{\text{OP}}) - \Gamma_{\text{OP}}\Delta)$, which controls the extensive margins for high collateral insurance buyers, is decreasing in Γ_{OP} and increasing in ρ_O. By increasing ρ_O, decreasing ρ_C, and consequently increasing Γ_{CR}, the novation gap becomes larger. Yet if the opacity gap is large enough relative to the regulatory gap, the enlargement of the novation gap can be undone. This is, the current form of regulation that promotes transparency and clearing through CCPs un-does itself by increasing the opacity gap, making the adjustments to risk weights partially or fully redundant. There is an extra subtle redundancy hidden in the lower novation threshold $\underline{N}$. The novation gap can be enlarged to include more low collateral insurance buyers by reducing $\underline{N}$, which the current regulation implements by low ρ_C (we take $\rho_C = 0$ for simplicity). But this can also be implemented by low Γ_{OP}, as long as Γ_{CR} is not too small. If clearance of exposures would not entail increased transparency, even a small regulatory gap would achieve the outcome of the current from of regulation that implements a large opacity gap by way of low CCP risk weights, and a large regulatory gap. Large opacity gap and large regulatory gap by way of low CCP risk weights is a redundant combination for low collateral trades. Small opacity gap and small regulatory gap can achieve the same outcome. These redundancies are inherent in bankers' incentives and naturally find their counterparts in exposures. They are general phenomena regardless of our assumption dividing banks into high and low collateral banks.

Under our assumption regarding the types of banks, all net exposures of h insurance buyers remain OTC and all net exposures of l insurance buyers are cleared in either case of post-regulation or alternative-regulation, as long as alternative OTC regulation is tighter than alternative CCP regulation, no matter by how much. As the collateral of high collateral banks is large enough, high collateral insurance buyers are not constrained by the OTC risk weights in either regime and their margins do not change. The low collateral insurance buyers novate their contracts, and they are not constrained post-regulation. In the alternative-regulation regime, they can be constraint by larger CCP risk weights, which can reduce their, which can reduce the probability of coordination failures. If alternative regulation, for some reason, features low CCP risk weights, then the resulting systems in post-regulation and alternative-regulation regimes are identical.

7.5 Regulating the core is strongly redundant

Perhaps "achieving" the same outcome with post-regulation or even a better outcome than post-regulation is not desirable for reasons we have highlighted earlier. Probability of coordination failures can be higher in post-regulation than in pre-regulation. When alternative regulation, for some reason, sets low CCP risk weights, the alternative-regulation system is identical to the post-regulation system which is weakly worse than pre-regulation due to weak redundancy. If the CCP risk weights were not low, it is possible that the alternative-regulation is strictly better than post-regulation. It can even be possible than the alternative-regulation is strictly better than pre-regulation and post-regulation, which is *strong redundancy.*

Theorem 6. ***(Strong redundancy of regulating the core)*** *Suppose that $\frac{c_h}{c_l} > \frac{\kappa}{m^*} + 1$. Let the matching structure be uniformly peripheral and downstreamed. Take an alternative regulation that does not reduce the CCP risk weights: $\rho_C''' = \rho_O'$. In all regimes, the probability of coordination failures are determined by the exposures to core banks: $\phi^* = \phi_h^*$. Exposure within the core are the same on the extensive and intensive margins across all regimes. Exposure of the* *periphery to the core vary, making alternative regulation strictly better than pre-regulation, and pre-regulation strictly better than post-regulation:* $\phi^*_{alt} < \phi^*_{pre} < \phi^*_{post}$. *The regulation is strongly redundant.*

For a core-periphery network where the core has large collateral and supplies insurance to the periphery, a regulation that introduces a large regulatory gap between risk weights of OTC and cleared derivatives in order to promote clearing through a (transparent) CCP strictly hurts stability. A slight regulatory gap to promote clearing through an (opaque) clearinghouse would have strictly improved stability.

This is our pinnacle result. We consider a core-periphery network wherein the core supplies insurance to the system and it has large capital, or can raise its capital, so that the tightening OTC regulation does not bind the core to the point of being forced to clearing. Due to high capital, the core is safer than the periphery and so coordination failures are determined by the default probabilities of the core. The systemic events are trigged by bad aggregate shocks that destabilize the core through lack of coordination on cycles. Defaults then spread to the periphery.

Given that the core is an insurance supplier, the unintended consequence does not hurt stability. The net exposures between the core and the periphery are the same with their gross counterparties. Also, the periphery is never net-exposed to each other as they have similar insurance needs. Therefore, the exposures to core, including the exposures of the core to itself and exposures of the periphery/CCP to the core, are the sole targets of regulation on the extensive and intensive margins. The cycles are explicitly inside the core, and cycles are the triggers of coordination failures, meaning that the exposures within the core are the primary targets of regulation on both margins. But the core has high capital, the exposure within the core react neither on the extensive nor the intensive margins. This makes regulation ineffective and redundant. The alternative regulation does not help the exposure within the core either: the CLH has small added costs similar to the CCP so the unconstrained core-to-core exposures remain OTC.[37]

On the other hand, exposures of the periphery to the core react on both the extensive and intensive margins. The regulation shifts these exposures to clearing. On the extensive margin these become the exposures of the CCP to the core. On the intensive margin, exposures change by two components. First is the probability of insurance that reduces exposures due to transparency. Second is the average position, which increases since CCP risk weights are lower than OTC risk weights, making the contracts less constraint, and larger. The regulation's CCP risk weights are too small, so even the low collateral banks are unconstrained, which makes the average position very large, which dominates the reduced probability of insurance. The regulation increases exposures to the core. Alternatively, CLH risk weights can be kept high, which would constrain low capital banks, reduce the contract size, which would then reduce exposures together with the reduced probability of insurance. Therefore, the regulation is strongly redundant: CLH is better than OTC, which is better than CCP, in terms of stability. This is, the regulation increases the probability of coordination failures. An alternative form of regulation which does not introduce transparency, but increases OTC risk weights without reducing CCP risk weights would reduce the probability of coordination failures compared to pre-regulation regime, let alone the post-regulation regime.

Finally note that we shut down the unintended consequence in Theorem 6 by assuming a

[37] Additionally, the CLH could have slightly larger transparency than OTC, although not as high as the CCP.

downstreamed matching structure. If the matching structure is not streamed, the exposures to the core increase furthermore through the unintended de-coupling, making the CCP heavily exposed to the core. This creates a "stronger" redundancy. If the CCP is exposed to non-modeled risks, the unintended consequence can create further adverse consequences. We aim to explore this in future work.

8 Welfare

We have shown how the probability of coordination failures increase when large banks have high capital. This is because there is not enough novation on the part of the network that actually requires clearing in order to mitigate coordination failures. Insurance gains are decreasing in transparency. The welfare components other than insurance gains are decreasing in the probability of a coordination failure. Thus the regulation decreases welfare in environments we have studied with core-periphery networks. For the sake completeness we also consider identical banks (except for the matching structure) and consider various scenarios to dissect the welfare effects of a CCP into various components. This helps put the regulation in better perspective besides the adverse consequences that arise under heterogeneity.

Regarding the dimension of probability of a coordination failures, the best-case scenario is when OTC is banned so that all implemented contracts are implemented on CCP. Technically this corresponds to $\rho_O = \infty, \rho_C < \infty$.[38] On the other hand, the benchmark scenario is when $\rho_O = \rho_C < \infty$. In this case, all implemented contracts are implemented on OTC. The economy is effectively unregulated on the extensive margin as there is no novation, regulated on the intensive margin depending on the value of $\rho_O = \rho_C < \infty$. We want to understand the welfare implications of clearing. The effects on the intensive margins are important but they are of secondary interest. For this reason we highlight extensive margins and focus on cases $(\rho_O, \rho_C) = (\infty, 0)$ and $(\rho_O, \rho_C) = (0, 0)$. The former constitutes a *cleared economy* wherein all implemented contracts are unconstrained, and implemented on CCP, whereas the latter constitutes an *uncleared economy* wherein all implemented contracts are unconstrained, and implemented on OTC.

The second important dimension to consider is the level implied transparency. OTC and CLH yield τ_O transparency whereas CCP yields τ_C transparency. Then notice that by setting $\rho' = \rho_C''' = 0$ $\rho'' = \rho_O''' = \infty$, the pre-regulation regime is an uncleared opaque (τ_O) economy, post-regulation regime is a cleared transparent (τ_C) economy, and the alternative-regulation regime is a cleared opaque economy. We call the first economy the *OTC-economy:* $(\rho_O, \rho_C) = (0, 0)$ with τ_O. The second is called the *CCP-economy*: $(\rho_O, \rho_C) = (\infty, 0)$ with τ_C. The last one is called

[38]Recall that bankers of same quality never novate their contracts because success probabilities are ex-ante identical. This is seen in the internal capital constraint $k_i \geq \rho_O(D_{ii^*} - D_{i^*i}) = 0$ since $D_{ii^*} - D_{i^*i} = 0$ between bankers of same quality. This means internal OTC capital constraint never binds. For any given ρ_O, this is robust to sufficiently small perturbations in success probabilities, making them possibly slightly different across bankers of same quality. So bankers of same quality can not be endogenously induced to novate their contracts. But for any given perturbation of success probabilities bounded away from 0, there is a large enough ρ_O all bankers are induced to novate their contracts. Regardless of one's view on size of OTC regulation relative to perturbations of success probabilities, the contribution of these contracts to net exposures is negligible. But the effect of clearing on welfare is only exposure scalers in Φ. Therefore, in so far as welfare is the concern, it is without loss to assume that all implemented contracts are implemented on CCP, not only those between bankers of same quality under $\rho_O = \infty$. We take the view that all are on CCP when $\rho_O = \infty$ which allows for a broader range of interpretations, including the outright banning of OTC and enforced novation whenever the contracts are not annulled.

a *CLH-economy*: $(\rho_O, \rho_C) = (\infty, 0)$ with τ_O. For completeness let the uncleared transparent economy be called *EXC-economy,* $(\rho_O, \rho_C) = (0, 0)$ with τ_O, referring to the similarity between exchanges and the combination of no-netting with high transparency:

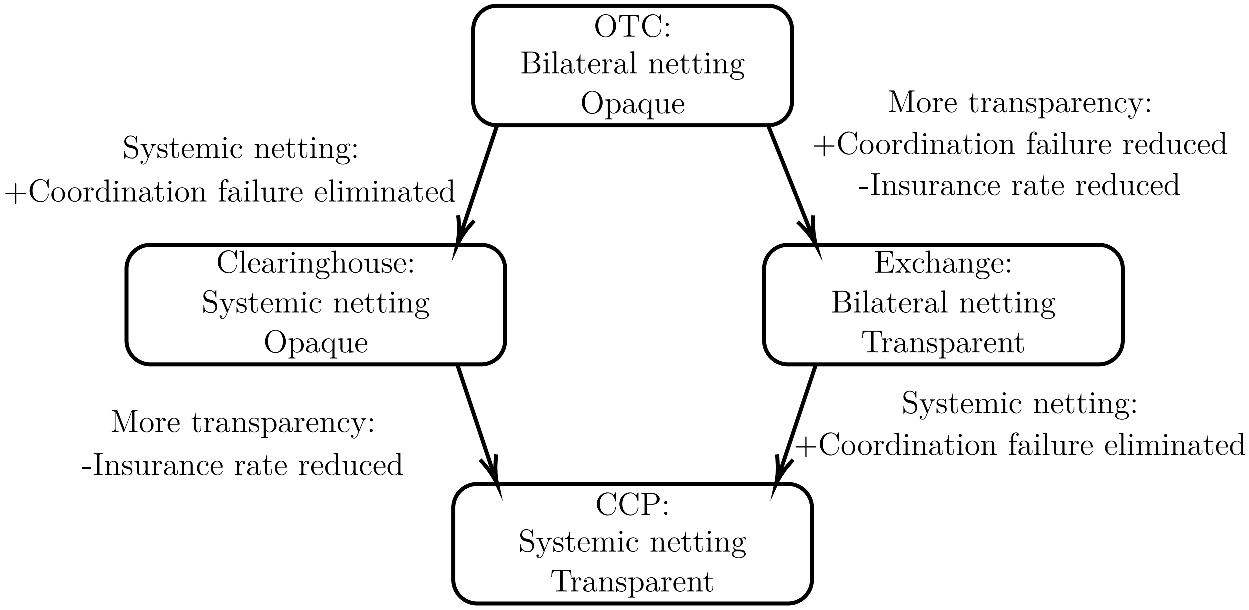


Figure 15: Dissection of the CCP

At a high level, we call the netting benefits $W_{CLH} - W_{OTC}$ and $W_{CCP} - W_{EXC}$ the *clearinghouse effects.* We call $W_{EXC} - W_{OTC}$ and $W_{CCP} - W_{CLH}$ the *transparency effects.* Transparency alone improves financial stability by reducing coordination failure probability. To the extent that transparency is successful in improving financial stability, the added stability through the clearinghouse effect is reduced. In reverse, the clearinghouse effect readily improves stability more effectively than transparency possibly can. Thus all potential stability benefits of the transparency effect are subsumed into the clearinghouse effect. The consequences of introducing transparency on top of a clearinghouse remain outside of the implications of stability. Therefore -if- one believes that main benefit of market transparency is to improve stability whether for the sake of welfare or for the sake of stability itself as the objective, then a CCP is redundant. A clearinghouse would have been equally effective. In fact, whatever negative welfare consequences transparency might have can cancel out stability benefits of the clearinghouse effect. Somewhat paradoxically, this redundancy of the CCP is more pronounced when the CCP's implied level of transparency is more effective in achieving stability by itself. For example, suppose for illustration that the transparency benefits are fixed. Then

$$
\begin{aligned}
&W_{CCP} - W_{OTC} = (W_{CCP} - W_{EXC}) + (W_{EXC} - W_{OTC}) \\
&= \text{ClearinghouseEffect}(\tau_C) + \text{TransparencyEffect}(\tau_O \to \tau_C) \\
&= \text{StabilityBenefit}(\Phi^*(\tau_C) \to 0) + \text{StabilityBenefit}(\Phi^*(\tau_O) \to \Phi^*(\tau_C)) \text{ - InsuranceLoss}(\tau_O \to \tau_C) \\
&= \text{StabilityBenefit}(\Phi^*(\tau_O) \to 0) \text{ - InsuranceLoss}(\tau_O \to \tau_C) \\
&= \text{ClearinghouseEffect}(\tau_O) \text{ - InsuranceLoss}(\tau_O \to \tau_C) \\
&= (W_{CLH} - W_{OTC}) + (W_{CCP} - W_{CLH})
\end{aligned}
$$

In practice, the clearinghouse effect's benefits depend on the status-quo upon which clearing is imposed. Therefore, clearinghouse effect benefits are reduced if stability is already improved otherwise. In reverse, if clearinghouse effect is introduced, other effects that improve stability are redundant, such as through transparency. But if there is a tradeoff within the transparency effect, which is the case for $W_{EXC} - W_{OTC}$, all stability improving effects inside the transparency could actually be harmful as they reduce remaining benefits inside the transparency effect. For a thought exercise, suppose that the benefits of transparency effect is fixed. This is, all "uncleared" economies, in particular OTC-economy and EXC-economy have the same welfare. Then

$$\begin{aligned}0 =& \text{TransparencyEffect}(\tau_O \to \tau_C)\\ =& \text{StabilityBenefit}(\Phi^*(\tau_O) \to \Phi^*(\tau_C)) \text{ - InsuranceLoss}(\tau_O \to \tau_C)\end{aligned}$$

Introducing a large opacity gap and widening $\tau_C - \tau_O$ increases StabilityBenefits$(\Phi^*(\tau_O) \to \Phi^*(\tau_C))$, which increases InsuranceLoss$(\tau_O \to \tau_C)$. But the clearinghouse effect introduces the maximum stability to whichever status-quo economy it is imposed upon. Seeing the clearinghouse effect as this flexible benefit,

$$W_{CCP} - W_{OTC} = \text{ClearinghouseEffect - InsuranceLoss}(\tau_O \to \tau_C)$$

This is, trying to improve stability through increased transparency or increased opacity gap is redundant and subsumed into the clearinghouse effect and the corresponding increases in insurance losses can reduce welfare if imposed transparency is too high. Alternatively, the larger the CCP transparency is, the less effective is the CCP. Thus it is mistaken to think of CCPs transparency aspect as beneficial as long as one believes transparency benefits are mainly due to stability.

Next we formalize the welfare analysis. Let $W(\tau, \Phi)$ welfare in a partial equilibrium wherein the probability of a coordination failure is Φ and transparency is τ in the payoff functions of the infinitesimal agents, as shown below in the list of equations (7). Note that this is well-defined regardless of CCP or CLH adoption because the effect of exposures and netting on welfare is solely through Φ.

$$\begin{aligned}W(\tau, \Phi) &= \sum_u W_u(\tau, \Phi) \qquad (7)\\ W_u(\tau, \Phi) &= W^{\text{fin}}(\tau) + W_u^{\text{ins}}(\tau, \Phi) + W^{\text{pro}}(\Phi) + W^{\text{inv}}(\Phi) + W^{\text{sha}}(\Phi) + W^{\text{cre}}(\Phi)\\ W^{\text{fin}}(\Phi) &= \mu(\overbrace{1-\Phi}^{\text{C.F. prob.}})\ (\overbrace{\pi(0)(rs' + \theta\beta)}^{\text{financing utility to bankers}}))\\ W_u^{\text{con}}(\tau, \Phi) &= (1-\Phi)\Big(J_{00}\sum_v \mu_{uv}^{11} + \pi(\tau)J_{10}\sum_v(\mu_{uv}^{10} + \mu_{uv}^{10}) + \pi(\tau)^2 J_{00}\sum_v \mu_{uv}^{00}\Big)\beta\theta\Big/2\\ W^{\text{pri}}(\Phi) &= \mu(1-\Phi)(\quad\underbrace{\mathbb{E}[\alpha|\alpha > \phi_\Phi]c}_{\text{proj. value cond. on no C.F.}}\quad - r)\xi\theta s''\\ W^{\text{inv}}(\Phi) &= \mu\frac{\pi(0)}{2\overline{\omega}}\left(\left(\overline{\omega}\big/\pi(0)\right)^2 + (\Omega_{u,\Phi}\omega^*)^2\right)\\ W^{\text{sha}}(\Phi) &= V_Q((1-\Phi)\mu(\mathbb{E}[\alpha|\alpha > \phi_\Phi]c - m + (1-s-s')\pi^0 rs'))\\ W^{\text{cre}}(\Phi) &= V_A(\mu((1-\Phi)m - m'))\end{aligned}$$

Partial equilibrium welfare for u, $W_u(\tau, \Phi)$, captures the contribution of the activities of bank u. In it, $W^{\text{fin}}(\Phi)$ is the payoff of financed bankers from investing in investments and getting a share of returns. $W_u^{\text{con}}(\tau, \Phi)$ is the contracting gains of bankers that consist of insurance gains less the cost of collateral. This includes the matching rates, insurance probability, and $\frac{1}{2}\beta\theta J_{qq'}$ as half of the interim total contracting gain between two bankers of quality q and q' from u and v who sign an unconstrained insurance contract. Here

$$J_{qq'} = (\sigma_q + \sigma_{q'} - 2\sigma_q\sigma_{q'} - 2\xi)$$

$W^{\text{pro}}(\tau, \Phi)$ is the private management gains of bankers from providing their expertise to manage projects. Here $\phi_\Phi = \Phi(\overline{\alpha} - \underline{\alpha}) + \underline{\alpha}$ is the contagion threshold that yields Φ. $W_u^{\text{inv}}(\Phi)$ is the expected payoff of investors who choose between their outside option and financing. Here $\Omega_{u,\Phi}$ is utility recovery rate for an investor that lent to a banker in, as defined in equation (5). $W_u^{\text{sha}}(\Phi)$ is the payoff of the representative shareholders. V_Q is their utility function which is linear for simplicity. Shareholders get $\mathbb{E}[\alpha|\alpha > \phi_\Phi]c_u$ per unit of financed projects/financed bankers when there is no coordination failure. Their shares from the contracts add up to zero across the economy so insurance return shares can be ignored. When there is no coordination failure, shareholders pay back the creditors m per unit of financed projects. The representative creditor's payoffs is $W_u^{\text{cre}}(\Phi)$ where V_A is their utility function which is linear for simplicity. When there is no coordination failure he is paid m against the initial loan m' is per unit of financed project.

Index the probability of a coordination failure in an OTC-economy as described by Theorem 8 with transparency is τ, $\Phi^*(\tau)$. As bankers and banks are identical, $\Phi^*(\tau) = F_\alpha(\phi^*(\tau))$ and $\phi^*(\tau) = (\pi(\tau)\hat{e} + m^*)/c$ where

$$\hat{e} = \beta(\sigma_1 - \sigma_0) \min_u \frac{1}{\mu_u} \sum_v \langle \eta_{vu} - \eta_{uv} \rangle,$$

Then OTC-economy equilibrium welfare is $W(\tau_O, \Phi^*(\tau_O))$ and the EXC-economy equilibrium welfare is $W(\tau_C, \Phi^*(\tau_C))$. CCP-economy equilibrium welfare is $W(\tau_C, 0)$ and CLH-economy equilibrium welfare is $W(\tau_O, 0)$,

Clearly $\Phi^*(\tau)$ is decreasing in τ through $\pi(\tau)$ and $W_{CLH} > W_{CCP} \geq W_{EXC}$. CLH and CCP have no coordination failures, but the CLH protects bankers' opacity and allows them more insurance gains. CCP and EXC both impose transparency on bankers, but CCP does not have coordination failures. Also, $W_{CLH} \geq W_{OTC}$ because both protect bankers' opacity, but the clearinghouse does not have coordination failures. Where W_{OTC} sits with respect to $W_{CCP} \geq W_{EXC}$ is non-trivial. The insurance losses net of stability gains of reduced coordination failures in an OTC economy from raising transparency from τ_O to τ_C is captured in $W_{OTC} - W_{EXC}$. The stability benefits of eliminating coordination failures in an OTC economy with high transparency τ_C is captured in $W_{CCP} - W_{EXC} \geq 0$.

Theorem 7. *There exists $\overline{\alpha}^*$ such that if $\overline{\alpha} > \overline{\alpha}^*$, the following hold.*

$$W_{CLH} \geq W_{OTC} > W_{CCP} \geq W_{EXC}$$

Additionally, $W_{CLH} = W_{OTC}$ if and only if $\Phi^*(\tau_O) = 0$. Similarly, $W_{CCP} = W_{EXC}$ if and only if $\Phi^*(\tau_C) = 0$.

9 Empirical Analysis

In order to analyze empirically the role of CCPs in the financial network and the allocation of resources, we present evidence from mainly two sources. We use publicly available data for derivatives positions and aggregate exposure for Bank Holding Companies (BHCs) in the U.S. (Consolidated Financial Statements for BHCs Y-9C).[39] In addition, we work with confidential detailed data on derivative exposure by counterparty reported in BHCs FR Y-14Q filings, a quarterly regulatory collection which supports the Federal Reserve supervisory stress tests (under the Comprehensive Capital Analysis and Review (CCAR) program). This data allows us to study how the network has changed upon the implementation of new regulations by looking at the evolution of exposures at the counterparty level.[40] We focus on the period around the introduction of restrictions and changes in capital charges by the Dodd-Frank Act.[41]

The Y-14Q data consists of a series of data schedules with a broad range of information. We have access to the "Trading and Counterparty" schedule that is submitted by BHCs subject to supervisory stress tests and that satisfy the following requirements: (1) have aggregate trading assets and liabilities of $100 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.[42] Effectively, this schedule is only required for very large and complex institutions.

Using this information we are able to construct a consistent time series for 6 reporting banks. 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. While the number of reporting banks might look small, it is important to note that this is not much of 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 89.4 percent of all bank derivatives (by notional value). The largest 25 banks account for nearly 100 percent of all contracts.

This data contains unique information about the derivative profile by counterparty and aggregated across all counterparties of each reporting bank. Possible BHCs counterparties include (but are not limited to) other BHCs, financial institutions (domestic and foreign), sovereigns and central counterparties. Designated central clearing counterparty (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 of the counterparty which allows as 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.[43] We focus on the network within U.S. counterparties. Not all information currently available in the Y-14Q data is available pre and post-reform. For this reason, we document the changes in exposures using mostly the following variables:

1. Gross Credit Exposure (Gross CE): pre-collateral exposure after bilateral counterparty

[39]This data is used for example by the Office of the Comptroller of the Currency (OCC) in their Quarterly Report on Bank Derivatives Activities. See https://www.occ.treas.gov/topics/capital-markets/financial-markets/derivatives/index-derivatives.html

[40]More 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.

[41]See BCBS and IOSCO (2015) "Margin requirements for non-centrally-cleared derivatives" Technical report, BIS and OICU-IOSCO, Basel, Switzerland for a discussion of this regulatory change.

[42]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).

[43]For non-sovereigns and non-central counterparties banks report at the consolidated group/parent level. For sovereigns and central counterparties banks report at the entity level.

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.[44]

2. Net Credit Exposure (Net CE): Gross CE netting agreements for a given counterparty less the value of collateral posted by the counterparty to secure those trades.[45]

For the most recent periods, we also have information on Total Notional and the position Mark-to-Market (MtM). Our data as well as the Office of the Comptroller of the Currency (OCC) Quarterly Report on Bank Trading and Derivative Activities also shows that derivative activity is concentrated in Interest Rate Swaps (76.02 percent of total amount, measured using the notional amount) and the next category Foreign Exchange derivative contracts.

9.1 Main Findings

We document four facts:

1. Changes in capital regulation and the mandatory requirement to clear all standarized derivatives via CCPs that was announced in 2013 effectively affected the cost of trading in OTC derivative markets. The change in capital regulation removed the upper bound on risk-weights for derivatives (50%). Derivatives are reporting in different categories: OTC and Centrally cleared, with centrally cleared derivatives receiving risk-weights between 2 and 4 percent.

2. The imposition of mandatory central clearing (part of the Dodd-Frank Act's new rules) for a large set of derivatives and changes in capital rules resulted in a clear shift of exposure (measured using Net CE) of the "core" (defined as the group of 6 reporting banks) to CCPs. Most of this change in exposure is at expense of the periphery (i.e., counterparties that do not belong to the "core").

3. The "core" is more intensive in collateral use. This is evident when comparing exposures using Gross CE (i.e., exposures that do not take into account collateral) to exposure using Net CE (Gross CE net of collateral). Gross CE exposures still display a shift towards CCPs but the "core" remains as the main counterparty group.

4. Using a standard measure of centrality (Katz Centrality), we show that the centrality within the "core" did not change significantly during this period.

9.1.1 Regulatory Change: Capital Requirements for Derivatives

In the first quarter of 2015, a significant increase in the amount of capital required for transactions of over-the-counter (OTC) derivatives took effect. Under the new rules, the highest applicable

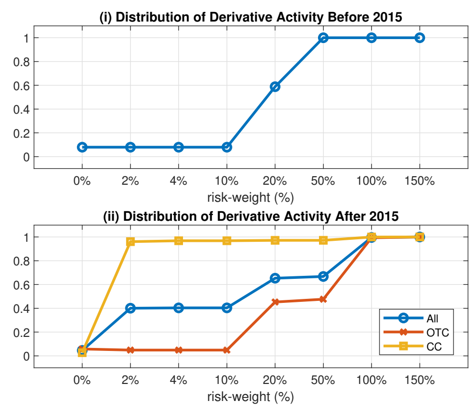
[44]For the purposes of this schedule, Gross CE to an individual counterparty is derived as follows: If a legally enforceable bilateral netting agreement is in place, the fair values of all applicable derivative contracts with that counterparty that are included in the scope of the netting agreement are netted to a single amount, which may be positive, negative, or zero. Gross CE is reported when the fair value is positive and set to zero otherwise.

[45]Only collateral that was actually exchanged is incorporated in the Net CE reporting.

risk-weight applicable to OTC derivatives (50 percent) does not longer apply, increasing the risk-weight for most transactions in OTC derivatives.[46] This change for OTC derivative exposures was accompanied by the implementation of relatively small risk-weights required for centrally cleared derivatives. The risk-weights generally applicable in relation to CCPs range from 2 to 4 percent.

Figure 16 presents the cumulative distribution of derivatives positions (measured using credit equivalents amounts) by risk-weight for the 6 reporting banks. Panel (*i*) shows the cumulative distribution of derivatives by risk-weight prior to 2015. This figure is constructed by taking an average of the asset-weighted bank level ratios for each quarter from quarter 1 in 2001 to quarter 4 in 2014. Panel (*ii*) presents the distribution of derivatives by risk-weight from 2015 to 2018. Since quarter 1 in 2015 banks are required to report the split between those derivatives that are traded over-the-counter and those that are centrally cleared. This panel shows the distribution conditional on the type of derivative (on average, 38.6 percent of banks' derivative holdings were centrally cleared).

Figure 16: Distribution of Derivatives by Risk-Weights (Pre and Post 2015)



Note: This figure shows the average distribution of derivatives (measured using credit equivalents) by risk-weight for the 6 largest banks in the US. Panel (*i*) corresponds to all derivatives prior to 2015 (average of quarterly information from 2001 to 2014). Panel (*ii*) presents the distribution distinguishing by over-the-counter (OTC) derivatives and Centrally Cleared (CC) (average of quarterly data from 2015 to 2018). Source: Consolidated Financial Statements for BHCs (Y-9C)

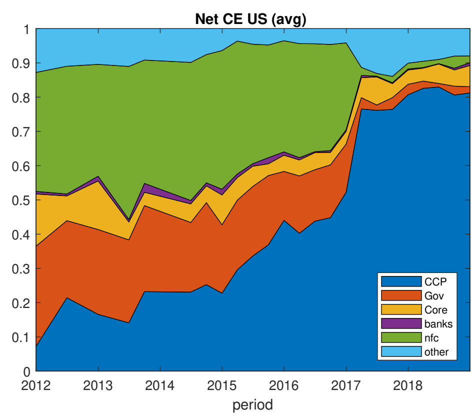
Figure 16 shows a shift in the distribution of positions across risk-weights for over-the-counter derivatives implying an increase in the cost of trading derivatives of this type. By construction, prior to 2015, all OTC derivatives received a risk-weight of 50% or less. After the regulatory changes, close to 60% of OTC derivatives received risk-weights higher than 50%. On the other hand, 98% of centrally cleared derivatives receive a risk-weight of 4% or lower (close to 100 percent of centrally cleared derivatives received a risk-weight of 2%).

[46] Risk weights are used to construct the measure of risk-weighted assets that is then used to compute regulatory ratios such as Tier 1 Capital to Risk-weighted assets. The risk weights depend fundamentally on the counterparty in the transaction. For example, sovereign exposures receive risk-weights from 0 to 150 percent (determined by the Organization for Economic Cooperation and Development (OECD) country risk; domestic banks generally receive risk weights of 20 percent; Foreign banks risk weights from 20 to 150 percent; corporate exposures 100 percent risk weight.

9.1.2 Shift in Exposure to CCPs

The changes in capital regulation (as described above) that took effect in 2015 and, to some extent, the mandatory requirement to clear all standarized derivatives via CCPs that was announced in 2013 induced a shift in exposure towards CCPs. We can study this shift using the Y-14Q data that became available on quarter 4 of 2011 (almost continuously). The schedule on counterparty risk provides information at the counterparty level. The information available includes the country of residence and the type/industry of the counterparty. We classify counterparties into the following groups: CCPs, Core (reporting banks), banks (other banks not in the Core), government entities, non-financial corporations, other (includes financial guarantors, pension funds, special purpose vehicles, other institutions). 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. Figure 17 presents the evolution of the (asset-weighted) average of exposures using Net CE for counterparties in the US. Recall that Net CE corresponds to the value of gross exposure less the value of collateral posted by the counterparty.

Figure 17: Counterparty Exposure (Net CE) by counterparty type (avg "core" banks)



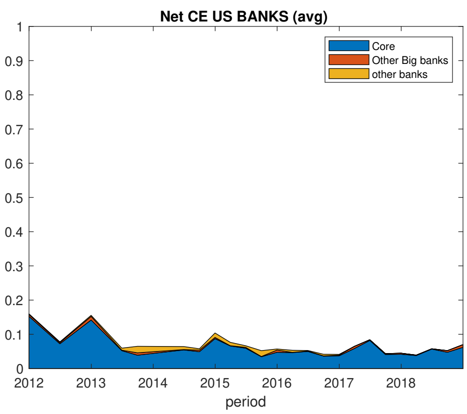
Note: Asset weighted average of bank level net credit exposure by counterparty type. "CCP" corresponds to Central Counterparty, "Gov" to government entities (central government or government enterprise), "Core" corresponds to the reporting banks (largest banks in the US), "banks" to other banks not in the "Core" category, "nfc" to non-financial corporations. Source: Consolidated Financial Statements for BHCs (Y-9C) and BHCs FR Y-14Q

Figure 17 makes evident that there is a significant increase of the exposure of the "core" (the reporting banks) to the CCP's. When measured using Net CE the exposure to the "core" to the CCP increased from below 10% of total exposure to above 80%. Most of the increase comes from a reduction in exposure to the "periphery" defined as entities in the "core". The figure shows also a decline in the "core" but we show below that this is mostly a change in the amount of collateral required in "core" to "core" transactions.

While confidentially issues prevent us from disclosing the evolution of the bank level information, 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. That being said, there is an interesting heterogeneity in our sample with banks moving from no exposure to CCPs in 2011 to Net CE exposure being larger than 90 percent of total exposure and other banks with smaller changes moving from forty percent in 2011 to ninety five percent in 2018.

To understand what drives the exposure from the "core" to all banks in the U.S. ("core" banks as well as other banks) we present the evolution of the "Core" and the "banks" categories included in Figure 17. Figure 18 shows the (asset-weighted) average fraction of total Net CE that corresponds to counterparties in the "core" and the "banks" category. The later category is split into two sub-categories: "other big banks" and "other banks". The sub-category "other big banks" corresponds to banks not included in the "core" but classified as Global Systemically Important Bank by the Financial Stability Board and "other banks" are all other banks. This figure shows that most of the exposure to banks corresponds to exposure within the core.

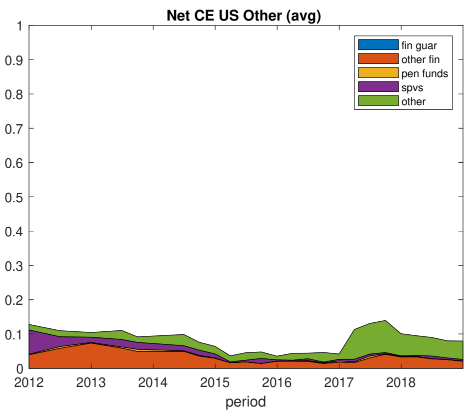
Figure 18: Counterparty Exposure (Net CE) to the "core" and "banks" categories (avg "core" banks)



Note: Bank level net credit exposure by counterparty type. "Core" corresponds to the reporting banks (largest banks in the US, also referred as the "core"), "other big banks" to banks not in the "Core" category classified as G-SIB by the Financial Stability Board, "other banks" to all other banks. Source: Consolidated Financial Statements for BHCs (Y-9C) and BHCs FR Y-14Q

Figure 19 presents a decomposition of the "other" category shown in Figure 17. In particular, Figure 19 shows the (asset-weighted) average for banks in the "core" where the "other" category is decomposed into the following 5 sub-categories: financial guarantors ("fin guar"), other financial institutions ("other fin"), pension funds ("pen funds"), special purpose vehicles ("spvs"), other (reported as "other" in the original sample).

Figure 19: Counterparty Exposure (Net CE) to “other” category (avg “core” banks)

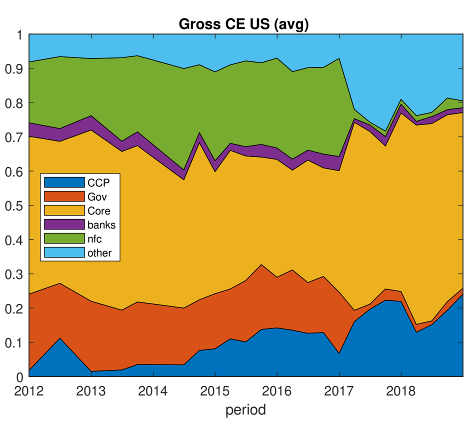


Note: Bank level net credit exposure by counterparty type for “Other” category. “fin guar” corresponds to financial guarantors, “other fin” to other financial institutions, “pen funds” to pension funds, “spvs” special purpose vehicles, “other” (reported as “other” in the original sample). Source: Consolidated Financial Statements for BHCs (Y-9C) and BHCs FR Y-14Q

9.1.3 The “Core” is More Intensive in the Use of Collateral

One interesting aspect of derivatives exposures for “core” banks is that exposure to “core” itself is much more intensive in collateral (i.e., Net Exposure is the result of a relative large Gross credit exposure position compensated by a similar amount of collateral). This is evident when looking at the size of the fraction of Gross CE that exposure to the “core” represents for “core” banks relative to the Net CE exposure shown in Figure 17. Figure 20 displays the (asset-weighted) average of Gross CE by counterparty type.

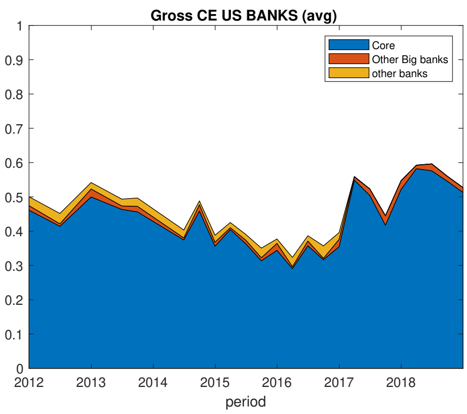
Figure 20: Counterparty Exposure (Gross CE) by counterparty type (avg “core” banks)



Note: Asset weighted average of bank level Gross credit exposure by counterparty type. “CCP” corresponds to Central Counterparty, “Gov” to government entities (central government or government enterprise), “Core” corresponds to the reporting banks, “banks” to other banks not in the “Core” category, “nfc” to non-financial corporations. Source: Consolidated Financial Statements for BHCs (Y-9C) and BHCs FR Y-14Q

Two key features are present when looking at Figure 20. First, when computed as Gross CE, the “core” is the largest counterparty group for reporting banks. While there is an increase in exposure to CCP's the increase is not as dramatic as described by Net CE (i.e., exposure net of collateral) implying that collateral requirements are larger for exposures within the "core".

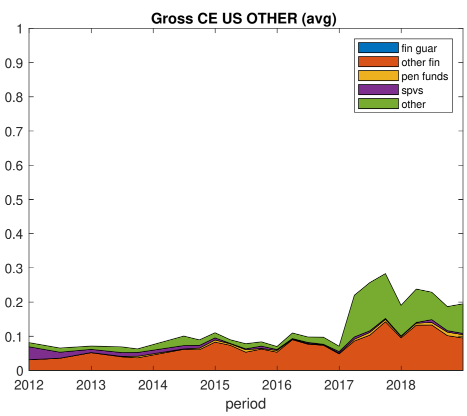
Figure 21: Counterparty Exposure (Gross CE) to "Core" and "banks" categories (avg "core" banks)



Note: Bank level gross credit exposure by counterparty type. "Core" corresponds to the reporting banks, "other big banks" to banks not in the "Core" category classified as G-SIB by the Financial Stability Board, "other banks" to all other banks. Source: Consolidated Financial Statements for BHCs (Y-9C) and BHCs FR Y-14Q

Figure 22 presents a decomposition of the "other" category shown in Figure 20. In particular, Figure 22 shows the (asset-weighted) average for banks in the "core" where the "other" category is decomposed into the following 5 categories: financial guarantors ("fin guar"), other financial institutions ("other fin"), pension funds ("pen funds"), special purpose vehicles ("spvs"), other (reported as "other" in the original sample).

Figure 22: Counterparty Exposure (Gross CE,"other" category avg "core" banks)



Note: Bank level gross credit exposure by counterparty type for "Other" category. "fin guar" corresponds to financial guarantors, "other fin" to other financial institutions, "pen funds" to pension funds, "spvs" special purpose vehicles, "other" (reported as "other" in the original sample). Source: Consolidated Financial Statements for BHCs (Y-9C) and BHCs FR Y-14Q

Figure 22 shows that the evolution of the "other" category is mostly driven by "other financial institutions" and "other" counterparties (i.e., a miscellaneous set of counterparties classified as “other” in the original sample).

9.1.4 Centrality Within the “Core”

We study how centrality within the “core” has evolved over time. We use a standard measured of centrality, the Katz centrality index. In particular, consider an $n \times n$ network ($n = 6$ in our case) with a matrix of exposures given by A. Denote $A^k = \underbrace{A \times A \times \ldots A}_{k \;\; \text{times}}$ with respect to matrix multiplication. A^k is the matrix that captures the weight of the links on paths of length k ($k-$step exposures). For a given $\alpha \in (0, 1)$, Katz Centrality is given by

$$C_{Katz}(i) = \sum_{k=1}^{\infty} \sum_{j=1}^{n} \alpha^k (A^k)_{ji},$$

where $(A^k)_{ij}$ captures the total indirect exposure of i to j via paths of length k.[47]

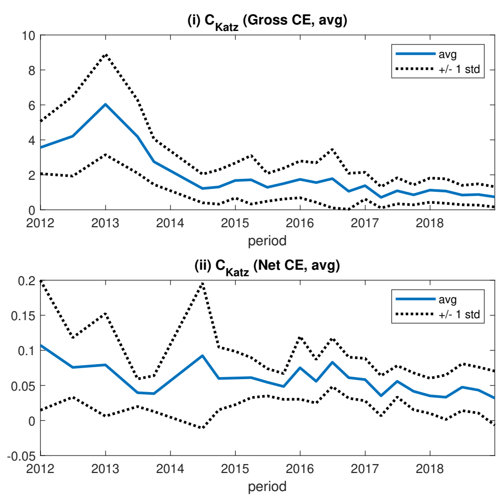
After some simple algebra, a closed form solution can be obtained. It is given by

$$C_{Katz}(i) = \left(\left(I - \alpha A^T \right)^{-1} - I \right) e_n, \tag{8}$$

where T is the transpose operator, I is the $n \times n$ identity matrix, e_n is an $n-$dimensional vector of 1’s.

Figure 23 presents the (asset-weighted) average of the Katz Centrality measure for Gross CE (Panel (i)) and Net CE (Panel (ii)).

Figure 23: Centrality within the “core” (avg)



Note: Figure presents (asset-weighted) average of $C_{Katz}(i)$ as defined in equation (8) for Gross CE and Net CE. Source: BHCs FR Y-14Q

Centrality within the “core” does not show any particular trend post 2013 when the first set of reforms was implemented.

[47] Note that if α is too large, then $C_{Katz}(i)$ might diverge, so α is chosen small enough

10 Conclusion

Recent regulations that tax the use of OTC insurance contracts and subsidize those channeled though CCPs have had mixed success. We have used a unique confidential dataset and have documented that this regulation has been successful for contracts between the core and the periphery, but not between banks in the core, which have remained connected through bilateral contracts.

We have proposed a model to understand the effects of regulation and capture that asymmetric success. While OTC markets maintain opacity about insurance needs, and then allows for insurance without affecting funding costs, they are more exposed to coordination failures that may drive the whole banking system to a collapse. While banks internalize the benefits of OTC contracts, they do not internalize the coordination costs. This justifies the regulation that tries to incentivize the use of CCPs. However when the gains of opacity are larger than the regulatory costs, which is usually the case when a bank has frequent needs for insurance, regulations are not very effective. These are, however, the banks that are more likely to trigger coordination failures.

Modeling coordination failures and what they depend on require a setting with endogenous formation of exposures. A contribution of this paper is proposing a tractable model in which this endogenous formation, and collapse, can be captured parsimoniously.

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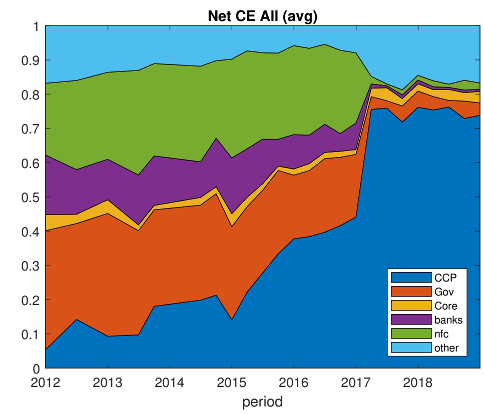
A Data appendix

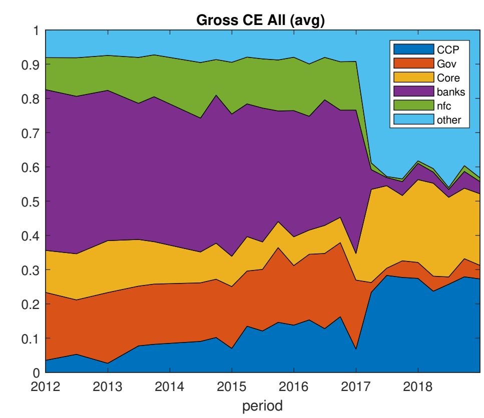
In this appendix, we present evidence using data for all counterparties and not only those located in the U.S.

Figure 24: Counterparty Exposure (Net CE) by counterparty type (avg)



Note: Asset weighted average of bank level net credit exposure by counterparty type. “CCP” corresponds to Central Counterparty, “Gov” to government entities (central government or government enterprise), “Core” corresponds to the reporting banks, “banks” to other banks not in the “Core” category, “nfc” to non-financial corporations. Source: Consolidated Financial Statements for BHCs (Y-9C) and BHCs FR Y-14Q

Figure 25: Counterparty Exposure (Gross CE) by counterparty type (avg)



Note: Asset weighted average of bank level gross credit exposure by counterparty type. “CCP” corresponds to Central Counterparty, “Gov” to government entities (central government or government enterprise), “Core” corresponds to the reporting banks (largest banks in the US, also referred as the “core”), “banks” to other banks not in the “Core” category, “nfc” to non-financial corporations. Source: Consolidated Financial Statements for BHCs (Y-9C) and BHCs FR Y-14Q