Heterogeneity and Netting Efficiency under Central Clearing: A Stochastic Network Analysis

Injun Hwang* Baeho Kim†

This Version: November 4, 2018

Abstract

This paper examines the effect of heterogeneity in exposures between banks on the netting efficiency under central clearing. Our network model specifies the pre-netted interbank exposures as a joint stochastic process that shapes cross-correlation of asymmetric distributions. Employing OTC derivatives market data provided by the U.S. Office of the Comptroller of the Currency, we analyze how the correlation between interbank exposure distributions and the dispersion in bank sizes affect multilateral netting efficiency in the presence of a central clearing counterparty across various bank-specific resiliency and volatility parameters. Our simulation results indicate that the multilateral netting benefit under central clearing outweighs the bilateral reduction of expected exposures within an environment of systemic homogeneity in the distributions of interbank exposure dynamics. Furthermore, we find that policymakers should incentivize individual banks to enhance the resiliency and stability of their management of interbank exposures in a less homogeneous way.

Keywords: Central Clearing; Exposure Distribution; Netting Efficiency; Heterogeneity; Simulation; Stochastic Network Model

*Korea University Business School, Anam-ro, Seongbuk-Gu, Seoul 02841, Republic of Korea. Tel: +82-2-3290-1307, Fax: +82-2-922-7220, E-mail: hwangi@korea.ac.kr

†Corresponding Author. Korea University Business School, Anam-ro, Seongbuk-Gu, Seoul 02841, Republic of Korea. Tel: +82-2-3290-2626, Fax: +82-2-922-7220, E-mail: baehokim@korea.ac.kr

We thank HeeJoon Jeong, Ji-Yeol Jimmy Oh, Jong Chil Son and participants at the Financial Stability Forum at Bank of Korea and 2018 Korean Finance Association Fall Conference for their helpful comments.

1 Introduction

The 2007-08 Global Financial Crisis has underlined the importance of holistic approaches to financial regulation and monetary policy based on systemic views that go beyond managing the risks of individual institutions in isolation. In response to the widespread calls for changes in regulatory systems, policymakers have enacted new regulations aiming to initiate structural changes in the over-the-counter (OTC) derivatives markets.[1] The core aim of the regulatory reform is to diversify risk away from systemically important market participants to forestall the collapse of the entire financial system. One of the reform's major dimensions is mandatory central clearing of standardized OTC derivatives. Specifically, the enforcement of mandatory central clearing of standardized OTC derivatives contracts is designed (i) to reduce aggregate risk in the entire financial system and (ii) to wedge a bulkhead in OTC markets by isolating individual entities from the propagation of systemic credit risk.

In the absence of central clearing, market participants in the OTC derivatives markets are exposed to potential losses due to unanticipated counterparty credit risks, intrinsic to bilateral contracts across various asset classes. However, exposures that are not fully netted without a central clearing counterparty (CCP) may cause a chain of liquidity insolvency problems throughout the entire market. For example, Brunnermeier & Pedersen (2008) document the vicious spiral of traders' funding liquidity and assets' market liquidity. As the funding liquidity of traders tightens, the asset liquidity provided by the traders tends to dry up, and vice versa.

Under central clearing, on the other hand, a CCP interposes between counterparties, acting as a buyer to every seller and vice versa. The CCP, in turn, provides a multilateral netting channel so that dealers offset their payments across

[1] The Dodd-Frank Wall Street Reform, the 2010 Consumer Protection Act, and the G20's 2009 movement are well known examples; see BCBS (2013) and BCBS (2016).

dealers. However, as illustrated by Duffie & Zhu (2011), the central clearing scheme limited to parts of asset classes may deprive dealers of bilateral netting chances across different asset classes. This is because only the payments implied by the novated contracts are netted within the CCP under central clearing, while, otherwise the remaining payments could be netted with the other contracts of different asset classes.

The goal of financial regulation is to ensure the stability of the entire financial system by precluding the acceleration of a self-reinforcing adverse feedback effect within the system. Thus, both micro- and macro-prudential risk management practices should be implemented in a complementary manner. Micro-level bank regulations commonly focus on a representative entity's response to a particular factor change such as the capital requirement. Obviously, however, an individual bank's decision on capital affects the other banks' investments. Thus, a central bank should design a holistic regulation at the aggregate level to maximize the sum of the welfare of all agents after netting any social costs induced by potential financial distress.

In this study, we examine the system-wide benefit from central clearing by gauging the reduction in the total expected counterparty exposures in the system. Specifically, we explore how the correlation between exposure distributions and the dispersion in banks size affect the netting efficiency. In addition, using sensitivity analyses that perturb the pre-netted exposure model parameters, we delve into the effect of bank-specific resiliency and stability in the management of interbank exposures on aggregate netting efficiency. Our simulation results confirm Duffie & Zhu (2011)'s finding that the amount of exposures novated to the CCP maintains its dominant role in determining whether or not the CCP improves netting efficiency. In other words, a single CCP dedicated to only CDS does not improve netting efficiency, as CDS contracts comprises a relatively small proportion of OTC derivatives.[2]

[2]The outstanding CDS contracts of the top 25 major dealers accounts for 0 to 5 percent of entire their OTC derivatives notional (Table 1).

Our dynamic exposure model framework extends the specifications in the existing literature. Duffie & Zhu (2011) investigate whether the mechanism of CCP really reduce a system's total expected counterparty exposure by examining the netting efficiency of a market with an inception of CCP. They conclude that a trade-off between bilateral netting across pairs of entities over different asset classes and multilateral netting across central clearing members for a certain asset class implies that CCP does not always reduce the total expected counterparty exposure. Their findings indicate that the number of central clearing members or the proportion of contracts cleared through CCPs play crucial roles in determining which netting method dominates the other. Cont & Kokholm (2014) extend Duffie & Zhu (2011) by introducing the concept of heterogeneity in asset classes in terms of riskiness as well as the inter-market exposure correlation. Under the assumption of homogeneity regarding the asset class riskiness, improving the system-wide netting efficiency via the CCP requires an unrealistically large number of central clearing members (461 in Duffie & Zhu, 2011); meanwhile, under the heterogeneity assumption and using the fat-tailed exposure distribution model generates a more reachable number of clearing members (14 in Cont & Kokholm, 2014) for the CCP to improve the system-wide netting efficiency.

Although the abovementioned studies provide simple but interesting lessons, the models they employ are subject to multiple crucial limitations. Above all, existing models typically presume that the netted exposure distributions are symmetric around their means. In reality, however, asymmetric dominance is often observed between the exposures of two counterparties, as the larger or more creditworthy bank tends to be more exposed to its counterparty, and vice versa. Consequently, elliptical distributions such as Gaussian or Student's t-distributions fail to describe the realistic aspects of the sum of the interbank exposures between two counterparties. To circumvent these drawbacks, we assume that pre-netted exposures, after being aggregated according to

the asset classes between two counterparties, are modeled by stochastic processes generating skewed and fat-tailed exposure distributions at the end of risk horizons. The advantage of our modeling approach resides in its economic realism, which stems from its flexibility in revealing higher-order moments. Because this is of paramount importance in the study of systemic events, our proposed framework enables holistic analyses of systemic risk based on more realistic characteristics of interbank exposure distributions

A growing body of literature has investigated the implications of central clearing. For instance, Amini, Filipović & Minca (2017) identify the optimal design of central clearing by setting the capital requirement of clearing members to circumvent systemic risk. Loon & Zhong (2014) examine how the CCP can mitigate counterparty risk between dealers under central clearing based on an event study of the CDS market. They find that the prudent role of the CCP increases settlement CDS spreads, leading to the reduction of the counterparty risk under central clearing. In another vein, Bignon & Vuillemey (2017) focus on the history of the 1974 central clearing house failure in the derivatives market. They report that both the inability of the central clearing house to manage members with large positions and the risk-shifting tendency of delaying the liquidation of defaulted positions were the main causes of the central counterparty's default. Menkveld (2017) supports the notion of central counterparties' systemic failure by measuring CCP exposure based on the tail risk in traders' portfolios. The simulation results reveal that crowded positions on the CCP may aggravate its exposure during downturns.

The benefit of a prudent exposure model goes beyond netting efficiency. Duffie, Scheicher & Vuillemey (2015) document the relation between central clearing schemes and system-wide collateral demand with party-to-party bilateral CDS exposure data. As the netting efficiency affects the initial margin requirement, the trade-off between

bi- and multilateral netting plays a key role changing the collateral demand with the inception of CCPs. This finding highlights the importance of a sensible and realistic exposure model.

Our pre-netted model of interbank exposure dynamics in the stochastic network model can produce unique insights regarding both individual and system-wide dimensions. Regardless of central clearing schemes, we find that heterogeneous interbank exposures are systemically beneficial to mitigate the amount of potential losses in the OTC derivatives market in a time of stress. This is because the strong positive correlation in exposure distributions coincides with bank tendencies to engage in more homogeneous asset management practices that may make their exposure networks more systemically vulnerable (Acharya 2009). Most importantly, our findings indicate that the systemic benefit of central clearing becomes more pronounced, as the co-movement between individual exposures becomes stronger. In other words, the multilateral netting benefit under central clearing outweighs the bilateral reduction of expected exposures within an environment of systemically homogeneous exposure dynamics between banks.

We also find a negative relationship between the CCP benefit and the dispersion in banks size, measured by their notional outstanding of OTC derivatives. We can derive a policy-oriented implication from this result. From the perspective of the system-wide netting efficiency, regulations are supposed to prevent large banks from taking new positions that increase their exposures. Our proposed approach extends the scope of the systemic implication of heterogeneity between banks as illustrated by Choi (2014) in that homogeneous management of interbank exposure can improve the aggregate netting efficiency under central clearing.

By varying bank-specific parameters, our simulation results indicate that the CCP benefit is sensitive to the realization of resiliency and stability parameters of pre-netted

exposure processes. More specifically, the CCP benefit is unduly responsive to the changes in bank-specific volatilities of exposure processes. Our findings demonstrate that regulators should allocate less central clearing operation costs to the banks with more positions on resilient and less volatile assets than those with inelastic and volatile assets.

The rest of this paper is organized as follows. Section 2 introduces the framework of our analyses and specifies the exposure models. Section 3 describes of our methodology and the data we employed. Section 4 provides the main results and discusses heterogeneity in banks and bank-specific characteristics. Section 5 concludes the paper.

2 Model Framework

2.1 Exposure and Stochastic Network Models

In the OTC derivatives markets, participants often take multiple positions in a variety of asset classes. An entity's default requires the resolution of the re-arrangement of the intricate payments to maintain a matched book and mitigate the systemic impact of losses caused by the credit event.[3] In the absence of CCPs, a netting arrangement between two counterparties should be established bilaterally at the inception of each contract.

In bilateral arrangements, two dealers offset payments with the same occurring dates from all contracts established between them. When one counterparty defaults, the bilateral netting scheme involves the following two detailed procedure. By pre-

[3]Motivated by the setup in Duffie & Zhu (2011), we restrict our scope to the the total counterparty exposure in the system. Specifically, our study does not consider the implications of jointly determined defaults in given networks.

netted exposure δ_{ij}^k, dealer i adds all exposures from its ongoing contracts with the counterparty j in the asset class k. The pre-netted exposure is the total ongoing liability of counterparty j to its lender i and it is nonnegative. This specification is an extension of Duffie & Zhu (2011) in that $X_{ij}^k := \delta_{ij}^k - \delta_{ji}^k$ represents the netted exposure of i losing upon j's default from all of the contracts in the asset class k. Because an entity only loses upon its counterparties' defaults but not from its own default, we only take the nonnegative part of X_{ij}^k into account. We later use these quantities by taking expectations and summations at the end of a given risk horizon to compute the system level total expected counterparty exposure.

In turn, we need specific assumptions regarding the distributions of future exposures in the presence of uncertainty. A straightforward example stems from the Normal distribution. Duffie & Zhu (2011) propose a model of the exposure with a joint independent multivariate Normal distribution to drive the closed-form expression of the total expected counterparty exposure in the system. Cont & Kokholm (2014) extend the model by adopting the Student's t-distribution to reflect the fat-tailed nature of the return distribution on the cash flows implied by non-equity derivatives. These elliptical exposure distribution models are limited to be symmetric around their means. In reality, two counterparties do not have the same or similar position sizes over contracts. Rather, one party typically has dominance in exposure to its counterparty, which in turn leads to an asymmetric distribution model. To account for this realistic property, we specify the model for exposures at a more primitive level of pre-netted exposure δ_{ij}^k.

To ensure realistic flexibility in the higher-order moments of future exposures along with their tractability, we adopt a mean-reverting square root process, which is also adopted by Cox, Ingersoll Jr & Ross (1985) for modeling $\delta_{ij}^k(t)$, whose distribution at a given time in the future forms the non-central χ^2 distribution. As a result, the

pre-netted exposure model can exhibit desirable statistical properties such as stationarity, non-negativity and parsimony, while retaining both flexibility and tractability. Intuitively, this feature guides us to an in-depth exploration of the system-wide CCP benefit in various scenarios based on varying model parameters.

Moreover, the netted exposure X_{ij}^k based on the Gaussian or $t-$distribution cannot provide a term-structure perspective; thereby one should assume that defaults certainly occur at some prefixed future times. By contrast, our proposed stochastic processes for pre-netted exposures are free from such horizon-specific constraints. The mean-reverting property of our pre-netted exposure processes ensures stationarity under mild parametric conditions, reflecting the target-oriented exposure dynamics in reality. The mean-reverting nature of the pre-netted exposure dynamics can be intuitively understood as a bank's tendency of approaching to the counterparty-specific target exposure level, which is often observed in practice. Specifically, the process level at a prefixed time follows a well-known non-central χ^2 distribution, which provides an exact and efficient simulation method to generate $\delta_{ij}^k(T)$ for a given $T > 0$ so that one can avoid producing biases within a reasonable computational budget in the continuous-time framework.

To specify the source of interdependency in bank-to-bank exposures, we presume that each pre-netted exposure process $\delta_{ij}^k(t)$ consists of a systematic component $Y(t)$ and an idiosyncratic component $\varepsilon_{ij}^k(t)$. Specifically, we assume that each of the factor processes are strong solutions of the stochastic differential equations given by

$$d\varepsilon_{ij}^k(t) = \kappa_{ij}^k(\theta_{ij}^k - \varepsilon_{ij}^k(t))dt + \sigma_{ij}^k\sqrt{\varepsilon_{ij}^k(t)}dZ_{ij}^k(t) \quad (1)$$

$$dY(t) = \kappa_Y(\theta_Y - Y(t))dt + \sigma_Y\sqrt{Y(t)}dZ_Y(t) \quad (2)$$

where the pre-netted and post-netted exposure processes take the form of

$$\begin{aligned} \delta_{ij}^k(t) &= w_{ij}^k S_{ij}^k Y(t) + \varepsilon_{ij}^k(t) && (3) \\ X_{ij}^k(t) &= \delta_{ij}^k(t) - \delta_{ji}^k(t) && (4) \\ &= \underbrace{\left(w_{ij}^k S_{ij}^k - w_{ji}^k S_{ji}^k\right)}_{:=\beta_{ij}^k} Y(t) + \left(\varepsilon_{ij}^k(t) - \varepsilon_{ji}^k(t)\right) && (5) \end{aligned}$$

where Z_{ij}^k and Z_Y are (N^2K+1) dimensional standard Brownian motions, respectively. We let S_{ij}^k represents the notional outstanding of dealer i to its counterparty j in the asset class k. We further assume that w_{ij}^ks are obtained from a copula model relating uniformly distributed quantities u_{ij}^k such that $0 \leq u_{ij}^k \leq 1$ and $u_{ij}^k + u_{ji}^k = 1$. As desired, the fundamental parity of $X_{ij}^k = -X_{ji}^k$ is respected by design.

The assumption of uniformly distributed u_{ij}^k is natural when the system contains a sufficiently large number of market participants. Specifically, the interbank exposure dependency is specified by the one-factor Gaussian copula taking the form

$$\Phi^{-1}(w_{ij}^k) = -\rho\Phi^{-1}(u_{ij}^k) + \sqrt{1-\rho^2}\Phi^{-1}(u_{ji}^k) \tag{6}$$

where Φ^{-1} is the inverse of the cumulative density function of Normal distribution.

Note that we intentionally set the correlation parameter ρ multiplied on the first term in the right hand side of the equation to take minus of its original sign. If $S_{ij}^k = S_{ji}^k$, the probability density function of β_{ij}^k varies from the delta function (when $\rho = -1$) to a uniform distribution over the support $[-S_{ij}^k, S_{ij}^k]$ (when $\rho = 1$). The density of β_{ij}^k disperses over the support as ρ increases from -1 to 1. Thus $\rho = -1$ implies the factor loading β_{ij}^k on $Y(t)$ in $X_{ij}^k(t)$ is zero almost surely, representing the case where all participants' exposures are totally independent with a systematic factor. Notice that $\rho = 1$ induces the maximum likelihood of β_{ij}^k taking large absolute values over

the support, minimizing the likelihood of β_{ij}^k being zero at the same time. This can be interpreted as the strongest dependency on the systematic factor.

2.2 Netting Efficiency under Central Clearing

Motivated by Duffie & Zhu (2011), we explore how the total expected counterparty exposure changes before and after the inception of CCP(s) to analyze the netting efficiency of central clearing in the OTC derivatives markets. Although the expected counterparty exposure simply measures the expected dollar amount losing upon counterparties' defaults, neglecting any cost or risk quantities, it provides an intuitive frame for analyzing whether a CCP is mechanically beneficial or not at the aggregate level in the system.

Suppose an OTC derivatives market with N participants and K asset classes. Let C be a subset of K in which each asset class is at least partially cleared through CCP. Let α_k be the fraction of asset class k that is cleared through the CCP. If all the centrally cleared asset classes have their own dedicated CCPs, the entity i's expected exposure to each k-devoted CCP is expressed by

$$\gamma_i^k = E\Big[\max\big(\sum_{j\neq i}\alpha_k X_{ij}^k, 0\big)\Big] \tag{7}$$

Therefore, the expected exposure of i to CCPs is the sum given by[4]

$$\gamma_i^C = \sum_{k\in C} E\Big[\max\big(\sum_{j\neq i}\alpha_k X_{ij}^k, 0\big)\Big] \tag{8}$$

[4]In the simplest case, if there is only one CCP handling all centrally cleared asset classes, a typical participant i's total expected exposure to the CCP is $\gamma_i^{C,*} = E\Big[\max\big(\sum_{k\in C}\sum_{j\neq i}\alpha_k X_{ij}^k, 0\big)\Big]$.

The sum of i's expected exposures to other participants over $K \setminus C$ is[5]

$$\phi_i^{K\setminus C} = \sum_{j\neq i} E\Big[\max\big(\sum_{k\in K\setminus C}(1-\alpha_k)X_{ij}^k, 0\big)\Big] \tag{9}$$

The total expected counterparty exposure of i to all other participants regardless of clearing channel is $\phi + \gamma$. We compute the percentage change in the total expected counterparty exposure with the intervention of CCP(s) by defining the CCP benefit given by

$$\begin{aligned} \text{CCP Benefit (\%)} &:= 1 - \frac{\text{Total Expected Exposure with CCP}}{\text{Total Expected Exposure without CCP}} &(10)\\ &= 1 - \frac{\sum_i \phi_i^{K\setminus C} + \sum_i \gamma_i^C}{\sum_i \phi_i^K} &(11)\end{aligned}$$

Intuitively, the CCP benefit measures the proportion of the total expected exposure that is eliminated by the intervention of the CCP under central clearing. For example, a CCP benefit of 5.13 (%) implies that the total expected counterparty exposure is reduced by 5.13 percent under central clearing compared to a case in which all contracts are bilaterally cleared.

3 Methodology

3.1 Simulation Setup

Our model specification beyond the Gaussian distribution gives rise to the absence of closed-form expressions of ϕ and γ. This motivates us to take advantage of Monte Carlo simulation to compute the total expected counterparty exposures to estimate

[5] If all of the positions are bilaterally cleared, the bank i's exposure to its counterparties becomes $\phi_i^K = \sum_{j\neq i} E\Big[\max\big(\sum_k X_{ij}^k, 0\big)\Big]$.

1-year ahead exposure distributions. Notably, our proposed stochastic models of pre-netted exposures provide well-known transition density functions in closed-form expressions, facilitating the exact simulation algorithm without causing bias in sampling future quantities.[6]

For each iteration, we generate a systematic factor $Y(T)$ and a set of i.i.d. idiosyncratic factors of the pre-netted exposures $\varepsilon_{ij}^k(T)$ from the non-central χ^2 distributions for a given $T > 0$. We estimate the volatility σ_{ij}^k of ε_{ij}^k as the expression given by

$$\sigma_{ij}^k = m_k \frac{S_i^k S_j^k}{\sum_{l \neq i} S_l^k} \tag{12}$$

where m_k is the risk-weight of the asset class k and S_i^k is the notional outstanding of dealer i in the asset class k.[7] The initial value $\varepsilon_{ij}^k(0)$ and the long-term mean level θ_{ij}^k are set to the same as σ_{ij}^k. The mean-reversion speed κ_{ij}^k is set to one for all combinations of (i, j, k); see equations (3)-(5). The parameters and initial value of the systematic factor, $\kappa_Y, \theta_Y, \sigma_Y$, and $Y(0)$ are all set to one.

We draw a set of i.i.d. factor loadings u_{ij}^k from the uniform distribution on $[-1, 1]$ and correlate each other using the one-factor Gaussian copula model to obtain the set of w_{ij}^ks. Based on the randomly generated sample, we compute and save each $\delta_{ij}^k(T)$ and $X_{ij}^k(T)$. We estimate the expected values ϕ and γ via Monte Carlo simulation.

3.2 Data and Sample

We proxy the standard deviations of pre-netted exposure processes by the notional outstanding of OTC derivatives contracts reported by the Office of the Comptroller of the Currency. While the raw data encompasses the top 25 holding companies as of June

[6] All of the analyses in this paper are based on the programming code implemented in Julia v.1.0.0.

[7] We select $(m_{\text{Forwards}}, m_{\text{IRS}}, m_{\text{Options}}, m_{\text{CDS}}) = (3, 1, 3, 3)$ based on the estimation results of Cont & Kan (2011).

30, 2017 (Table 1), we simply incorporate the top 13 holding companies, which account for over 99 percent of the total notional outstanding of OTC derivatives contracts. In the subsequent analyses, we draw 100,000 replications in the simulation.[8] If the number of CCPs in Panel A of Table 2 is two then it indicates that all the centrally cleared asset class are processed through their solely dedicated CCPs.

Table 2 provides the simulated results of the CCP benefit for the top 13 dealers in Table 1. In case 1, where all the CDS contracts are cleared through the CCP while other assets are all bilaterally cleared, the CCP slightly harms the netting efficiency. In addition, the 75% CDS CCP case 2 participation ratio shows a slight increase from the case 1 participation ratio, but the negative CCP benefit remains, as Duffie & Zhu (2011) point out. These seemingly counter-intuitive results stem from the fact that the amount of payments offset under the central clearing limited to CDS, which takes a small portion of all contracts, is less than the amount possibly offset across different asset classes between two dealers.

As the IRS CCP is introduced into a system to facilitate central clearing of the largest derivatives class in terms of the notional outstanding, the CCP starts to improve the netting efficiency. In cases 6 and 7, we observe that the introduction of the CCP dedicated to Options and Forwards contracts significantly increases the CCP benefit, while the versatility of the CCP enhances the magnitude of this benefit. These results generally coincide with the findings of Duffie & Zhu (2011), implying that our selected exposure model is reasonable in estimating the total expected counterparty exposures. Interestingly, median-size banks (dealers 7 and 8) appear to be the greatest beneficiaries of the central clearing. Notice that they have most of their positions in the IRS market; e.g., dealer 7's proportion of IRS contracts out of its total outstanding contracts is 78% and that of dealer 8 is 93%. Therefore, because the central clearing scheme provide

[8] We excerpt the scenarios of the existence and uniqueness of CCP from Duffie & Zhu (2011) as reported in Table 3 of Duffie & Zhu (2011).

Table 1: The Notional Outstanding of OTC Derivatives Held by Major U.S. Financial Institutions (Unit: million USD)

Bank Name	Forwards	Swaps	Options	Credits	Total
CITIGROUP INC.	7,945,286	29,055,530	8,062,163	1,716,142	46,779,121
GOLDMAN SACHS GROUP INC.	6,805,544	22,683,382	10,078,149	1,324,886	40,891,961
JP MORGAN CHASE & CO	9,677,683	26,347,419	8,107,704	1,818,418	45,951,224
BANK OF AMERICA CORPORATION	8,265,246	21,049,399	3,400,365	1,124,136	33,839,146
MORGAN STANLEY	2,575,192	16,857,281	6,124,248	737,916	26,294,637
WELLS FARGO & COMPANY	2,320,132	4,369,134	869,609	32,774	7,591,649
HSBC NORTH AMERICA HOLDINGS INC	904,550	4,248,108	215,796	102,273	5,470,727
MIZUHO AMERICA LLC	260,142	4,612,483	66,662	979	4,940,266
STATE STREET CORPORATION	1,507,674	11,462	25,932	0	1,545,068
RBC USA HOLDCO CORPORATION	194,676	51,215	425	397	246,713
CREDIT SUISSE HOLDINGS (USA)	800,936	79,826	6,040	51,051	937,853
BANK OF NEW YORK MELLON CO	495,609	302,210	26,298	160	824,277
BARCLAYS US LLC	256,187	19,831	0	89,490	365,508
PND FINANCIAL SERVICE GROUP INC.	29,780	298,286	27,374	6,616	362,056
U.S. BANKCROP	54,227	197,667	47,178	5,237	304,309
NORTHERN TRUST CORPORATION	283,753	13,385	1,111	0	298,249
SUNTRUST BANKS INC	19,459	134,295	58,310	5,376	217,440
TD GROUP US HOLDINGS LLC	7,678	181,002	660	599	189,939
DB USA CORPATION	53,879	22,557	4,870	4,924	86,230
CAPITAL ONE FINANCIAL CORPATION	11,073	152,193	248	3,049	166,563
MUFG AMERICAS HOLDINGS CO	78,949	64,107	7,080	0	150,136
CITIZENS FINANCIAL GROUP INC	4,332	80,722	9,226	3,092	97,372
KEYCORP	9,094	76,746	6,691	415	92,946
REGIONS FINANCIAL CORPORATION	16,840	50,708	4,249	3,497	75,294
BB&T CORPORATION	15,000	51,562	10,935	0	77,497
	42,592,921	131,010,510	37,161,323	7,031,427	

Note. This table provides the notional outstanding of OTC derivatives for the top 25 U.S. holding companies based on a report from the Office of the Comptroller of the Currency in the 3rd quarter of 2017. We define the asset classes in four categories: Forwards, Swaps, Options, and Credit derivatives. In practice, over 90% of Swap contracts are traded in the form of Interest Rate Swaps (IRS), while most of the standardized and liquid credit derivatives are traded in the form of CDS contracts. Thus, we presume that Swaps and Credit derivatives mainly represent IRS and CDS, respectively. Our dataset employs the top 13 dealers who account for over 99 percent of the total notional outstanding of OTC contracts.

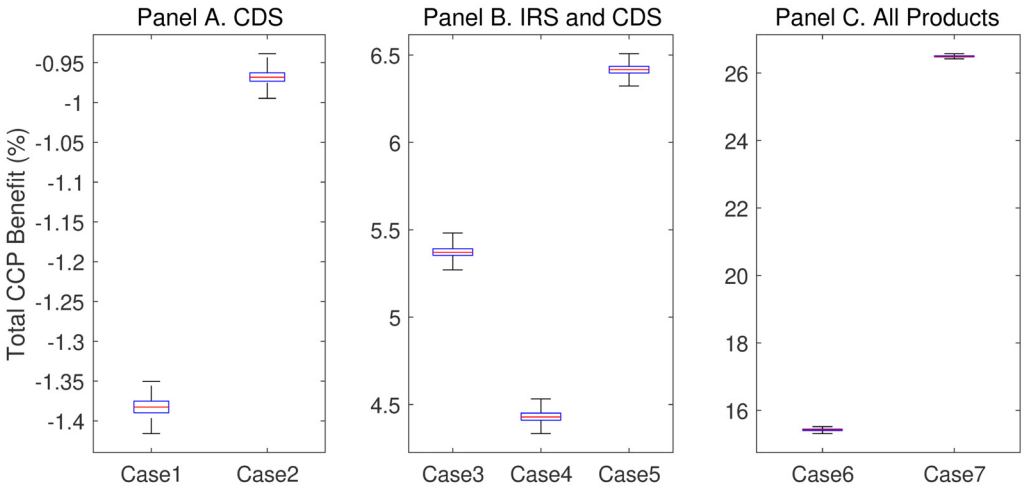
Table 2: Estimated CCP Benefit across Various Clearing Scenarios

Panel A. Clearing Scenarios							
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Forwards	0	0	0	0	0	0.4	0.4
IRS	0	0	0.75	0.75	0.75	0.75	0.75
Options	0	0	0	0	0	0.4	0.4
CDS	1	0.75	0	0.75	0.75	0.75	0.75
Multiplicity of CCP	Same	Same	Same	Mult.	Same	Mult.	Same

Panel B. CCP Benefit (%) for Selected Clearing Scenarios							
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Total CCP Benefit	-1.38 [-1.41 -1.36]	-0.97 [-0.99 -0.95]	5.37 [5.29 5.45]	4.43 [4.35 4.51]	6.42 [6.35 6.49]	15.42 [15.33 15.50]	26.50 [26.44 26.56]
Bank 1	-1.42 [-1.46 -1.37]	-0.99 [-1.02 -0.95]	4.99 [4.87 5.13]	4.05 [3.92 4.18]	6.13 [5.99 6.26]	13.30 [13.13 13.45]	24.18 [24.00 24.36]
Bank 2	-1.33 [-1.37 -1.29]	-0.94 [-0.97 -0.91]	2.81 [2.67 2.93]	1.86 [1.74 1.99]	3.75 [3.61 3.87]	12.11 [11.96 12.26]	23.26 [23.07 23.42]
Bank 3	-1.41 [-1.46 -1.36]	-0.98 [-1.02 -0.95]	3.45 [3.33 3.57]	2.49 [2.36 2.61]	4.54 [4.42 4.66]	12.18 [12.03 12.31]	22.77 [22.57 22.94]
Bank 4	-1.61 [-1.66 -1.56]	-1.13 [-1.17 -1.10]	6.30 [6.16 6.47]	5.23 [5.06 5.38]	7.63 [7.47 7.79]	16.70 [16.51 16.87]	29.37 [29.16 29.55]
Bank 5	-1.64 [-1.69 -1.59]	-1.16 [-1.20 -1.12]	7.85 [7.67 8.03]	6.73 [6.53 6.92]	9.13 [8.93 9.32]	19.32 [19.07 19.55]	32.94 [32.72 33.16]
Bank 6	-0.29 [-0.30 -0.29]	-0.22 [-0.23 -0.21]	5.22 [5.01 5.41]	4.98 [4.79 5.16]	5.35 [5.18 5.54]	25.27 [25.05 25.48]	37.02 [36.83 37.22]
Bank 7	-1.44 [-1.49 -1.39]	-1.03 [-1.06 -1.00]	25.53 [25.29 25.75]	24.68 [24.47 24.91]	26.59 [26.36 26.84]	36.87 [36.63 37.11]	47.10 [46.88 47.32]
Bank 8	-0.02 [-0.02 -0.02]	-0.02 [-0.02 -0.02]	48.72 [48.45 48.97]	48.70 [48.44 48.97]	48.73 [48.42 49.01]	50.34 [50.04 50.61]	53.68 [53.39 53.96]
Bank 9	0.00 [0.00 0.00]	0.00 [0.00 0.00]	-0.06 [-0.06 -0.06]	-0.06 [-0.06 -0.06]	-0.06 [-0.06 -0.06]	28.69 [28.53 28.84]	29.10 [28.95 29.26]
Bank 10	-0.08 [-0.08 -0.07]	-0.06 [-0.06 -0.06]	-1.42 [-1.46 -1.38]	-1.48 [-1.53 -1.44]	-1.42 [-1.46 -1.37]	29.02 [28.87 29.17]	31.45 [31.29 31.6]
Bank 11	-2.05 [-2.10 -2.00]	-1.47 [-1.51 -1.44]	-0.66 [-0.68 -0.64]	-2.16 [-2.20 -2.12]	-1.48 [-1.53 -1.44]	27.68 [27.53 27.84]	30.70 [30.55 30.84]
Bank 12	-0.01 [-0.01 -0.01]	-0.01 [-0.01 -0.01]	-1.36 [-1.45 -1.27]	-1.37 [-1.45 -1.27]	-1.35 [-1.46 -1.26]	27.39 [27.23 27.54]	32.80 [32.65 32.95]
Bank 13	-3.72 [-3.94 -3.49]	-1.16 [-1.31 -0.99]	-0.43 [-0.45 -0.42]	-1.66 [-1.83 -1.50]	-0.98 [-1.15 -0.81]	26.92 [26.74 27.10]	34.27 [34.10 34.43]
Average CCP Benefit	-1.16 [-1.18 -1.13]	-0.71 [-0.72 -0.69]	7.77 [7.71 7.81]	7.08 [7.02 7.13]	8.20 [8.14 8.25]	25.06 [25.00 25.12]	32.97 [32.93 33.02]

Note. This table reports the estimated CCP benefit specific to the selected scenarios of CCP participation along with the number of clearing houses. Panel A reports the constructed scenarios based on the analyses of Duffie & Zhu (2011). Panel B illustrates the scenario-specific CCP benefits based on the model parameters $\kappa_Y = \theta_Y = \sigma_Y = 1$ in Eq. (3). The numbers in parentheses indicate 99% confidence intervals obtained while conducting the Monte Carlo simulation.

Figure 1: Estimated CCP Benefit by Simulation



Note. These box plots depict the estimated CCP benefit, namely, the fraction of the expected total exposure under central clearing over that under an all-bilateral arrangement. The central line indicates the median CCP benefit, while the bottom and top edges of the box depict the first and third quartiles, respectively. The whiskers extend to the most extreme data points which are not considered outliers. Panel A groups the clearing scenarios with only the CDS are centrally cleared but different clearing fractions. Panel B represents the cases where IRS and CDS are at least partially centrally cleared. The cases in Panel C suppose that each asset class is at least partially cleared through CCPs. The case number in this figure coincides with those in Panel A of Table 1. We draw 100,000 replications for each simulation. As shown, the simulation setting provides sufficiently small standard deviations, implying a significant degree of accuracy in the simulation results.

them the greatest netting gain in their exposure reduction, they can take advantage of the largest CCP benefit.

4 Main Analysis

This section provides our baseline model along with its parameters. Based on our baseline model, we first explore the relationship between the cross-exposure correlation and the CCP benefit. In our stochastic network model, the systematic parts of exposure processes have factor loadings and are connected by the correlation parameter ρ with one-factor Gaussian copula model. By varying the correlation parameter from -1 to 1, we explore how the heterogeneity in exposure affect the efficiency of central clearing. If heterogeneous individual exposures are recommended, the argument to"bolster the strong, not weak (Choi 2014)" is applicable in a situation that involves bailing out multiple entities with limited resources.

We next investigate how the total expected counterparty exposure of a system responds to the changes in the macro level regulatory parameters. Specifically, our experiment is based on the dispersion in banks size measured by the standard deviation of their notional outstanding distribution. If there is any systematic relationship between the dispersion in banks size and entire CCP benefit, regulators are incentivized to drive banks in the direction of improving system-wide welfare.[9] For example, a negative relationship between the dispersion in banks size and the CCP benefit prompts regulators to prevent banks from taking too large positions creating larger size variations.

Our experiment goes on to investigate the policy-oriented implications in the

[9] Acharya (2009) evoke the necessity of collective correlation regulation as well as the importance of individuals participating in the system. The externalities of other members' payoffs affect the individuals so that the response analysis of individuals with respect to micro level regulatory variable changes does not serve as an optimal regulation solution.

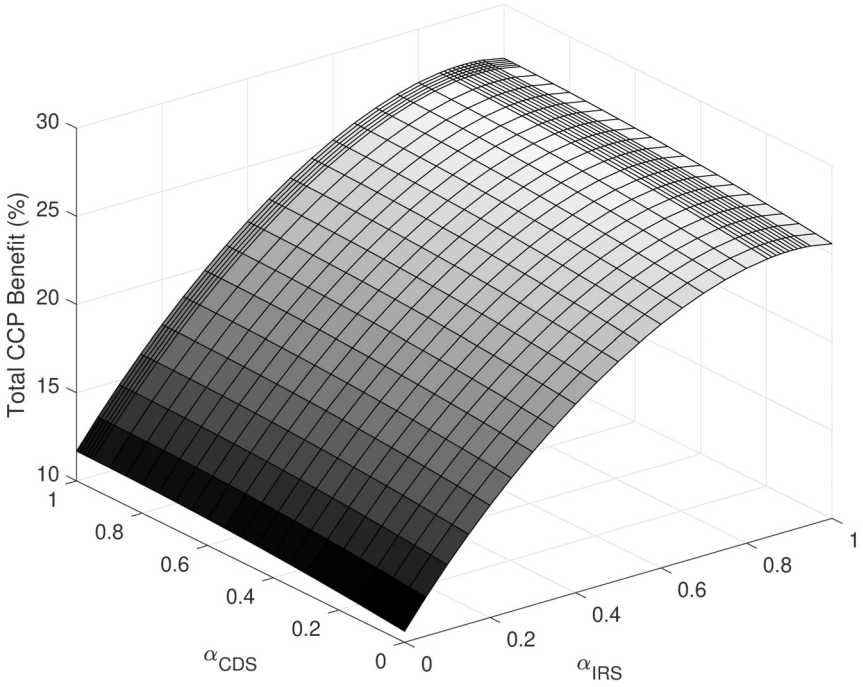
model parameters specific to the individual interbank exposures with respect to the overall CCP benefit under central clearing. The parameter κ_{ij}^k controls the mean-reversion speed of a stochastic process ε_{ij}^k. The speed of adjustment to its long-term mean, as the stabilized state of the exposure level, can be interpreted as the resiliency of exposures. If greater resiliency of exposure enhances the central clearing benefit, the dealers who has fewer positions on contracts with resilient exposures should assume more of the cost of running the central clearing system.

We also investigate the sensitivity of the CCP benefit with respect to the stability of exposure. The stability is demonstrated by the volatility σ_{ij}^k of the pre-netted exposure processes so that it can be interpreted as the uncertainty of the exposure level in the future. The relationship between the stability in the interbank exposures and the system-wide CCP benefit suggests that regulators should levy more of the central clearing operation costs on aggravating dealers in terms of the exposure volatilities.

4.1 Baseline model

To derive meaningful policy-oriented insights based on a battery of sensitivity analyses, we first develop our baseline model by identifying irrelevant parameters of analyses. We search for the optimal participation ratio in the central clearing system. We conduct a grid search for $(\alpha_{\text{Forwards}}, \alpha_{\text{IRS}}, \alpha_{\text{Options}}, \alpha_{\text{Credits}}) \in [0,1] \times [0,1] \times [0,1] \times [0,1]$ with 0.05 increments to determine the global maximum point of the CCP benefit under a single CCP assumption. The results indicate that complete participations in central clearing (all αs are 1) provide the largest multilateral netting efficiency. It seems obvious that the optimal solution takes the corner solution because the CCP benefit results from a trade-off between multilateral netting and bilateral netting. In our setting of $N = 13$ and $K = 4$, the multilateral

Figure 2: Estimated CCP Benefit across $\alpha_{\text{IRS}} \times \alpha_{\text{CDS}}$



Note. This figure depicts the estimated CCP benefit assuming a single CCP across various combinations of $(\alpha_{\text{IRS}}, \alpha_{\text{CDS}})$ by fixing $(\alpha_{\text{Options}}, \alpha_{\text{Forwards}}) = (0.4, 0.4)$. Using the adaptive grid search we find that the optimal central clearing ratio between IRS and CDS lies on the point $(0.9, 1.0)$ to maximize the CCP benefit.

netting ($N = 13$) has a greater chance of being netted than that the bilateral ($K = 4$). Although this is obvious optimal solution mathematically, OTC derivatives market participants may not be willing to fully participate in a central clearing system in practice. Moreover, some exotic structured products have complicated contingent payoff structures, which hinder standardization and they are too illiquid to be included in a central clearing system.

In this context, we restrict our focus to the IRS and CDS contracts that have attracted regulators' concerns from a systemic point of view. We obtain the survey results regarding market participants' willingness to take part in activity from Duffie

& Zhu (2011) to set α_{Forwards} and α_{Options} be 0.4. We conduct an adaptive grid search with for $(\alpha_{\text{IRS}}, \alpha_{\text{CDS}}) \in [0,1] \times [0,1]$ and find the local maximum of the CCP benefit as $(0.9, 1.0)$. In this procedure, we set the minimum increment to be 0.01 and compute the CCP benefit of all grid points using a 100,000 iteration of the Monte Carlo simulation.

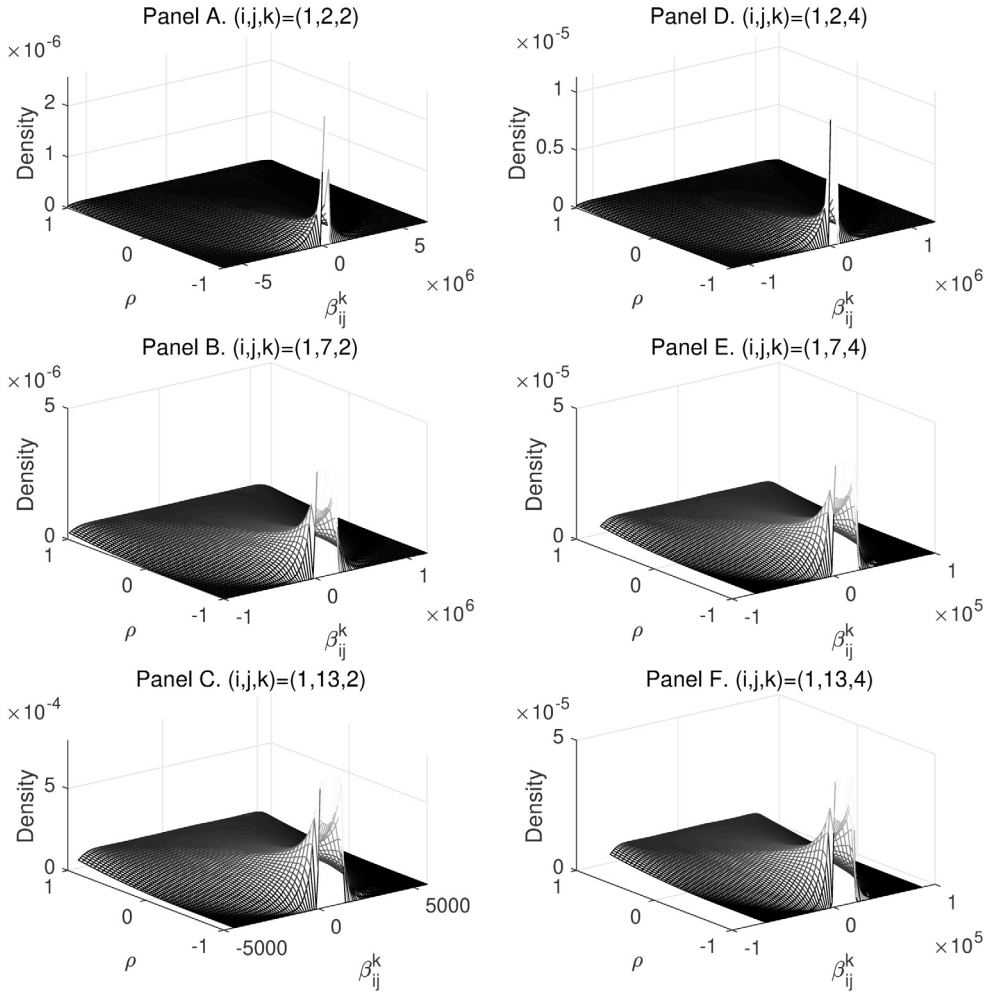
4.2 Heterogeneity in Exposure Distributions

Along with the stochastic network model described in section 2, we assume that, in nature, the factor loadings of individual exposure processes on a systematic factor are uniformly distributed. The interbank exposure dependency is specified by the one-factor Gaussian copula model connecting the factor loadings w_{ij}^k.

We proxy the size related constant S_{ij}^k with the standard deviation σ_{ij}^k of pre-netted exposure processes. It follows that $S_{ij}^k = S_{ji}^k$ holds for all i, j so that the probability density function of the systematic factor loading β_{ij}^k of post-netted exposure X_{ij}^k forms the delta function at zero, implying that the exposure is almost surely uncorrelated with the systematic factor. On the other hand, as the ρ increase from -1 to 1, the probability density function of β_{ij}^k spreads out to the interval $[-S_{ij}^k, S_{ij}^k]$ and finally forms a uniform distribution over $[-S_{ij}^k, S_{ij}^k]$. In other words, as the ρ increase from -1 to 1, the likelihood of producing large absolute values increases while the chance of β_{ij}^k being zero dramatically decreases.

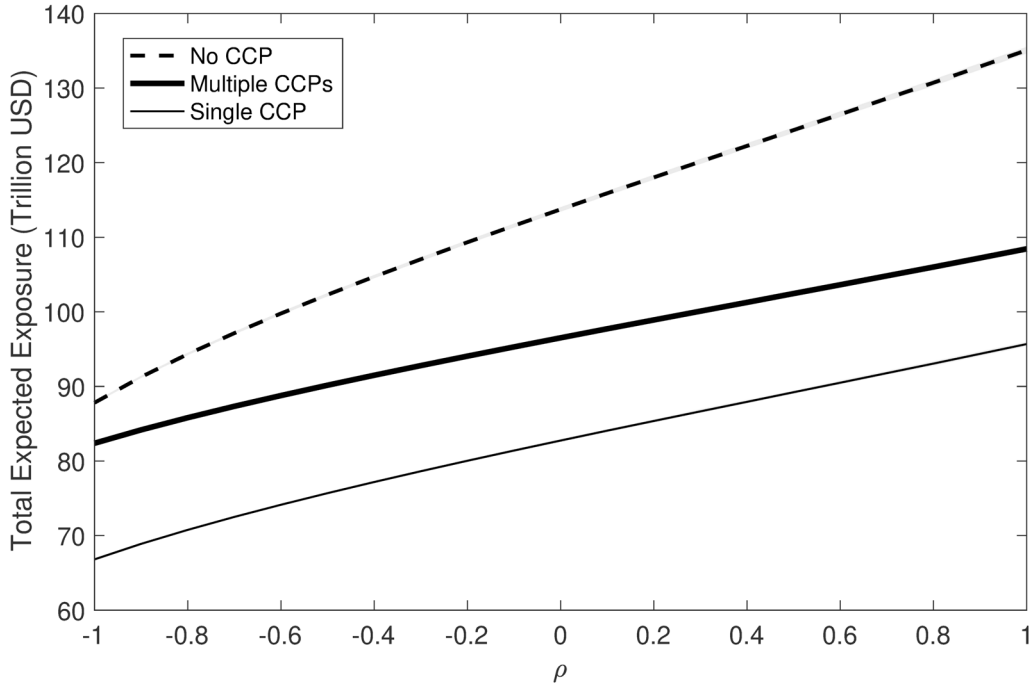
Figure 3 illustrates the distributions of some selected β_{ij}^k by varying ρ. Although the form of each density function shows mild asymmetry, we can observe that the density of β_{ij}^k spreads out from the concentration at zero as ρ increases from -1 to 1. We set our baseline correlation parameters to zero for subsequent analyses, intending for this to represent the neutral state of interconnectedness.

Figure 3: Density of the Selected β_{ij}^k by Varying ρ



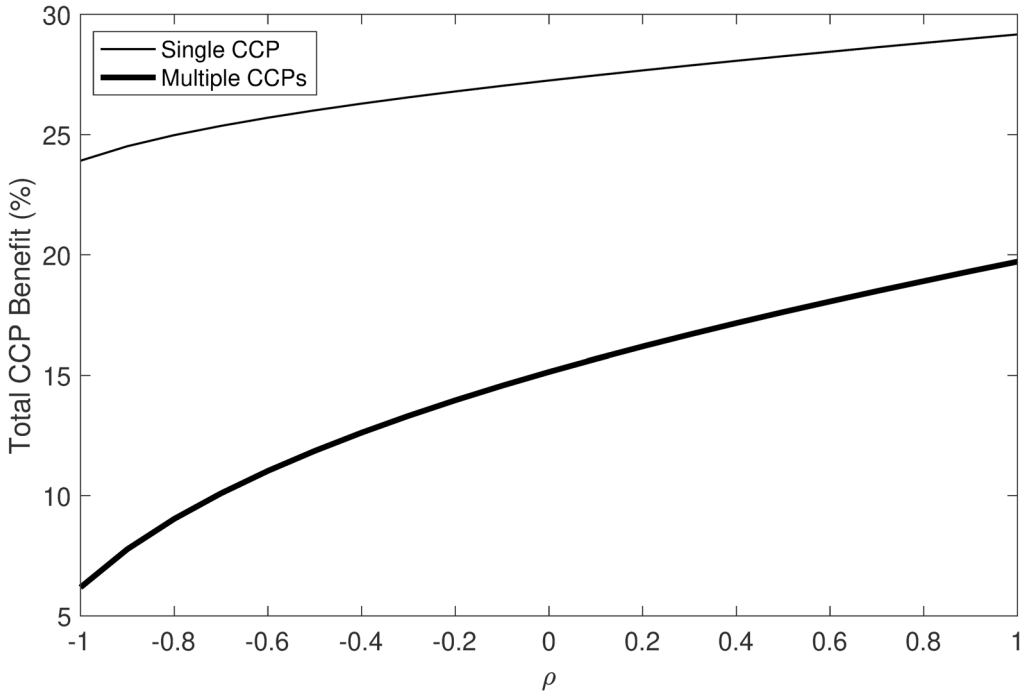
Note. These figures depict the density of β_{ij}^ks with respect to changes in ρ. The correlation between the interbank exposure distributions are indicated by ρ. Panels A–C represent factor loadings of $X_{1,2}^2, X_{1,7}^2, X_{1,13}^2$ on Y, which are representative exposure distributions of IRS, respectively. Panels D–F provide factor loadings of $X_{1,2}^4, X_{1,7}^4, X_{1,13}^4$ on Y, which are representative exposure distributions of CDS, respectively.

Figure 4: Total Expected Counterparty Exposures under Different Clearing Schemes



Note. This figure shows the total expected counterparty exposures under different clearing schemes across different $\rho \in [-1, 1]$ with their 99% confidence interval bands. "Single CCP" assumes only one CCP handling all of the asset classes. "Multiple CCPs" implies that the contracts in each asset class are cleared through the CCP dedicated to the asset class. "No CCP" represents the total expected counterparty exposure under the bilateral arrangement. We set the clearing fraction of each asset class to [0.4 0.9 0.4 1.0] under central clearing.

Figure 5: Cross-exposure Correlations and Estimated CCP Benefit



Note. This figure depicts changes in the CCP benefit based on the changes in ρ. Motivated by the optimal solution reported in Section 4.1, we choose the clearing fractions of Forwards, IRS, Options, and CDS at 0.4, 0.9, 0.4, and 1.0, respectively. From 1,000 bootstraps out of 100,000 samples, we obtain 99% confidence intervals for each CCP benefit and illustrate them with the gray bound. A higher ρ implies a higher dependency of individual exposures on a systematic factor.

Employing the baseline parameters specified in Section 4.1, we estimate the total expected counterparty exposures under different clearing schemes across different correlations in exposure distributions as shown in Figure 4. Regardless of central clearing schemes, heterogeneous interbank exposures tend to reduce the total expected exposure that proxies the amount of potential losses in the OTC derivatives market from a systemic point of view. We further observe a positive relationship between the multiplicities of CCP and the total expected counterparty exposure. Interestingly, the amount of potential losses under the integrated CCP becomes less distinctive from that under asset-specific CCPs as the interbank exposures become more homogeneous. In addition, Figure 5 illustrates that the benefit of the central clearing becomes more pronounced, as the co-movement between individual exposures becomes stronger.

In summary, it is desirable to promote heterogeneity in interbank exposure distributions as it always reduces the amount of potential losses in the system. This implication coincides with the findings of Acharya (2009) and Choi (2014) in that heterogeneity is systemically prudential. In the meanwhile, the multilateral netting benefit under central clearing outweighs the bilateral reduction of expected exposures within an environment of systemic homogeneity in the distributions of interbank exposure dynamics.

4.3 Heterogeneity in Bank Size

Throughout the analyses, we estimate the parameters of exposure distributions based on the notional outstanding of each asset class, which is the key determinant in generating exposure and, in turn, the netting efficiency of central clearing. The notional outstanding of OTC derivatives contracts can be regarded as a proxy candidate for dealer size. Note that the log of notional outstanding reported by the Office of the Comptroller of the Currency are virtually distributed uniformly over 25

major dealers in United States. Inspired by this observation, we set the baseline case as the log uniformly distributed outstanding for the 13 dealers across 4 asset classes, where the means are equal to the geometric average of outstanding data for each asset class.[10]

We then conduct an experiment on the scaling constant of the baseline case standard deviation. The scaling constant multiplied at the baseline standard deviation varies from 0 to 1, range that covers no variation in outstanding to the largest such variation in those. For each iteration, we draw the notional outstanding from the distribution we provide. We test the dispersion in bank size for the correlation in inter-bank exposure distributions of selected cases, that is, we set ρs to -1, 0, and 1. The results show that regardless of the dependency of exposures on the systematic factor, the CCP benefit monotonically decreases as the dispersion in bank size increases. From the system-wide netting efficiency perspective, the large banks might be restricted from taking new positions that increase their exposure, because treating small banks in the opposite manner is practically infeasible.

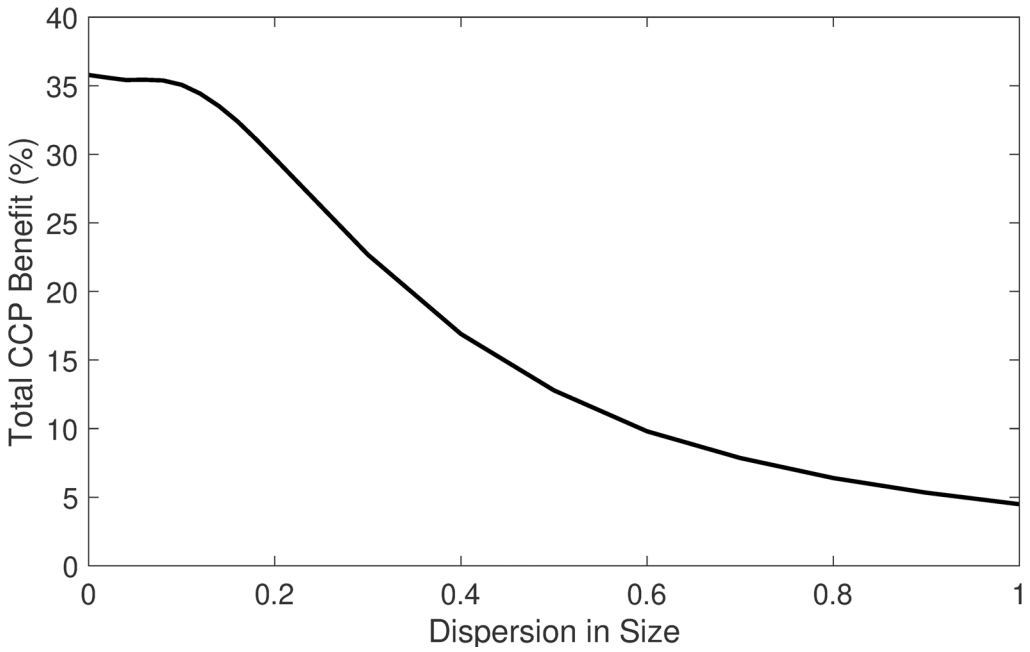
4.4 Bank-Specific Resiliency and Stability

Well-established regulations should be based on not only the objective risk measure's response to collective level variables, but also the impact of individual member level variables on the risk measure. Allocating the cost of a central clearing system to its participating members can be justified based on the contribution of a clearing member to the total risk. By adjusting the parameters of our exposure process models, we explore the effect of bank-specific resiliency and stability on the netting efficiency.

In our model of pre-netted exposure, κ_{ij}^k represents the speed of adjustment to its

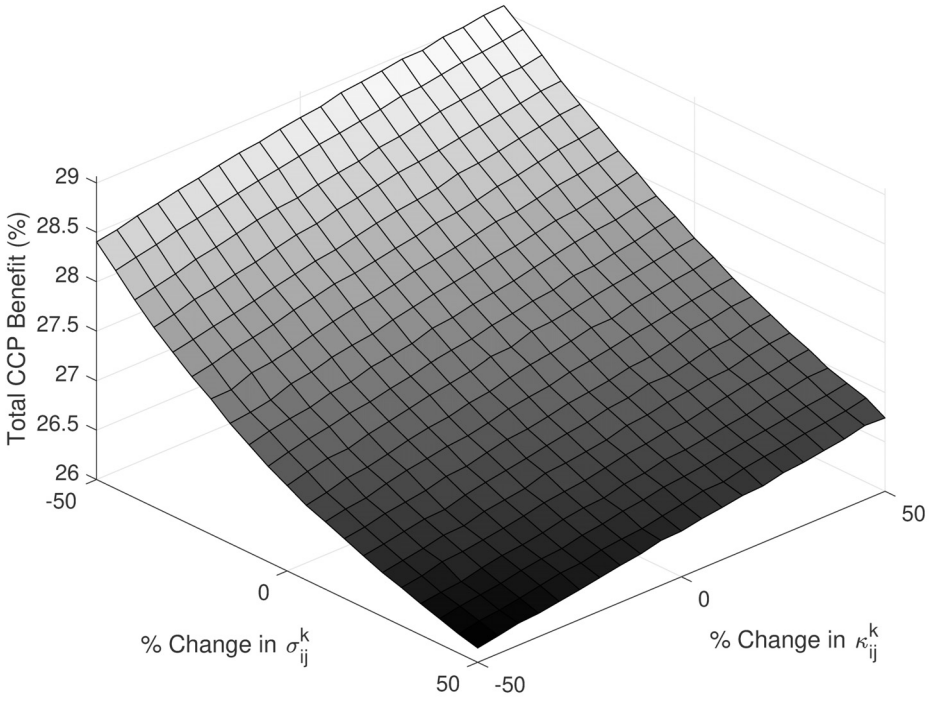
[10] We also conduct the experiment using the median as the mean of the baseline case. The qualitative and quantitative results are almost the same. We therefore do not report the results, but we are open to providing them upon readers request.

Figure 6: Dispersion in Bank Size and Estimated CCP Benefit



Note. This figure illustrates the CCP benefit by varying cross-exposure correlations across different scenarios on bank size dispersions. We proxy bank size by its notional outstanding of OTC derivatives. We define the size dispersions by the scaling constants on the standard deviation of baseline case. We draw samples of banks' outstanding by each asset class from uniform distributions.

Figure 7: Estimated CCP Benefit by Varying κ and σ



Note. This figure depicts the estimated CCP benefit in response to the percentage changes in κ^k_{ij} and σ^k_{ij} relative to the baseline setting.

long-term exposure level. The mean-reversion speed parameter κ^k_{ij} can be interpreted as the bank-specific resiliency of the pre-netted exposure. We conduct an experiment on bank-specific resiliency by varying κ^k_{ij} from 50% to 150% of baseline parameter. The results show that as the exposures become more resilient in converging to their long-term levels, the central clearing system provides more netting efficiency. Dealers with positions of more resilient exposures should be compensated with lower central clearing participation costs than other counterparts.

We also conduct a sensitivity analysis of CCP benefit on the bank-specific exposure stability, which is defined by the volatility of pre-netted exposure processes. We expect that less volatile exposure distributions provide greater CCP benefit because, for the

fixed risk horizon, smaller exposure volatility has a similar effect in stabilizing long-term exposure levels. In the similar fashion to the experiment on κ_{ij}^k, we investigate the CCP benefit alongside the changes in σ_{ij}^k of pre-netted exposure processes from 50% to 150% of baseline parameter. We verify that the existence of non-linear positive relationship between the volatility parameters of exposure processes and the CCP benefit; we also determine that its sensitivity is larger than that of bank-specific resiliency. In summary, the banks with more inelastic and unstable exposures should cover more of the central clearing system operation cost.

5 Conclusion

We revisit the advantage of multilateral netting in mitigating the magnitude of total expected counterparty exposure over a bilateral netting scheme with a more realistic model of exposure processes. Our proposed stochastic network model of the pre-netted interbank exposures illustrates that the amount of exposures novated to the CCP maintains its dominant role in determining whether or not the CCP improves netting efficiency, confirming the findings of Duffie & Zhu (2011). Also, it should be highlighted that central clearing may not improve the entire netting efficiency, if the CCP's dedication is limited to a subset of the outstanding asset classes in the market.

Viewed in this light, our simulation study investigates how the correlation and dispersion in the pre-netted exposure processes affect the netting efficiency. Our simulation results indicate that heterogeneity in interbank exposures is systemically desirable, while the multilateral netting benefit of central clearing counterparties becomes more pronounced in an environment of systemically homogeneous interbank exposure dynamics. The strong positive correlation in exposure distributions is consistent with banks' tendencies to employ more homogeneous asset management

practices that may lead to a more systemically vulnerable exposure networks. Thus, the regulators, who are responsible for macro-prudential supervision, should be cautious in prompting market participants to choose similar assets even though doing so improves the system-wide netting efficiency under the central clearing scheme.

We subsequently explore the sensitivities of the CCP benefit to changes in bank-specific resiliency and stability parameters. Our findings demonstrate that the CCP benefit is sensitive to changes in bank-specific characteristics, especially to the stability of exposures. A greater proportion of the costs of joining the central clearing system should be allotted to the members who contribute more to the deterioration of the netting efficiency at large.

References

Acharya, Viral V (2009), 'A theory of systemic risk and design of prudential bank regulation', *Journal of Financial Stability* **5**(3), 224–255.

Amini, Hamed, Damir Filipović & Andreea Minca (2017), 'Systemic risk and central clearing counterparty design', *Working Paper* .

BCBS, Basel Committee on Banking Supervision (2013), 'Discussion paper: The regulatory framework: Balancing risk sensitivity, simplicity and comparability', *Bank for International Settlements* .

BCBS, Basel Committee on Banking Supervision (2016), 'Consultative document: Reducing variation in credit risk-weighted assets constraints on the use of internal model approaches', *Bank for International Settlements* .

Bignon, Vincent & Guillaume Vuillemey (2017), 'The failure of a clearinghouse: Empirical evidence', *Working Paper* .

Brunnermeier, Markus K & Lasse Heje Pedersen (2008), 'Market liquidity and funding liquidity', *The Review of Financial Studies* **22**(6), 2201–2238.

Choi, Dong Beom (2014), 'Heterogeneity and stability: Bolster the strong, not the weak', *The Review of Financial Studies* **27**(6), 1830–1867.

Cont, Rama & Thomas Kokholm (2014), 'Central clearing of otc derivatives: Bilateral vs multilateral netting', *Statistics & Risk Modeling* **31**(1), 3–22.

Cont, Rama & Yu Hang Gabriel Kan (2011), 'Statistical modeling of credit default swap portfolios', *Working Paper* .

Cox, John C, Jonathan E Ingersoll Jr & Stephen A Ross (1985), 'A theory of the term structure of interest rates', *Econometrica* **53**(2), 385–408.

Duffie, Darrell & Haoxiang Zhu (2011), 'Does a central clearing counterparty reduce counterparty risk?', *The Review of Asset Pricing Studies* **1**(1), 74–95.

Duffie, Darrell, Martin Scheicher & Guillaume Vuillemey (2015), 'Central clearing and collateral demand', *Journal of Financial Economics* **116**(2), 237–256.

Loon, Yee Cheng & Zhaodong Ken Zhong (2014), 'The impact of central clearing on counterparty risk, liquidity, and trading: Evidence from the credit default swap market', *Journal of Financial Economics* **112**(1), 91–115.

Menkveld, Albert J (2017), 'Crowded positions: An overlooked systemic risk for central clearing parties', *The Review of Asset Pricing Studies* **7**(2), 209–242.