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Does OTC Derivatives Reform Incentivize Central Clearing?*

Samim Ghamami[†] and Paul Glasserman[‡]

Abstract

The reform program for the over-the-counter (OTC) derivatives market launched by the G-20 nations in 2009 seeks to reduce systemic risk from OTC derivatives. The reforms require that standardized OTC derivatives be cleared through central counterparties (CCPs), and they set higher capital and margin requirements for non-centrally cleared derivatives. Our objective is to gauge whether the higher capital and margin requirements adopted for bilateral contracts create a cost incentive in favor of central clearing, as intended. We introduce a model of OTC clearing to compare the total capital and collateral costs when banks transact fully bilaterally versus the capital and collateral costs when banks clear fully through CCPs. Our model and its calibration scheme are designed to use data collected by the Federal Reserve System on OTC derivatives at large bank holding companies. We find that the main factors driving the cost comparison are (i) the netting benefits achieved through bilateral and central clearing; (ii) the margin period of risk used to set initial margin and capital requirements; and (iii) the level of CCP guarantee fund requirements. Our results show that the cost comparison does not necessarily favor central clearing and, when it does, the incentive may be driven by questionable differences in CCPs' default waterfall resources. We also discuss the broader implications of these tradeoffs for OTC derivatives reform.

JEL Codes: G01, G18, G20, G28.

Keywords: Central clearing, OTC derivatives, margin, collateral, capital.

1 Introduction

In response to the financial crisis of 2008, leaders of the Group of Twenty nations agreed to reforms in the over-the-counter (OTC) derivatives markets with the goal of reducing the systemic risk posed by these

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markets. This program of reforms, launched in 2009, includes the following two elements:¹

- All standardized OTC derivatives should be cleared through central counterparties (CCPs);
- Non-centrally cleared derivatives contracts should be subject to higher capital and collateral requirements.

An important motivation for the second of these elements is to create a cost incentive in favor of central clearing (BCBS and IOSCO [2015]). Our goal is to evaluate whether this objective has been met and to identify the main drivers of the cost comparison and their implications.

In a centrally cleared market, after two parties agree to an OTC derivative transaction, they replace their bilateral contract with two back-to-back contracts through a CCP. The original bilateral relationship is eliminated, and each of the two original parties continues to face the CCP throughout the life of the contract. In a market without central clearing, the two original parties would instead face each other.

A centrally cleared market offers potential netting and operational benefits; it may be better able to respond to the failure of a market participant; and it may yield greater transparency. It may also create a network of exposures that is more vulnerable to a single point of failure (see the remarks by Bernanke [2011] and Yellen [2013] on various aspects of CCPs and their role in financial stability and financial reform). The effect of derivatives CCPs on financial stability, and the right design and regulation of the OTC derivative market continue to generate debate among industry participants, government officials, and the public; research and discussion of these questions includes Culp [2010], Stulz [2010], Singh [2010], Duffie and Zhu [2011], Heller and Vause [2012], Pirrong [2011], Pirrong [2013], Cont and Kokholm [2014], Duffie et al. [2015], Duffie [2016], and France and Kahn [2015].

The goal of this paper is to gauge whether new rules imposed on bilateral trading² achieve the objective of incentivizing central clearing, and to identify the main factors driving the cost comparison and their implications. The cost comparison requires some assessment of both types of markets, particularly the associated netting efficiency and risk management practices. Creating a cost incentive for central clearing is a specific objective of the OTC derivatives reform program (see BIS [2014] and BCBS and IOSCO [2015]). It remains relevant, despite the clearing mandate, because the question of when a contract is sufficiently standard to require central clearing involves some discretion. Single-name credit default swaps, for example, continue to trade both bilaterally and through CCPs. In the absence of a cost advantage for central clearing, market participants may be motivated to customize contracts in order to trade them bilaterally. Without a cost advantage, banks may also be less inclined to move legacy trades to CCPs.

¹See Bernanke [2011], Yellen [2013], Fischer [2015], BCBS and IOSCO [2015], and the references therein for additional background.

²We use the term “bilateral trading” as a simple way to refer to the part of the market that is not centrally cleared. The term is imprecise because even centrally cleared OTC contracts are initially traded bilaterally, rather than through an exchange, and then novated to a CCP. The more precise but more cumbersome term is “non-centrally cleared derivatives.”

We limit our analysis to the capital and collateral costs of bilateral trading and central clearing. We take the perspective of a derivatives dealer within a bank holding company that is a clearing member of the CCPs through which it trades. Under both bilateral trading and central clearing, the dealer faces collateral costs resulting from margin requirements and capital charges resulting from counterparty credit risk. Central clearing also requires contributions to a CCP’s guarantee fund,³ which carries both a collateral and capital cost.

We compare these costs under two market configurations — a fully bilateral market and a fully centrally cleared market. The detailed rules covering all the relevant costs are complex; we develop a simplified framework that captures the key features driving these costs. Our model and its calibration are designed to take advantage of a confidential dataset collected by the Federal Reserve Bank of New York and the Division of Banking Supervision and Regulation at the Board of Governors of the Federal Reserve System. The dataset provides information on institution-to-institution derivatives exposures, including some information on both bilateral and centrally cleared transactions.

We find that three factors drive the comparison of costs between fully bilateral and fully centrally cleared market configurations:

- (i) the degree of netting achieved in each case;
- (ii) the *margin period of risk* (MPOR) used to set initial margin and capital requirements in each case; and
- (iii) CCP risk management practices — specifically, their relative reliance on initial margin and guarantee fund contributions.

Greater netting efficiency is often viewed as a benefit of central clearing through which total counterparty risk in the financial system is reduced.⁴ In our cost comparison, greater netting lowers margin and capital requirements. A single, global CCP clearing all derivatives would theoretically achieve maximal netting efficiency. However, as noted by Duffie and Zhu [2011], Heller and Vause [2012], and Cont and Kokholm [2014], central clearing may lose its netting advantage in a market with multiple CCPs. In our analysis, the cost comparison is driven by the relative benefits of netting by counterparty versus netting by product category. Although the importance of this tradeoff has been understood for some time, this study is the first to be able to estimate these effects across multiple product categories using necessary confidential data.⁵

³We use the terms “guarantee fund” and “default fund” interchangeably.

⁴Pirrong [2013] argues that netting does not reduce risk but merely redistributes it by giving seniority to derivatives claims over other claims. Whether netting is welfare-improving is an important question for the regulation of derivatives but it does not affect the cost comparison on which we focus.

⁵Duffie et al. [2015] compare bilateral and centrally cleared netting as well, but their analysis is limited to the CDS market.

Initial margin is intended to cover losses between the time of a counterparty’s default and the time the position is closed out, known as the margin period of risk. This interval is currently set at five days for centrally cleared OTC derivatives and ten days for bilateral trading. With all else equal, this difference favors central clearing.

CCPs generally require clearing members to contribute to a guarantee fund through which losses to the clearinghouse from the failure of one member are mutualized among surviving members. Guarantee fund contributions create capital and collateral costs for member banks and thus favor bilateral trading. At the same time, lowering these costs through smaller guarantee funds would undermine the financial stability objective of the clearing mandate. We find wide variation in the practices of CCPs in setting their margin and guarantee fund levels, which highlights the importance of this issue.

After taking into account these and other sometimes conflicting considerations and calibrating our model to the Federal Reserve data, we cannot conclude that OTC derivatives reform creates an unambiguous cost incentive in favor of central clearing; indeed, for a wide range of realistic parameter values, bilateral trading carries lower capital and collateral costs. This conclusion contrasts with a report from the Bank for International Settlements (BIS [2014]), which finds that capital and collateral costs favor central clearing. In addition to providing our overall comparison, our analysis allows a decomposition into the key factors driving the tradeoff and their sensitivity to modeling assumptions, insights that are difficult to glean from the results reported in BIS [2014]. Appendix C gives a brief discussion of BIS [2014].⁶

The rest of this paper is organized as follows. Section 2 reviews the pros and cons of central clearing and the objectives of OTC derivatives reform that provide the backdrop to our investigation. Section 3 describes the capital and collateral rules we seek to capture in our analysis. Section 4 develops our model. Section 5 describes our dataset and connects the data with the elements of our model. Section 6 discusses the calibration of the model, and Section 7 presents our numerical results. In Section 8, we discuss the main implications of our investigation.

2 OTC Derivatives Reform

To put our analysis in context, we briefly review the objectives of the clearing mandate for OTC derivatives and the accompanying requirements of higher margin and capital requirements in the bilateral market. OTC derivatives reform faces some competing objectives, and these tensions influence the cost comparison we analyze.

As discussed in a joint report by the Basel Committee on Banking Supervision and the International Organization of Securities Commissions (BCBS and IOSCO [2015]), margin requirements for non-centrally

⁶An article titled “Unclear incentives: do capital and margin rules support CCPs?” in *Risk Magazine* in March 20, 2015, also discusses various aspects of BIS [2014].

cleared derivatives serve two objectives: to reduce counterparty credit risk in the bilateral market, and to promote central clearing. More broadly, central clearing of derivatives can support financial stability in several ways:

- Requiring collateral for derivatives reduces counterparty credit risk.
- Central clearing can create greater opportunities for netting of derivatives, and netting also reduces counterparty credit risk.
- Through its default management procedures, a CCP should be better prepared than the bilateral market to deal with the failure of a major derivatives participant, managing an orderly disposal of the failed party's positions and the protection of its client's trades. A CCP also monitors the creditworthiness of its members and the risks they take on.
- Central clearing can improve price discovery and transparency. A CCP can observe the prices of transactions among its members, and it can rely on its members to provide price quotes for marking positions. This information might make a centrally cleared market less likely to freeze in times of market stress.
- Through its default waterfall resources (margin and default fund contributions), a CCP absorbs losses that would otherwise be borne by the derivatives counterparties of its member firms. This backstop should reduce the risk of a downward spiral of collateral calls as a firm's credit quality declines, as happened in the case of American International Group, Inc., in 2008.
- Central clearing should facilitate regulatory oversight of the OTC derivatives market by allowing regulators to monitor the market through CCPs rather than through a diffuse network of bilateral transactions.

Critics of the clearing mandate for OTC derivatives argue that CCPs can threaten financial stability by concentrating risk in institutions that might ultimately require government support in a crisis. The extent to which the potential benefits of clearing listed above are realized in practice is also open to debate. Moreover, *many of these benefits are best achieved with fewer CCPs*, so the advantages of central clearing can be at odds with concerns over concentrating risk.

For our analysis, this tension between risk concentration and the advantages of central clearing is particularly relevant to the comparison of netting benefits with and without central clearing. The greatest possible netting efficiency would be achieved by clearing all trades through a single CCP. Netting opportunities are lost as market participants split their portfolios across multiple CCPs. In OTC clearing, CCPs have generally limited the scope of products they clear, requiring separate clearing of interest rate swaps

and credit default swaps, for example; this separation limits spillovers from one market to another, but it also reduces netting opportunities. We will see that the possibility of netting across product categories also has a big impact on the bilateral market. Supervisory guidelines (BCBS and IOSCO [2015]) oppose bilateral netting across product categories; this stance is conservative in the sense that it leads to higher margin requirements, but it raises the question of whether collateral is a more effective tool for reducing counterparty credit risk than netting.⁷

Several of the other benefits listed above for central clearing are also supported by having a smaller number of CCPs. A CCP should be better able to monitor its members if it sees a greater fraction of its members' trades. The CCP should also be better able to sell the positions of a member in default if it does not need to contend with other CCPs managing the same default at the same time, a point emphasized in Glasserman et al. [2015].

Fragmentation of the OTC derivatives market has also been blamed for recent persistent price dislocations. Standard U.S. dollar interest rate swaps have traded at different rates for the past year at the two largest CCPs in this market. The difference is reportedly driven by a preference for one CCP over the other among fixed-rate payers, because one CCP offers portfolio margining between swaps and listed Treasury futures while the other does not. The trade imbalance creates a price difference that reflects the value of greater netting opportunities. More recently, a price difference has emerged between yen denominated interest rate swaps cleared in Japan and London, based in part on regulatory constraints on Japanese banks. See Younger et al. [2016b] for a discussion of both of these examples of imbalances across CCPs.

We noted above that a CCP's default waterfall resources generally, and default fund in particular, play an important role in enhancing financial stability through central clearing. The capital and collateral costs associated with default fund contributions will be an important part of our analysis — all else equal, they raise the cost of central clearing. To the extent that regulators seek to promote central clearing over the bilateral market, this raises the concern that default fund requirements might be relaxed.

As we discuss in Section 4, for CCPs designated systemically important, default waterfall resources are required to meet a "Cover 2" standard, meaning that they should be sufficient to cover losses resulting from the failure of any two clearing members under stress conditions. This is a principles-based standard that leaves room for interpretation and implementation. Moreover, we will argue that the adequacy of the Cover 2 standard, even if properly implemented, depends on the distribution of exposures across a CCP's members. We will quantify this effect through a parameter we call the concentration ratio. This parameter will be important in our cost comparison.

⁷Some studies have raised concerns about the supply of high quality liquid assets required to meet the collateral demands of OTC derivatives reform. See Anderson and Joever [2014], Heller and Vause [2012], and Sidanius and Zikes [2012] for analysis of this question.

3 Capital and Collateral Rules

Before proceeding to the details of our model, we describe the capital and collateral costs that banks face when trading in the bilateral OTC markets and when trading through derivatives CCPs. The key elements are summarized in Table 1 and illustrated in Box 1. Our model in Section 4 addresses each of these elements.

Table 1: Banks’ collateral and capital requirements under bilateral and central clearing.

	Trading Bilaterally	Clearing through CCPs
Collateral Requirements	Initial Margin	Initial Margin Default Fund Contribution
Capital Requirements	Counterparty Risk Capital	CCP Risk Capital

3.1 Counterparty Risk Capital and CCP Risk Capital

Bilateral case. Suppose banks A and B are parties to a swap or other OTC derivatives contract. Suppose the contract has positive value to bank A and therefore negative value to bank B. Then bank A is exposed to the risk of default of bank B, and this exposure carries a capital requirement for bank A.

Under Basel III (BCBS [2011]), the capital charge for counterparty credit risk (CCR) has two elements. The first is the Basel II CCR capital requirement, which is similar to the capital requirement bank A would face if it had made a loan to bank B. In addition, Basel III includes a credit valuation adjustment (CVA) capital requirement, which is intended to capture losses in the market value of bank A’s position with bank B resulting from a decline in bank B’s creditworthiness without an outright default.⁸

Whereas the Basel II CCR capital requirement is a static calculation, CVA ordinarily reflects the possibility that a counterparty may default at any time during an extended horizon and that the value of the exposure may change over time (see Gregory [2012], Ghamami and Goldberg [2014], Carr and Ghamami [2015], Pykhtin [2011] and the reference therein). Our model approximates a bank’s CCR risk capital by multiplying Basel II pre-specified risk weight representing the counterparty’s credit quality (default probability) by an average measure of the bank’s exposure to the counterparty.

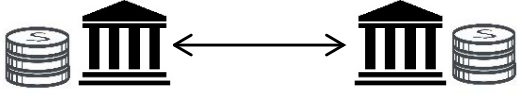
The bank’s exposure must be calculated *net of any collateral posted by the counterparty*. We emphasize this point because once banks exchange margin for bilateral transactions, the residual exposure — and the resulting CCR capital requirement — should be small, even though a bank counterparty usually carries a much higher risk weight than a CCP.⁹

⁸See Goodhart [2011] for a comprehensive and insightful historical account of the BCBS, Hull [2012] for a description of variations of the Basel credit risk and counterparty risk capital rules.

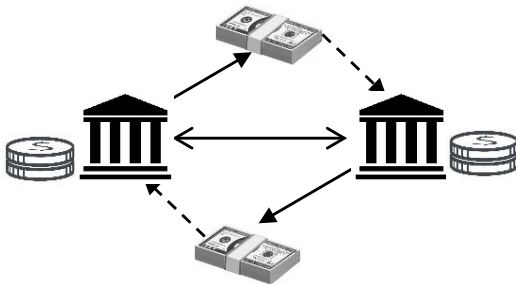
⁹The *static* element of Basel III CCR capital requirement is calculated net of the CVA risk capital charge (pages 36-37 of BCBS [2011]). The exposure at default (EAD) component of the CVA charge is reduced by potential “CVA hedges” using

Bilateral Market

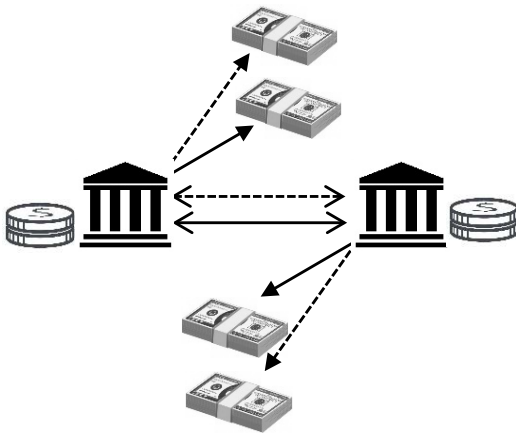
In a bilateral transaction, two banks enter into a swap. Each bank holds capital to absorb potential losses if the other party fails to make promised payments.



Under new rules, each bank is required to set aside initial margin, which is collateral that guarantees required payments.



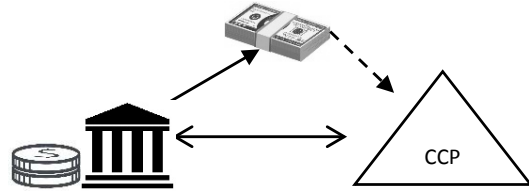
Collateral reduces each bank's exposure to the other party and therefore reduces the amount of capital each bank must hold.



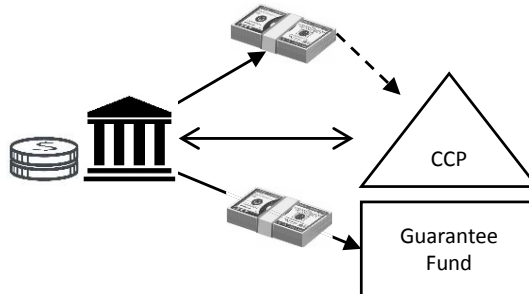
Without netting, separate initial margin must be calculated for different types of trades. Netting allows pooling of collateral and reduces collateral costs.

Centrally Cleared Market

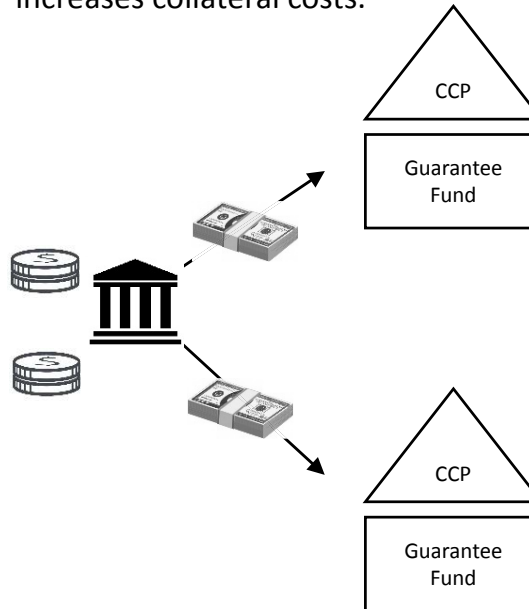
With central clearing, the bank posts initial margin to the CCP. The CCP does not post initial margin to the bank.



The bank also contributes to the CCP's guarantee fund and holds capital against the risk of loss from the CCP.



When a bank trades through multiple CCPs, it posts separate initial margin and guarantee fund contributions to each CCP. The loss of netting opportunities increases collateral costs.



Box 1: Overview of capital and collateral in two market configurations

Centrally cleared case. When a bank trades through a CCP, it takes on counterparty risk through the possibility that the CCP or its members may fail. This exposure carries a capital requirement.

Under Basel II and Basel III, the CCP risk capital requirement has two components. The bank incurs a *trade exposure* capital charge, based on its exposure to the CCP in its current trades. This component is similar to the Basel II capital charge a bank would face in trading with another bank, though typically with a much lower risk weight for a CCP than for a bank. In addition, the bank incurs a *default fund exposure* capital charge. This component is based on the risk that the bank’s contribution to the CCP’s default fund would be tapped in the event of the failure of other clearing members.¹⁰ Our model of OTC clearing closely follows the Basel II-III formulation to approximate banks’ CCP risk capital.

3.2 Collateral Requirements

Next, we describe collateral requirements in OTC derivatives trading. We first discuss requirements under central clearing, then turn to the bilateral case.

Centrally cleared case. A CCP collects three types of collateral from its clearing members to protect the CCP against the failure of a clearing member:

- variation margin (VM);
- initial margin (IM);
- prefunded contributions to the guarantee fund.

Variation margin reflects the daily (or intraday) marking-to-market of a clearing member’s portfolio with the CCP. Depending on the direction of the market, VM is posted by the clearing member to the CCP or credited to the clearing member’s account by the CCP.¹¹ Whereas VM is based on realized price changes, IM is based on potential price changes to which the CCP would be exposed following the default of a clearing member. For example, IM is often set based on a value-at-risk (VaR) model measuring the 99th percentile of the loss distribution (from the perspective of the CCP) over a risk-measurement horizon of five days, which is the margin period of risk.

If a clearing member defaults, the CCP needs to replace the failed member’s positions to return the CCP to a “matched book” with no net market risk. The margin period of risk is intended to be a conservative

credit default swap trades; it should also be reduced by margin requirements as mentioned above. Some computational aspects of the CVA capital charge have not been finalized yet (pages 4-5 of BCBS [2016]). Our approximation of the CCR capital charge does not take in to account CCR hedges but captures margin requirements.

¹⁰See Ghamami [2015] for a detailed description of CCP risk capital charges.

¹¹We do not include VM payments in Table 1 because they reflect price settlements and, as we argue later, should be roughly equal under bilateral and central clearing.

estimate of the time needed for this replacement. During this period the market may move, leading to losses to the CCP. The CCP’s default waterfall is intended to allow the CCP to withstand these losses.¹² The CCP first taps the failed member’s VM and IM, and then the failed member’s contribution to the CCP’s guarantee fund. If losses exceed the failed member’s contributions, the next layer of the default waterfall is usually a layer of capital contributed by the CCP.¹³ Losses beyond that level are then absorbed by the guarantee fund contributions of the surviving members. If the prefunded guarantee fund is depleted, the CCP typically has the right to call for additional contributions from the surviving members. Our model approximates the collateral cost to a clearing member of margin requirements and prefunded contributions to the guarantee fund. We do not explicitly account for the potential costs of additional assessments, except in the default fund exposure component of the CCP risk capital charge. Adding the funding costs of assessments would increase the total cost of central clearing.

Bilateral case. Prior to the introduction of the 2009 reforms, the OTC derivatives market was not subject to regulations requiring the exchange of margin between counterparties. The market developed its own practices and legal arrangements regarding the exchange of variation margin (often at a weekly frequency) and an *independent amount* at trade inception similar to initial margin. (See, e.g., Pykhtin and Zhu [2006] for details of these practices.)

In the G-20 OTC derivatives reform program (BCBS and IOSCO [2012] and BCBS and IOSCO [2015]), regulators have introduced VM and IM requirements in the non-centrally clearing OTC markets in a way that closely resembles the VM and IM requirements at CCPs. VM is to be exchanged on a daily basis, and IM is to be based on a margin period of risk of 10 days. In fact, BCBS and IOSCO [2015] states that *promotion of central clearing* has been one of the motivations and perceived benefits behind bilateral margin requirements.¹⁴ Our model captures the cost of collateral resulting from margin requirements in the bilateral OTC markets.

In the overall cost comparison summarized in Table 1, two points are worth highlighting. First, although IM collateral costs are included in both market configurations, the associated costs could be quite different, even if the margining rules in the two scenarios were identical, because the portfolios in the two scenarios would be different: in the bilateral case, portfolios are defined by counterparty; in the centrally cleared case, we will form portfolios by product class because different classes of derivatives are generally cleared

¹²For more on CCP default waterfalls, see Duffie et al. [2010], Pirrong [2011], Cont [2015], Ghamami [2015] and references therein.

¹³This layer is often called the CCP’s *skin in the game*; it creates an incentive for the CCP to monitor and manage risk diligently.

¹⁴Page 3 of BCBS and IOSCO [2015] states: “...(central) clearing imposes costs, in part because CCPs require margin to be posted. Margin requirements on non-centrally cleared derivatives, by reflecting the generally higher risk associated with these derivatives, will promote central clearing....”

through different CCPs.¹⁵ In contrast, the VM collateral costs should be approximately the same under bilateral trading and central clearing, as long as all trades are subject to variation margin, because VM reflects realized market moves and is therefore not dependent on how trades are grouped into portfolios.

The second point to emphasize about the costs in Table 1 is that capital and collateral costs will to some extent offset each other, in the following sense: greater use of margin reduces exposure to a counterparty and thus reduces the capital charge associated with the exposure. This is particularly important in the bilateral case, where the counterparty risk weight is generally much larger. Thus, the added bilateral collateral cost of the derivatives reform program is partly offset by a lower CCR capital charge, thereby reducing the cost incentive for central clearing.

4 A Model of OTC Clearing Capital and Collateral Costs

In this section, we develop a model of the costs described in the previous section. We begin with a high-level summary, then detail the analysis of costs in the bilateral and centrally cleared scenarios.

4.1 An Overview of the Model

We suppose there are K asset classes and N market participants simply referred to as banks. Each asset class is cleared through a single CCP, which clears only that asset class. The asset class categories we have in mind are interest rate swaps, credit default swaps, equity derivatives, commodity derivatives, and foreign exchange derivatives. Consistent with our model, these categories of derivatives are typically cleared through separate clearinghouses. Our assumption of a single CCP for each category is conservative in the sense that trading through multiple CCPs reduces opportunities for netting and therefore increases costs. We relax this assumption later.

Viewed from the perspective of bank i , central clearing is less costly than bilateral trading if

$$c_l \sum_k (\text{IM}_{ik} + \text{DF}_{ik}) + c_p \sum_k \text{CCP-RC}_{ik} < c_l \sum_{j \neq i} \text{IM}_{ij} + c_p \sum_{j \neq i} \text{CCR}_{ij}, \quad (1)$$

where the sums on the left run over asset classes k , and the sums on the right run over counterparties j . For each asset class k , IM_{ik} and DF_{ik} are bank i 's initial margin and default fund contribution at CCP k , and CCP-RC_{ik} is the capital charge incurred by bank i through its exposure to CCP k , assuming all trades are centrally cleared. Similarly, under fully bilateral trading, IM_{ij} is the initial margin bank i posts to bank j , and CCR_{ij} is the capital charge bank i incurs through its exposure to bank j . The coefficients

¹⁵Younger et al. [2016a] have recently studied initial margin cost incentives to clear swaptions with CME in the U.S. interest rate derivatives interdealer market. Considering a representative portfolio of trades, the paper concludes that dealers may not be incentivized to clear. This is despite of the fact that at the single contract level, the bilateral IM model considered in their study tends to produce higher margin than the central clearing IM model.

c_l and c_p measure the marginal cost of collateral and the marginal cost of capital for the bank. For these coefficients, we will use the same values as in BIS [2013b] and BIS [2014], taking $c_l = 0.7$ percent and $c_p = 6.7$ percent.

Each term in each of the sums in (1) depends on the risk in a portfolio. Each term on the left depends on the risk of bank i 's portfolio in asset class k ; each term on the right depends on the risk of bank i 's portfolio of trades with bank j . In our model, each term in (1) is proportional to the corresponding portfolio standard deviation.

To be more specific, let ν_{ik} denote the standard deviation of the one-day change in value of bank i 's trades in asset class k , and let σ_{ij} denote the standard deviation parameter¹⁶ for the one-day change in value of bank i 's trades with bank j . Let Δ_b and Δ_c denote, respectively, the margin period of risk under bilateral trading and central clearing, currently set at ten days and five days, respectively.¹⁷ Then each term on the left side of (1) is proportional to $\sqrt{\Delta_c}\nu_{ik}$, and each term on the right side is proportional to $\sqrt{\Delta_b}\sigma_{ij}$. The comparison in (1) then takes the form

$$K_c \sqrt{\Delta_c} \sum_k \nu_{ik} < K_b \sqrt{\Delta_b} \sum_{j \neq i} \sigma_{ij}, \quad (2)$$

for some coefficients K_c and K_b .

To develop this approach, we will need to derive the coefficients K_c and K_b by analyzing the details of each of the cost terms in (1): initial margin, default fund contributions, and capital charges for counterparty exposures. This will be the focus of Sections 4.2 and 4.3. We will also need to estimate the parameters ν_{ik} and σ_{ij} . The relative sizes of the sums over standard deviations on the two sides of (2) reflect the degree of netting that banks are able to achieve when trading bilaterally or through CCPs: greater netting yields a smaller sum of standard deviations.

4.2 Trading Fully Bilaterally

We proceed to model the terms on the right side of (1), assuming all trades are bilateral. Let¹⁸

$$\bar{X}_{ij}^k = \text{change in value to } i \text{ of trades with } j \text{ in asset class } k \text{ over the margin period of risk.} \quad (3)$$

¹⁶We will see that this parameter may itself be a sum of standard deviations, depending on whether banks are able to net across asset classes when they trade bilaterally.

¹⁷The ten-day Δ_b and five-day Δ_c are often associated with bilateral and central clearing IM requirements. There is less consensus among regulators on whether MPOR's associated with counterparty and CCP risk capital should also be 10 and 5 days, (see BCBS [2014a], BIS [2014], and BCBS [2014b]). For instance, using Basel's standardized approach for measuring counterparty risk exposures (SA-CCR BCBS [2014b]), it may well be the case that $\Delta_c = \Delta_b = 10$ days for counterparty and CCP risk capital calculations. As will be seen in the sequel, our $\Delta_b/\Delta_c = 2$ baseline ratio favors central clearing costs estimates.

¹⁸We put a bar over variables that denote changes in value over a margin period of risk. Later, we will use the same variables without bars to indicate values at a single point in time. Table 13 in the appendix summarizes our notation.

We assume that \bar{X}_{ij}^k is normally distributed¹⁹ with mean zero and standard deviation $\sigma_{ijk}\sqrt{\Delta_b}$. From bank j 's perspective, $\bar{X}_{ji}^k = -\bar{X}_{ij}^k$ has the same distribution. The change in the total value of the derivatives portfolio that bank i holds with bank j is given by

$$\bar{V}_{ij} = \bar{X}_{ij}^1 + \dots + \bar{X}_{ij}^K. \quad (4)$$

It follows that \bar{V}_{ij} is normally distributed with mean zero and variance $\Delta_b\sigma_{ij}^2$, for some σ_{ij} .

We model bilateral initial margin as the value-at-risk (VaR) in the trades between counterparties at a confidence level α ; a typical value is $\alpha = 0.99$. If banks i and j are able to net exposures across asset classes, then the IM that bank i is to receive from bank j should be based on the overall portfolio \bar{V}_{ij} . In this case,

$$\text{IM}_{ji} = \text{VaR}_\alpha(\bar{V}_{ij}) = \sqrt{\Delta_b}z_\alpha\sigma_{ij}, \quad (5)$$

where $z_\alpha \equiv \Phi^{-1}(\alpha)$, with Φ^{-1} denoting the inverse of standard normal cumulative distribution function. If the banks are unable to net across asset classes, the total initial margin to be exchanged between bank i and bank j will be the sum of asset class specific initial margins, each estimated based on the α -confidence-level VaR associated with $\bar{X}_{ij}^k \sim N(0, \Delta_b\sigma_{ijk}^2)$. That is, the IM bank i receives from bank j in the absence of bilateral cross-asset netting becomes

$$\text{IM}_{ji} = \sum_k \text{IM}_{ji}^k = \sqrt{\Delta_b}z_\alpha(\sigma_{ij1} + \dots + \sigma_{ijK}), \quad \text{IM}_{ji}^k = \text{VaR}_\alpha(\bar{X}_{ij}^k) = \sqrt{\Delta_b}z_\alpha\sigma_{ijk}. \quad (6)$$

Next, we turn to the counterparty credit capital charge. We measure bank i 's exposure to bank j net of collateral received. Under full cross-asset netting this exposure is given by

$$e_{ij} = \max\left\{\bar{V}_{ij} - \text{IM}_{ji}, 0\right\}. \quad (7)$$

Recall that \bar{V}_{ij} is the change in value, from the perspective of bank i , of the portfolio of trades between banks i and j , over the MPOR. In this expression, we are assuming that the two banks have exchanged variation margin so that the current portfolio value, net of VM, is zero.²⁰ Bank i 's exposure results from the possibility that the portfolio value may move in bank i 's favor, just as bank j defaults. The exposure is limited to an increase in value beyond the IM that bank j has posted to bank i .

The difference $\bar{V}_{ij} - \text{IM}_{ji}$ inside the maximum in (7) is a normal random variable with mean $-\sqrt{\Delta_b}z_\alpha\sigma_{ij}$ and variance $\Delta_b\sigma_{ij}^2$. It follows that

$$E[e_{ij}] = \sqrt{\Delta_b}(\phi(z_\alpha) - z_\alpha(1 - \alpha))\sigma_{ij}, \quad (8)$$

¹⁹Most of our analysis extends to the broader classes of elliptical distributions and can thus accommodate heavy tails.

²⁰In practice, there may be some lag between the time a counterparty is asked to post variation margin and the time it is received by the other bank. This VM lag is not included in our formulation.

where ϕ is the standard normal density.

In the absence of cross-asset bilateral netting, bank i 's exposure to bank j is a sum of exposures over individual asset classes, each with its own IM. Thus,

$$e_{ij} = \sum_k \max \left\{ \bar{X}_{ij}^k - \text{IM}_{ji}^k, 0 \right\}, \quad (9)$$

with IM_{ji}^k as in (6). The logic behind (9) is the same as that behind (7). Each \bar{X}_{ij}^k is the change in value for one asset class over the MPOR; each IM_{ji}^k is the initial margin held by bank i against that change in value; and the excess difference is bank i 's exposure to bank j in that asset class. In the absence of cross-asset netting, bank i 's total exposure to bank j is the sum of its exposures in each asset class.

Each difference $\bar{X}_{ij}^k - \text{IM}_{ji}^k$ is normally distributed with mean $-\sqrt{\Delta_b} z_\alpha \sigma_{ijk}$ and variance $\Delta_b \sigma_{ijk}^2$. In the absence of cross-asset netting, bank i 's expected exposure becomes

$$E[e_{ij}] = \sqrt{\Delta_b} (\phi(z_\alpha) - z_\alpha (1 - \alpha)) \sum_k \sigma_{ijk}, \quad (10)$$

in place of (8).

In either case, with or without cross-asset bilateral netting, we model the counterparty risk capital that bank i is to hold against its exposure to bank j as

$$\text{CCR}_{ij} = c_r \times E[e_{ij}] \times p_b, \quad (11)$$

where $c_r=8$ percent is the Cooke ratio for regulatory capital, p_b denotes the regulatory risk weight representing the credit quality (default probability) of a bank, and $E[e_{ij}]$ is given either by (8) or (10).

We can now summarize the capital and collateral costs in the case of fully bilateral trading. To simplify some formulas, set

$$\beta = \phi(z_\alpha) - z_\alpha (1 - \alpha). \quad (12)$$

In the case of full bilateral netting, the total cost on the right side of (1) becomes

$$\sqrt{\Delta_b} \left(c_l z_\alpha + c_p c_r p_b \beta \right) \sum_{j \neq i} \sigma_{ij}. \quad (13)$$

If banks are unable to net across asset classes, the total cost becomes

$$\sqrt{\Delta_b} \left(c_l z_\alpha + c_p c_r p_b \beta \right) \sum_{j \neq i} \sum_k \sigma_{ijk}. \quad (14)$$

Remark 1 International regulatory guidelines discourage cross-asset netting in initial margin modeling for non-centrally cleared derivatives transactions (see Key Principle 3 of BCBS and IOSCO [2015]). Our IM formulation in (6) reflects this perspective.²¹ However, bilateral cross-asset netting might be allowed when banks calculate measures of bilateral exposures that drive counterparty risk capital costs. Specifically, when regulators judge a bank to be sufficiently sophisticated to use its internal counterparty exposure models, cross-asset netting is allowed in capital calculations. Otherwise, banks are to use the standardized approach for measuring counterparty exposures (SA-CCR BCBS [2014b]), which does not recognize cross-asset netting. Our formulation of the total cost of bilateral trading in the absence of netting (14) is a representation of the total trading costs of a bank that uses SA-CCR. This formulation favors central clearing because bilateral counterparty risk capital costs decrease with cross-asset netting in counterparty exposure calculations.²² The total bilateral trading cost of a bank whose counterparty exposure models allow full bilateral netting but trades under margin rules without cross-asset netting becomes

$$c_l \sqrt{\Delta_b} z_\alpha \sum_{j \neq i} \sum_k \sigma_{ijk} + c_p c_r p_b \sum_{j \neq i} E \left[\max \left\{ \bar{V}_{ij} - \sqrt{\Delta_b} z_\alpha \sum_k \sigma_{ijk}, 0 \right\} \right],$$

where $\bar{V}_{ij} \sim N(0, \Delta_b \sigma_{ij}^2)$.

4.3 Trading Fully Through CCPs

We now turn to the left side of (1) and account for capital and collateral costs when all trades are centrally cleared, beginning with initial margin. We assume (for now) that all trades in asset class k are cleared through a single CCP that clears only trades in that asset class.

Initial Margin

The IM that bank i posts to CCP k will depend on the quantity

$$\bar{U}_{ik} = \text{change in value to } i \text{ of trades in asset class } k \text{ over the margin period of risk } \Delta_c. \quad (15)$$

The relevant MPOR under central clearing is Δ_c , which is typically shorter than the bilateral MPOR Δ_b . Adjusting for this difference, we have the equality in distribution

$$\bar{U}_{ik} \stackrel{d}{=} \frac{\sqrt{\Delta_c}}{\sqrt{\Delta_b}} \sum_{j \neq i} \bar{X}_{ij}^k.$$

²¹In practice, bilateral IM may or may not be model based (page 14 of BCBS and IOSCO [2015]). A bank that does not obtain regulatory approval for model based IM would likely be required to use the BCBS-IOSCO's less risk sensitive IM *schedule* (Appendix A of BCBS and IOSCO [2015]), resulting in substantially higher levels of margin. Our formulation of initial margin resembles a model based, risk sensitive IM. For a bank using the BCBS-IOSCO IM schedule, collateral costs under bilateral trading could be significantly higher.

²²The BCBS may impose various constraints on the use of bank internal models by the end of 2016 (BCBS [2016]), based on doubts about the reliability of bank internal models following the financial crisis; see also BCBS [2013]. The extent to which banks can use their internal counterparty exposure models is still unclear (page 3 and pages 10-12 of BCBS [2016]).

In particular, we take \bar{U}_{ik} to be normally distributed with mean zero, and we denote its variance by $\sqrt{\Delta_c}\nu_{ik}$. The corresponding change in value from the CCP's perspective is $\bar{U}_{ki} = -\bar{U}_{ik}$, and thus $\nu_{ki} = \nu_{ik}$. The VaR-based initial margin that bank i posts to CCP k is given by

$$\text{IM}_{ik} = \text{VaR}_\alpha(\bar{U}_{ki}) = \sqrt{\Delta_c}z_\alpha\nu_{ik}, \quad (16)$$

where, as before, $z_\alpha = \Phi^{-1}(\alpha)$ is the α quantile of the standard normal distribution.

For later analysis, we will need the exposures of the bank and CCP to each other. As in (7), the CCP's exposure to the bank, net of margin received, is given by

$$e_{ki} = \max\left\{\bar{U}_{ki} - \text{IM}_{ik}, 0\right\}. \quad (17)$$

CCPs do not post IM to their clearing members, so the exposure of bank i to CCP k is given by

$$e_{ik} = \max\left\{\bar{U}_{ik}, 0\right\}. \quad (18)$$

Guarantee Fund

The current regulatory framework for CCP risk management is guided by a set of broad principles referred to as the Principles for Financial Market Infrastructures (PFMI), detailed in CPMI and IOSCO [2012]. Under the PFMI, derivatives CCPs are to size their total prefunded guarantee funds using the *Cover 1/Cover 2* principle.²³ According to the PFMI, a Cover 2 based guarantee fund “*should maintain financial resources to cover the default of two participants that would potentially cause the largest aggregate credit exposure for the CCP in extreme but plausible market conditions.*” The PFMI do not state how the total guarantee fund requirement should be allocated to the clearing members, and CCPs differ in their calculation of the guarantee fund and its allocation (CPMI and IOSCO [2012], Ghamami [2015], Cont [2015], and Murphy and Nahai-Williamson [2014]). In what follows we formulate the PFMI's Cover 2 principle within our framework and also specify the allocation of guarantee fund contributions to clearing member banks.

To be consistent with the Cover 2 standard, we need to size the guarantee fund to cover losses from the default of two clearing members under extreme but plausible conditions. Recall that CCP k 's exposure to bank i , net of margin received, is given by e_{ki} in (17). The guarantee fund is intended to cover more extreme losses than the initial margin, so we base the guarantee fund on $\text{VaR}_{\tilde{\alpha}}(e_{ki})$ for some higher confidence level $\tilde{\alpha} > \alpha > 0$. For example, we might have $\alpha = 0.99$ and $\tilde{\alpha} = 0.999$. The more stringent VaR is given by

$$\text{VaR}_{\tilde{\alpha}}(e_{ki}) = \sqrt{\Delta_c}(z_{\tilde{\alpha}} - z_\alpha)\nu_{ik}. \quad (19)$$

²³The Cover 2 standard applies to systemically important CCPs; the Cover 1 standard to all others. Taking the PFMI guidelines as minimum standards, we use the Cover 2 standard throughout our analysis.

We take the size of the CCP's Cover 2 guarantee fund to equal the sum of the two largest values among $\text{VaR}_{\tilde{\alpha}}(e_{k1}), \dots, \text{VaR}_{\tilde{\alpha}}(e_{kN})$. Equivalently, we can write

$$\text{DF}_k = \sqrt{\Delta_c}(z_{\tilde{\alpha}} - z_{\alpha})(\nu_{(1)k} + \nu_{(2)k}), \quad (20)$$

where $\nu_{(1)k}$ and $\nu_{(2)k}$ denote the first and second largest of the standard deviations ν_{ik} , $i = 1, \dots, N$.²⁴

To gain further insight into the choice of $\tilde{\alpha}$, observe that when bank i defaults, CCP k has positive exposure to the bank, net of margin received, with probability

$$P(e_{ki} > 0) = P(\bar{U}_{ki} > \text{IM}_{ik}) = 1 - \alpha,$$

so this is already a tail event. The guarantee fund is intended to ensure the financial resilience of CCPs in these tail events, conditional on the default of clearing members. When interpreting and specifying the level of $\tilde{\alpha}$, the confidence level associated with the guarantee fund, we therefore recommend considering the conditional probability that the CCP's exposure to bank i exceeds the more stringent VaR at level $\tilde{\alpha}$ given that the value of its positions with bank i exceeds the IM posted by the bank, which is the VaR at level α :

$$P\left(e_{ki} > \text{VaR}_{\tilde{\alpha}}(e_{ki}) \mid e_{ki} > 0\right) = \frac{1 - \tilde{\alpha}}{1 - \alpha}.$$

In other words, we suggest considering the *conditional confidence level*,

$$\tilde{\alpha} \equiv \frac{\tilde{\alpha} - \alpha}{1 - \alpha} = P\left(e_{ki} < \text{VaR}_{\tilde{\alpha}}(e_{ki}) \mid e_{ki} > 0\right), \quad (21)$$

in determining the level of $\tilde{\alpha}$. Let $e_{k(1)}$ and $e_{k(2)}$ denote the exposures driving the guarantee fund in (20), and $\bar{U}_{k(1)}$ and $\bar{U}_{k(2)}$ represent the associated changes in portfolio values in (17). When the linear correlation between $\bar{U}_{k(1)}$ and $\bar{U}_{k(2)}$ is 1, we have

$$P\left(e_{k(1)} + e_{k(2)} \leq \text{DF}_k \mid e_{k(1)} > 0 \text{ and } e_{k(2)} > 0\right) = \tilde{\alpha}. \quad (22)$$

In fact, in the context of the Cover 2 principle, our recommended interpretation of PFMI's "extreme but plausible" market conditions is that at default, the CCP's two largest exposures become perfectly positively correlated. The conditional confidence level $\tilde{\alpha}$, then, represents the probability that the Cover 2 guarantee fund protects the CCP against the default of two banks with the largest exposures, conditional on both exposures being positive and becoming perfectly correlated under "extreme but plausible" market

²⁴It is well-known that VaR is subadditive for elliptical distributions, (see e.g. page 242 and Theorem 6.8 of McNeil et al. [2005]). So, in our Gaussian setting, we are being conservative when defining the Cover 2 based DF using the sum of the two largest VaRs associated with the e_{ki} , as opposed to the largest VaR associated with $e_{ki} + e_{kj}$ for $i \neq j$ varying from 1 to N .

conditions. More generally and less conservatively, without taking a view on the correlation between the defaulting clearing member banks' portfolio values, we have

$$P\left(e_{k(1)} + e_{k(2)} \leq \text{DF}_k \mid e_{k(1)} > 0 \text{ or } e_{k(2)} > 0\right) \geq \tilde{\alpha}, \quad (23)$$

where $\tilde{\alpha}$ becomes a lower bound on the probability that the Cover 2 guarantee fund protects the CCP against the default of the two banks with the largest exposures conditional on at least one positive exposure.

We turn next to the allocation of the required guarantee fund to the clearing members. We assume that bank i 's required contribution to CCP k 's guarantee fund is proportional to $\text{VaR}_{\tilde{\alpha}}(e_{ki})$, which measures the risk associated with the CCP's net exposure to the bank. Bank i 's contribution to the guarantee fund then becomes

$$\text{DF}_{ik} = \frac{\nu_{ik}}{\sum_j \nu_{jk}} \text{DF}_k = \frac{\nu_{(1)k} + \nu_{(2)k}}{\sum_j \nu_{jk}} \sqrt{\Delta_c} (z_{\tilde{\alpha}} - z_{\alpha}) \nu_{ik}.$$

We refer to

$$\gamma_k = \frac{\nu_{(1)k} + \nu_{(2)k}}{\sum_j \nu_{jk}} \quad (24)$$

as CCP k 's Cover 2 based *concentration ratio*. For a CCP with a small number of clearing members and portfolios with widely varying levels of risk, γ_k would be close to 1, and the Cover 2 standard should be a reasonable basis for the size of the guarantee fund. But the Cover 2 standard becomes inadequate in the case of a CCP with a large number of clearing members or a CCP in which the members' portfolios have very similar levels of risk. In such cases, γ_k could be considerably smaller than 1; if all ν_{ik} , $i = 1, \dots, N$, are equal then $\gamma_k = 2/N$.

Holding fixed all other parameters, we can view bank i 's contribution to CCP k 's guarantee fund as a function of the concentration ratio γ_k by writing

$$\text{DF}_{ik} = \sqrt{\Delta_c} \gamma_k (z_{\tilde{\alpha}} - z_{\alpha}) \nu_{ik}. \quad (25)$$

Here it becomes evident that the guarantee fund contribution is inversely proportional to the concentration ratio. The concentration ratio will also be useful when we examine the relative size a clearing member's initial margin and guarantee fund contributions. We can write the ratio of the two as

$$\frac{\text{IM}_{ik}}{\text{DF}_{ik}} = \frac{1}{\gamma_k} \frac{z_{\alpha}}{z_{\tilde{\alpha}} - z_{\alpha}}. \quad (26)$$

Given fixed confidence levels α and $\tilde{\alpha}$ associated with IM and the guarantee fund, the IM to DF ratio will be larger when the concentration ratio is smaller — that is, when the Cover 2 standard becomes inadequate. Given a fixed concentration ratio, IM/DF increases as the total guarantee fund confidence level $\tilde{\alpha}$ decreases. These simple observations will be useful in our calibration scheme because we have information on the IM/DF ratio in our data.

CCP Risk Capital

We turn next to the calculation of CCP risk capital — that is, the capital charge incurred by a bank through its exposure to a CCP. As mentioned in Section 3.1, CCP risk capital has two components: a guarantee fund exposure capital charge and a trade exposure capital charge. The first component results from the risk that a member’s contribution to the guarantee fund might be tapped if other members were to fail; the second component results from the counterparty risk a bank faces in its trades with the CCP. The CCP risk capital charge for a given direct clearing member bank is equal to the sum of these two components (BCBS [2014a] and Ghamami [2015]).²⁵

The trade exposure component of the CCP risk capital is similar to the counterparty risk capital in (11) and is given by

$$\text{TE}_{ik} = c_r \times E[e_{ik}] \times p_c,$$

where p_c denotes the regulatory risk weight representing the average credit quality (default probability) of CCPs. From (18) we get

$$E[e_{ik}] = \frac{\sqrt{\Delta_c}}{\sqrt{2\pi}} \nu_{ik}. \quad (27)$$

BCBS [2014a] has defined the default fund exposure component of the CCP risk capital as²⁶

$$\text{DE}_{ik} = c_r \times \max \left\{ p_c \times \text{DF}_{ik}, p_b \times \frac{\text{DF}_{ik}}{\text{DF}_k} \sum_j (E[e_{kj}] - \text{DF}_{jk})^+ \right\}.$$

The first term inside the max treats the guarantee fund contribution DF_{ik} as a direct exposure of bank i to the CCP; the second term is bank i ’s pro rata share of the exposure to other clearing members, net of their IM and DF contributions. The second term carries the risk weight p_b we used in (11) for exposure to other banks. Typical values for these risk weights are $p_b = 20$ percent and $p_c = 2$ percent.

Our model gives

$$\text{DE}_{ik} = c_r \times \max \left\{ p_c \times \gamma_k \tilde{\beta}, p_b \times \left(\beta - \gamma_k \tilde{\beta} \right)^+ \right\} \times \sqrt{\Delta_c} \nu_{ik} \quad (28)$$

with

$$\tilde{\beta} = \frac{\text{VaR}_{\tilde{\alpha}}(e_{ki})}{\sqrt{\Delta_c} \nu_{ik}} = z_{\tilde{\alpha}} - z_{\alpha}, \quad (29)$$

²⁵An article titled “Dealers disagree over charge for CCP counterparty risk,” in *Risk Magazine* on May 11, 2016, reports some recent issues surrounding CCP risk capital calculations. CCP risk capital is perhaps the best example of the coarse interplay between the formulaic bank regulation and the principle-based CCP regulation as discussed in Ghamami [2015].

²⁶As discussed in Remark 2 of this section, our numerical results indicate that the maximum term in (28) equals $p_c \times \text{DF}_{ik}$ in the practical part of the parameter space. According to BCBS [2014a], the ratio appearing in the second term inside the maximum should be $\text{DF}_{ik}/(\text{DF}_k + e_c)$ with e_c denoting the CCP’s equity contribution. Given Remark 2, we assume $e_c = 0$ in our approximation of default fund exposure capital charges.

and β as defined in (12). Consequently, bank i 's total CCP risk capital becomes

$$\sum_k (\text{TE}_{ik} + \text{DE}_{ik}) = c_r \sqrt{\Delta_c} \left[\frac{p_c}{\sqrt{2\pi}} \sum_k \nu_{ik} + \sum_k d_k \nu_{ik} \right], \quad (30)$$

where d_k denotes the maximum term on the right side of (28),

$$d_k = \max \left\{ p_c \times \gamma_k \tilde{\beta}, p_b \times \left(\beta - \gamma_k \tilde{\beta} \right)^+ \right\}. \quad (31)$$

Remark 2 Using the representative values $p_c = 2$ percent and $p_b = 20$ percent for the regulatory risk weights, our numerical examples indicate that d_k equals the first term inside the maximum in (31) unless γ_k is unrealistically small and $\tilde{\alpha}$ is close to α . For instance, setting $\alpha = 99.75$ percent and $\tilde{\alpha} = 99.9$ percent, d_k becomes equal to the first term for all $\gamma_k \geq .0024$. Setting $\alpha = 99.75$ percent and $\tilde{\alpha} = 99.77$ percent, d_k becomes equal to the first term for $\gamma_k > .0250$. A very small γ_k would require the CCP to have an unrealistically large number of clearing members. Assuming a homogeneous setting with $\gamma_k = 2/N$, d_k equals the first term inside the maximum for $N \leq 839$ and $N < 80$, respectively, in the examples just given.

Total Cost of Trading Fully Through CCPs

By combining the IM expression in (16), the guarantee fund contribution in (25), and the risk capital charge in (30), we can write the cost of trading fully through CCPs (the left side of (1)) as

$$\sqrt{\Delta_c} \left[c_l \left(z_\alpha \sum_k \nu_{ik} + (z_{\tilde{\alpha}} - z_\alpha) \sum_k \gamma_k \nu_{ik} \right) + c_p c_r \left(\frac{p_c}{\sqrt{2\pi}} \sum_k \nu_{ik} + \sum_k d_k \nu_{ik} \right) \right]. \quad (32)$$

where, as before, c_l and c_p denote the marginal costs of collateral and capital. If all CCPs have the same concentration ratio γ , the total cost of trading through CCPs becomes

$$\sqrt{\Delta_c} \left[c_l \left(\gamma z_{\tilde{\alpha}} + (1 - \gamma) z_\alpha \right) + c_p c_r \left(\frac{1}{\sqrt{2\pi}} p_c + d \right) \right] \sum_k \nu_{ik} \quad (33)$$

with d being the maximum term on the right side of (28) when $\gamma_k = \gamma$, i.e.,

$$d = \max \left\{ p_c \times \gamma \tilde{\beta}, p_b \times \left(\beta - \gamma \tilde{\beta} \right)^+ \right\}. \quad (34)$$

The expression in (33) and (13) (or (14)) implicitly define the coefficients K_c and K_b appearing in (2).

Multiple Asset-Class-Specific CCPs

We have so far assumed that a single CCP clears a given asset class in the OTC markets. This assumption underestimates the total central clearing costs because it overestimates the netting benefits of central clearing. To see this explicitly, suppose that derivatives in asset class k are cleared through n_k different CCPs. Let \bar{U}_{ik_j} , $j = 1, \dots, n_k$, denote the change in value of bank i 's portfolio at CCP k_j over the margin period of risk Δ_c . The total change \bar{U}_{ik} for asset class k introduced previously is the sum $\bar{U}_{ik_1} + \bar{U}_{ik_2} + \dots + \bar{U}_{ik_{n_k}}$ over CCPs that clear asset class k . Suppose that each \bar{U}_{ik_j} is normally distributed with mean zero and standard deviation $\sqrt{\Delta_c}\nu_{ik_j}$.

The steps leading to (33) show that the total cost of trading through CCPs now becomes

$$\sqrt{\Delta_c} \left[c_l \left(\gamma z_{\bar{\alpha}} + (1 - \gamma) z_{\alpha} \right) + c_p c_r \left(\frac{1}{\sqrt{2\pi}} p_c + d \right) \right] \sum_k \sum_j \nu_{ik_j}. \quad (35)$$

This cost will be at least as large as the cost with a single CCP for each asset class, as measured in (33), because $\bar{U}_{ik} = \sum_j \bar{U}_{ik_j}$ implies that $\nu_{ik} \leq \sum_j \nu_{ik_j}$.

Generally speaking, the greater the number of CCPs through which a bank clears trades, the greater the last factor in (35) because of the loss of netting opportunities.²⁷ To be conservative, we may consider the case of two CCPs for each asset class. If the bank's positions at the two CCPs had the same standard deviation, $\nu_{ik_1} = \nu_{ik_2}$, and if they were uncorrelated with each other, we would have $\nu_{ik_1} + \nu_{ik_2} = \sqrt{2}\nu_{ik}$. Positive correlation in the bank's portfolios at the two CCPs would result in a factor smaller than $\sqrt{2}$, and negative correlation would result in a larger factor. This suggests that a conservative estimate of the cost increase in (35) relative to a setting with one CCP per asset class is a factor between 1 and $\sqrt{2}$.²⁸

4.4 Central Clearing Versus Bilateral Trading: Correlations

We have now derived all the terms needed for the cost comparison in (1). Central clearing has lower cost for bank i than bilateral trading if the cost expression in (32) is smaller than the cost in (13), assuming cross-asset bilateral netting, or the cost in (14), in the absence of cross-asset netting.

In the case that all CCPs have the same concentration ratio γ , we can substitute the corresponding expressions in (1) and write the condition for central clearing to yield lower costs as

$$\underbrace{\sum_k \nu_{ik}}_{r_1} < \underbrace{\frac{\sqrt{\Delta_b}}{\sqrt{\Delta_c}} \frac{c_l z_{\alpha} + c_p c_r p_b \beta}{c_l (\gamma z_{\bar{\alpha}} + (1 - \gamma) z_{\alpha}) + c_p c_r \left(\frac{1}{\sqrt{2\pi}} p_c + d \right)}}_{r_2}, \quad (36)$$

²⁷Cost incentives would lead a bank to clear all trades through a single CCP, but other factors lead to the use of multiple CCPs, including the preferences of counterparties, jurisdictional constraints, and a reluctance to grant monopoly power to a single CCP.

²⁸In their analysis of credit default swaps, Duffie et al. [2015] (p.248) estimate that doubling the number CCPs clearing all CDS from two to four increases total collateral requirements by 23.4 percent, roughly in the middle of this range.

with d as defined in (34). In the absence of cross-asset bilateral netting, σ_{ij} would be replaced by $\sum_k \sigma_{ijk}$; with multiple CCPs for each asset class ν_{ik} would be replaced by $\sum_j \nu_{ikj}$.

Condition (36) decomposes the cost comparison into the ratio r_1 on the left, a factor based on the relative MPORs, and a factor that depends on various cost and risk parameters. Except for the cost coefficients c_l and c_p , the parameters of r_2 are driven by regulatory considerations and risk management practices. The ratio r_1 measures the relative netting efficiency in bilateral and centrally cleared markets. Letting $\sigma(\cdot)$ denote the standard deviation of a random variable, we can write this ratio as

$$r_1 = \frac{\sigma\left(\sum_{j \neq i} \bar{X}_{ij}^1\right) + \cdots + \sigma\left(\sum_{j \neq i} \bar{X}_{ij}^K\right)}{\sigma\left(\sum_k \bar{X}_{i1}^k\right) + \cdots + \sigma\left(\sum_k \bar{X}_{iN}^k\right)}. \quad (37)$$

The numerator is a sum of standard deviations over portfolios grouped by asset class, whereas the denominator is a standard deviation over portfolios grouped by counterparty. An r_1 ratio smaller than 1 indicates that greater netting of risk is achieved through central clearing than through bilateral trading.

The value of r_1 will clearly depend on correlations among the \bar{X}_{ij}^k . Define

$$\rho_{ij}^{kl} = \frac{\text{cov}\left(\bar{X}_{ij}^k, \bar{X}_{ij}^l\right)}{\Delta_b \sigma_{ijk} \sigma_{ijl}} \quad \text{and} \quad \rho_{ijm}^k = \frac{\text{cov}\left(\bar{X}_{ij}^k, \bar{X}_{im}^k\right)}{\Delta_b \sigma_{ijk} \sigma_{imk}}. \quad (38)$$

On the left, ρ_{ij}^{kl} is a correlation across asset classes k and l for a fixed counterparty j ; on the right, ρ_{ijm}^k is a correlation across counterparties j and m for a fixed asset class k . Larger values of ρ_{ij}^{kl} reduce cross-asset netting efficiency in the bilateral case; larger values of ρ_{ijm}^k reduce the netting efficiency of central clearing.

We can say more about the ratio (37) when all standard deviations σ_{ijk} are equal. If all cross-asset correlations ρ_{ij}^{kl} are equal and positive, and all cross-bank correlations ρ_{ijm}^k are zero, then (37) converges to zero as the number of banks N grows. However, if the cross-bank correlations are all equal and strictly positive, then (37) converges to a strictly positive constant. From (36) we know that a smaller ratio favors central clearing. This comparison therefore indicates that costs in a market with a large number of banks need not favor central clearing when cross-bank correlations are positive.

5 Connecting the Model to the Counterparty Exposure Data

The value of the key ratio r_1 is an empirical question, and we address it with data on banks' derivatives portfolios. Our institution-to-institution exposure data are provided by the Federal Reserve Bank of New York and the Division of Banking Supervision and Regulation at the Board of Governors of the Federal Reserve System; see Sections C and D of BIS [2013a] for a detailed description of the template used for this data collection.²⁹ Our dataset has reports from five of the ten largest U.S. banks for five asset classes:

²⁹The BIS International Data Hub (IDH) compiles data on counterparty credit risk in cooperation with participating supervisory agencies and central banks. Our dataset is part of the counterparty exposure data that the Federal Reserve Bank of New York collects from the U.S. banks.

OTC interest rate derivatives, credit derivatives, commodity derivatives, equity derivatives, and foreign exchange derivatives. Our sample includes 31 consecutive monthly values from January 2013 to July 2015. For each month, we have data on the net exposures between pairs of banks and the total market value of trades between banks in each asset class. We also have data on initial margin and guarantee fund contributions made by each bank to 17 CCPs.

To formulate a precise connection between the data and our model, we need some additional notation. Let

$$X_{ij}^k(t) = \text{total value to } i \text{ at time } t \text{ of trades initiated with } j \text{ in asset class } k. \quad (39)$$

Recall that \bar{X}_{ij}^k denoted a change in value over an MPOR, whereas $X_{ij}^k(t)$ denotes a market value at time t . (Time is indexed by months.) We include in $X_{ij}^k(t)$ trades between banks i and j that were subsequently novated to a CCP. Of this total amount, we assume that a fraction ω_k continues to trade bilaterally. The total time- t value of bilateral trades between banks i and j is then given by

$$V_{ij}^\omega(t) = \omega_1 X_{ij}^1(t) + \dots + \omega_K X_{ij}^K(t). \quad (40)$$

The model development in Section 4 assumed either of two extreme scenarios: full bilateral trading or full central clearing. But we see both types of trading in the data. From bilateral information, we can at best observe the bilateral portions $V_{ij}^\omega(t)$ and then use our model to infer what the corresponding amounts would be under fully bilateral or fully centrally cleared trading. In (40) and throughout, we assume that the fractions ω_k are time-independent and common across all bank pairs. We approximate them as described in Appendix B using Financial Stability Board (FSB) reports on the implementation of the OTC derivatives market reforms.

Our dataset includes monthly values $Y_{ij}(t) \geq 0$ of the total exposure of bank i to bank j at time t summed across the five derivatives asset classes and based on legally enforceable bilateral netting arrangements. In other words, $Y_{ij}(t)$ represents bank i 's *derivatives receivables* from bank j at time t in the absence of any collateral exchanged between the two banks. These observed variables are related to the variables in our model through the equation

$$V_{ij}^\omega(t) = Y_{ij}(t) - Y_{ji}(t). \quad (41)$$

This difference is the net value to bank i of its bilateral contracts with bank j . Table 2 reports descriptive statistics on the distribution of relative exposures across institutions and across time for 8 bank pairs in our dataset.

Our bilateral counterparty exposure data also records monthly values for the total mark-to-market value of trades for each bank pair in each of the five asset categories. These totals are calculated by summing the absolute values of trades between each pair of banks. To make this explicit, suppose that

Table 2: Mean, standard deviation, 25th percentile (Q1), median (Q2), and 75th percentile (Q3) of interbank gross exposures. Values have been normalized by a common factor to preserve confidentiality, so they measure the distribution of relative exposures across institutions and across time for a fixed bank pair. Two bank pairs have been omitted because of questionable data quality. Source: Federal Reserve and authors’ analysis.

		Gross Exposures				
		Mean	SD	Q1	Q2	Q3
Pair 1	Y_{ij}	1.00	0.15	0.90	1.00	1.09
	Y_{ji}	0.44	0.03	0.41	0.44	0.46
Pair 2	Y_{ij}	0.13	0.04	0.10	0.13	0.17
	Y_{ji}	0.21	0.12	0.10	0.18	0.28
Pair 3	Y_{ij}	0.25	0.12	0.18	0.24	0.32
	Y_{ji}	0.47	0.35	0.17	0.31	0.80
Pair 4	Y_{ij}	0.28	0.20	0.13	0.20	0.47
	Y_{ji}	0.50	0.17	0.34	0.46	0.66
Pair 5	Y_{ij}	0.12	0.02	0.11	0.12	0.13
	Y_{ji}	0.98	0.13	0.96	0.99	1.05
Pair 6	Y_{ij}	0.50	0.09	0.45	0.50	0.57
	Y_{ji}	0.19	0.05	0.17	0.18	0.23
Pair 7	Y_{ij}	0.13	0.02	0.11	0.13	0.16
	Y_{ji}	0.61	0.10	0.54	0.61	0.66
Pair 7	Y_{ij}	0.85	0.29	0.49	0.89	1.00
	Y_{ji}	0.13	0.14	0.03	0.05	0.29
Pair 8	Y_{ij}	0.14	0.09	0.09	0.11	0.20
	Y_{ji}	2.76	0.76	2.13	2.35	3.42

banks i and j have n bilateral contracts in asset class k , and let $T_{ijl}^k(t)$ denote the value of the l th such contract from the perspective of bank i . In the data we observe

$$A_{ij}^k(t) \equiv A_{ij}^{k,\omega}(t) = \omega_k \sum_{l=1}^n |T_{ijl}^k(t)|, \quad (42)$$

for $k = 1, \dots, 5$. We include the factor ω_k on the assumption that the current bilateral contracts between the banks are a fraction ω_k of what we would observe in a market without central clearing. The values (42) are not always reported consistently by the two banks i and j , particularly for foreign exchange derivatives.³⁰ Our calibration scheme uses the average of the two values, $(A_{ij}^k(t) + A_{ji}^k(t))/2$. Table 3 gives the relative magnitudes of the average and standard deviation of total mark-to-market values, A_{ij}^k ’s, across bank pairs and across asset classes.

The central counterparty exposure part of the dataset consists of monthly time series of the aggregate

³⁰More consistent reporting would enhance the value this data collection to banking supervisors. The sources of the inconsistencies do not appear to be well understood.

Table 3: Mean and standard deviations (in parentheses) of total mark-to-market values A_{ij}^k by bank pair (i, j) and asset class k . Values have been normalized by a common factor to preserve confidentiality, so they measure the relative magnitudes of total mark-to-market values across bank pairs and across asset classes. Source: Federal Reserve and authors' analysis.

Pair	Credit		Interest Rate		Commodity		Equity		Currency	
1	1.00	(0.20)	6.90	(0.96)	0.06	(0.02)	0.25	(0.02)	1.26	(0.48)
2	1.10	(0.31)	4.29	(0.96)	0.12	(0.04)	0.23	(0.02)	0.59	(0.13)
3	1.06	(0.20)	9.10	(1.94)	0.06	(0.03)	0.29	(0.03)	1.03	(0.33)
4	1.42	(0.21)	5.11	(0.60)	0.08	(0.04)	0.39	(0.06)	1.12	(0.37)
5	0.49	(0.08)	2.07	(0.23)	0.04	(0.02)	0.12	(0.01)	0.44	(0.14)
6	0.46	(0.06)	3.69	(0.47)	0.03	(0.01)	0.12	(0.04)	0.71	(0.34)
7	0.75	(0.10)	3.70	(0.35)	0.04	(0.01)	0.17	(0.01)	0.67	(0.29)
8	0.55	(0.16)	3.08	(0.53)	0.04	(0.01)	0.24	(0.02)	0.27	(0.10)
9	0.63	(0.20)	3.32	(0.37)	0.08	(0.02)	0.37	(0.03)	0.28	(0.08)
10	0.74	(0.15)	8.05	(0.99)	0.07	(0.03)	0.37	(0.07)	0.53	(0.22)

initial margin and aggregate guarantee fund contributions of each of the five banks to 17 central counterparties globally from January 2013 to July 2015. In other words, for each bank i , we observe the total initial margin $IM_i(t)$ and the total guarantee fund contributions $DF_i(t)$ paid by bank i in each month t , summed over all 17 CCPs. This information is quite limited, so our calibration scheme relies minimally on the CCP exposure part of the dataset.

6 Calibration

We now turn to the calibration of our model, given the available data. Section 6.1 addresses the estimation of the standard deviations in r_1 on the left side of (36), and Section 6.2 addresses the estimation of r_2 on the right side of (36).

6.1 Estimating r_1

Recall that σ_{ijk} and ν_{ik} are standard deviation parameters for changes in portfolio values over MPORs. In particular, the change \bar{X}_{ij}^k defined in (3) has standard deviation $\sigma_{ijk}\sqrt{\Delta_b}$. We do not observe these changes in portfolio value in our dataset, so we will need to take an indirect approach and introduce additional assumptions to estimate the standard deviations.

The change in portfolio value from t to $t + \Delta_b$ is related to the value itself through the identity

$$\bar{X}_{ij}^k = X_{ij}^k(t + \Delta_b) - X_{ij}^k(t).$$

We will assume that portfolio value X_{ij}^k is the sum of independent and identically distributed such increments. In particular, $X_{ij}^k(t) - X_{ij}^k(0)$ is normally distributed with mean zero and standard deviation

$\sigma_{ijk}\sqrt{t}$. We will use this relationship to estimate σ_{ijk} . In fact, we can rewrite (37) as

$$r_1 = \frac{\sigma\left(\sum_{j \neq i} X_{ij}^1(t)\right) + \cdots + \sigma\left(\sum_{j \neq i} X_{ij}^K(t)\right)}{\sigma\left(\sum_k X_{i1}^k(t)\right) + \cdots + \sigma\left(\sum_k X_{iN}^k(t)\right)}, \quad (43)$$

canceling a factor of \sqrt{t} in the numerator and denominator. We can also write the correlations in (38) as

$$\rho_{ij}^{kl} = \frac{\text{cov}\left(X_{ij}^k(t), X_{ij}^l(t)\right)}{t\sigma_{ijk}\sigma_{ijl}} \quad \text{and} \quad \rho_{ijm}^k = \frac{\text{cov}\left(X_{ij}^k(t), X_{im}^k(t)\right)}{t\sigma_{ijk}\sigma_{imk}} \quad (44)$$

and use these identities to estimate the correlations.

We do not observe the market values $X_{ij}^k(t)$ for individual asset classes k in our dataset. Instead, we observe the total bilateral amount $V_{ij}^\omega(t)$ in (41). To estimate parameters, we will randomly generate candidate paths of the $X_{ij}^k(t)$ that are consistent with the observed paths of $V_{ij}^\omega(t)$. Each set of paths yields estimates of the standard deviations σ_{ijk} and correlations (44) needed for r_1 .³¹ Specifically, let $t = 0$ correspond to the first of the 31 monthly values of market variables (V_{ij}^ω and A_{ij}^k) from January 2013 to July 2015. Then, the sample standard deviation of the simulated $\frac{1}{\sqrt{\Delta}}(X_{ij}^k(\Delta) - X_{ij}^k(0))$, $\frac{1}{\sqrt{2\Delta}}(X_{ij}^k(2\Delta) - X_{ij}^k(0))$, ..., $\frac{1}{\sqrt{30\Delta}}(X_{ij}^k(30\Delta) - X_{ij}^k(0))$, with $\Delta = 1/12$, will be our estimate of the annualized σ_{ijk} . Given estimates of σ_{ijk} 's, we estimate the covariance terms in (44) to obtain estimates of cross-asset and cross-bank correlations ρ_{ij}^{kl} and ρ_{ijm}^k . This is done using the sample covariance of $\frac{1}{\sqrt{t}}(X_{ij}^k(t) - X_{ij}^k(0))$ and $\frac{1}{\sqrt{t}}(X_{ij}^l(t) - X_{ij}^l(0))$, and the sample covariance of $\frac{1}{\sqrt{t}}(X_{ij}^k(t) - X_{ij}^k(0))$ and $\frac{1}{\sqrt{t}}(X_{im}^k(t) - X_{im}^k(0))$ with the discrete time t varying from Δ to 30Δ , and $\Delta = 1/12$. Combining the estimates from multiple paths yields a distribution for each parameter.

We simulate candidate paths of $X_{ij}^k(t)$ by simulating stochastic weights $W_{ij}^k(t)$ and setting

$$X_{ij}^k(t) = W_{ij}^k(t)V_{ij}^\omega(t)/\omega_k. \quad (45)$$

As long as the weights satisfy

$$W_{ij}^1(t) + \cdots + W_{ij}^K(t) = 1, \quad (46)$$

the resulting portfolio values will satisfy (41), as required. We choose the weights based on two principles. First, we make them proportional (in a sense to be made precise) to the total value of contracts in each asset class between each pair of banks. Second, we design the weights to be consistent with interbank netting ratios observed in practice.

³¹This approach can be viewed as an instance of Approximate Bayesian Computation, surveyed in Marin et al. [2012]. We simulate the $X_{ij}^k(t)$ from a prior distribution, reject paths that violate certain constraints, and evaluate a posterior distribution of parameters from the accepted paths.

In more detail, we will use the values $A_{ij}^k(t)$ that we observe in the data to generate the weights. Recall from the discussion of (42) that $A_{ij}^k(t)$ is the total value of contracts between banks i and j in asset class k . We generate weights by setting

$$W_{ij}^k(t) = \frac{I_{ij}^k A_{ij}^k(t)}{I_{ij}^1 A_{ij}^1(t) + \cdots + I_{ij}^K A_{ij}^K(t)}, \quad (47)$$

where for each fixed pair of banks i and j , $I_{ij}^1, \dots, I_{ij}^K$ are independent $[-1, 1]$ uniform random variables. This construction makes the random variable $I_{ij}^k A_{ij}^k(t)$ uniformly distributed on the interval $[-A_{ij}^k(t), A_{ij}^k(t)]$. For any fixed i, j, k , the random variable $I_{ij}^k A_{ij}^k(\cdot)$ does not change sign over time. It follows that $\omega_k X_{ij}^k(\cdot)$ as constructed using (45) changes sign over time only when the market observed $V_{ij}^\omega(\cdot)$ change sign.

Allowing the weights to take both positive and negative values is essential to letting the gross exposure between pairs of banks exceed the net exposures $V_{ij}^\omega(t)$ that we observe in the data. The Office of the Comptroller of the Currency (OCC) estimates netting ratios for U.S. commercial banks and savings associations on a quarterly basis. According to the OCC, bilateral net-to-gross ratios were between 9 percent and 14 percent from 2009 to the third quarter of 2015.³² The institutions in our dataset are bank holding companies; the Federal Financial Institutions Examination Council (FFIEC) Call Reports indicate that net-to-gross ratios for major U.S. bank holding companies are similar. We design our procedure to be consistent with these observed ratios.

We define the net-to-gross ratio between banks i and j by³³

$$N_{ij}(t) \equiv \frac{E \left[\max\{V_{ij}^\omega(t), 0\} \right]}{E \left[\max\{\omega_1 X_{ij}^1(t), 0\} + \cdots + \max\{\omega_K X_{ij}^K(t), 0\} \right]}. \quad (48)$$

If, for fixed banks i and j , all the weights W_{ij}^k had the same sign, this ratio would be 1: if all exposures run in the same direction, there is no opportunity to net payments across asset classes. Based on the OCC reports, a more representative value for this ratio would 5 percent to 25 percent, so we impose this restriction in our sampling. Larger values of this ratio lead to larger values of r_1 , so the upper limit of 25 percent is conservative for our cost comparison.

After we generate a set of random weights, we evaluate the net-to-gross ratio in the simulation (using the sample counterparts of the expectations in (48)). We estimate the net-to-gross ratio (48) by replacing $E[\max\{V_{ij}^\omega(t), 0\}]$ and $E[\max\{\omega_k X_{ij}^k(t), 0\}]$ with time averages of the observed $\max\{V_{ij}^\omega(t), 0\}$ and simulated $\max\{\omega_k X_{ij}^k(t), 0\}$ in the sample period. Let \hat{N}_{ij} denote our simulation based estimate of (48). Then,

³²The OCC reports 1 minus the net-to-gross ratio, for values between 86 percent and 91 percent; see Graph 6 of OCC [2015].

³³The net-to-gross ratio, also referred to as net-replacement ratio, is often defined for *current exposures*, i.e., the right side of (48) without the expected values, (see page 264 of Hull [2012]).

we check if the estimated ratio falls between prescribed lower and upper limits, n_i^l and n_i^u ,

$$n_i^l \leq \frac{1}{N-1} \sum_{j \neq i} \hat{N}_{ij} \leq n_i^u. \quad (49)$$

If this condition is satisfied, we accept the generated weights (and resulting paths of $X_{ij}^k(t)$); otherwise, we reject the weights and discard the paths. We estimate the standard deviations σ_{ijk} and the correlations in (44) using the accepted paths. We obtain an estimate of r_1 using (43).

Remark 3 The net-to-gross ratio in (48) and in the OCC statistics refers to cross-asset netting of *payment obligations* rather than cross-asset netting of *risk*, and it is important to distinguish the two notions. The numerator in (48) is the expected amount due from bank j to bank i at time t , and the terms in the denominator are corresponding amounts for each asset class. The numerator nets the payment obligations in the denominator regardless of whether positions across asset classes are margined separately or jointly. In contrast, the difference between bilateral costs based on σ_{ij} , as in (13), and bilateral costs based on $\sum_k \sigma_{ijk}$, as in (14), is the difference between allowing and not allowing cross-asset netting of risk in setting margin requirements. We use realistic values of the net-to-gross ratio (48) to sample values of X_{ij}^k consistent with observed values of V_{ij}^ω ; other than that, the netting of payment obligations plays no role in our cost calculations. In contrast, we will see that whether cross-asset netting of risk is allowed (as in (13)) or not (as in (14)) has a big impact on our cost comparison.

We can summarize the steps in our estimation of r_1 as follows, evaluating r_1 from the perspective of bank i :

- For each bank $j \neq i$ generate K independent $[-1, 1]$ uniform random variables $I_{ij}^1, \dots, I_{ij}^K$ to construct the signed weights (47) and the time series $\{X_{ij}^1(t), t = 0, 1, \dots\}, \dots, \{X_{ij}^K(t), t = 0, 1, \dots\}$ using (45).
- Estimate the net-to-gross ratio by replacing $E[\max\{V_{ij}^\omega(t), 0\}]$ and $E[\max\{\omega_k X_{ij}^k(t), 0\}]$ with the time averages of $\max\{V_{ij}^\omega(t), 0\}$ and $\max\{\omega_k X_{ij}^k(t), 0\}$ in the sample period. If the bilateral netting constraint (49) is satisfied, go to the next step. Otherwise, discard the current paths and return to the previous step.
- Estimate each σ_{ijk} , and the cross-asset and cross-bank correlations ρ_{ij}^{kl} and ρ_{ijm}^k in (44) from the paths of X_{ij}^k .
- Using the estimated σ_{ijk} , ρ_{ij}^{kl} , and ρ_{ijm}^k , calculate the standard deviations σ_{ij} and ν_{ik} . Return the resulting estimate of r_1 .

Adding Correlation Restrictions

We now introduce a variant of the estimation procedure just described that imposes two restrictions on the correlation parameters. The first restriction assumes that cross-asset correlations for a pair of banks depend on the identities of the banks but not on the assets. The second restriction makes a similar assumption across different bank pairs.

Imposing these restrictions has two benefits. First, it reduces the total number of parameters we need to estimate by adding structure to the model. Second, we will see that it limits our use of simulated paths to the estimation of standard deviations; correlations can then be estimated from values in our dataset.

Our first restriction applies to the cross-asset correlations ρ_{ij}^{kl} , as in (44). We assume that these correlations depend on the banks i and j , but not on the assets k and l ; that is, we set

$$\frac{\text{cov}\left(X_{ij}^k(t), X_{ij}^l(t)\right)}{t\sigma_{ijk}\sigma_{ijl}} \equiv \rho_{ij}, \quad (50)$$

for all $k \neq l$ varying from 1 to K . Under this assumption we can estimate ρ_{ij} using

$$\left(\sigma_{ij}^\omega\right)^2 = \sum_k \omega_k^2 \sigma_{ijk}^2 + \rho_{ij} \sum_l \sum_{k \neq l} \omega_l \omega_k \sigma_{ijl} \sigma_{ijk}, \quad (51)$$

where $(\sigma_{ij}^\omega)^2$, the variance of $V_{ij}^\omega(t)/\sqrt{t}$, is estimated directly from the observed portfolio values in our dataset, and σ_{ijk}^2 , the variance of $X_{ij}^k(t)/\sqrt{t}$, is estimated from the synthetically constructed time series as before. This approach makes greater use of our dataset by estimating σ_{ij}^ω directly and then imputing a value of ρ_{ij} through (51).

Our second restriction applies to cross-asset correlations between pairs of banks with a common member. For distinct banks i , j , and m , we set

$$\frac{\text{cov}\left(X_{ij}^k(t), X_{im}^l(t)\right)}{t\sigma_{ijk}\sigma_{iml}} \equiv \rho_{ijm} \quad (52)$$

for all k and l varying from 1 to K . Under this correlation assumption we can estimate ρ_{ijm} using

$$\frac{1}{t} \text{cov}\left(V_{ij}^\omega(t), V_{im}^\omega(t)\right) = \rho_{ijm} \sum_l \sum_k \omega_l \omega_k \sigma_{ijl} \sigma_{imk}, \quad (53)$$

where the left side above is estimated from the portfolio values between banks i and j and between i and m , and the σ_{ijk} are estimated from the synthetically constructed asset class specific portfolio values. The restriction (52) thus allows us to make greater use of the interbank portfolio values in our dataset and rely less on the simulated paths. The restriction (52) also allows us to estimate ν_{ik} using

$$\nu_{ik}^2 = \sum_{j \neq i} \sigma_{ijk}^2 + \sum_{j \neq i} \sum_{m \neq i, j} \rho_{ijm} \sigma_{ijk} \sigma_{imk}.$$

To summarize, with the two correlation restrictions (50) and (52), the third step in our 4-step calibration scheme becomes

- Estimate each σ_{ijk} as the standard deviation of $\{\frac{1}{\sqrt{t}}X_{ij}^k(t), t \geq 0\}$ as before and estimate the cross-asset and cross-bank correlations ρ_{ij} and ρ_{ijm} from (51) and (53).

Remark 4 In some of our numerical results, we will impose the restriction

$$\frac{\text{cov}\left(X_{ij}^k(t), X_{im}^k(t)\right)}{t\sigma_{ijk}\sigma_{imk}} \equiv \rho_i^k. \quad (54)$$

This allows us to write

$$\nu_{ik}^2 = \sum_{j \neq i} \sigma_{ijk}^2 + \rho_i^k \sum_{j \neq i} \sum_{m \neq i, j} \sigma_{ijk}\sigma_{imk},$$

and then impute ρ_i^k from estimates of the other parameters. The restriction (54) will be convenient in summarizing the impact of cross-bank correlations on our estimates of r_1 .

6.2 Approximating r_2

We turn next to the calculation of r_2 in (36). As discussed in Remark 2, the quantity d is typically given by the second term in (34), representing the default fund exposure component of the CCP risk capital charge. In this case, assuming a common concentration ratio $\gamma_k \equiv \gamma$, we get

$$r_2 = \frac{\sqrt{\Delta_b}}{\sqrt{\Delta_c}} \frac{c_l z_\alpha + c_p c_r p_b \beta}{c_l (\gamma(z_{\tilde{\alpha}} - z_\alpha) + z_\alpha) + c_p c_r p_c \left(\frac{1}{\sqrt{2\pi}} + \gamma(z_{\tilde{\alpha}} - z_\alpha)\right)}. \quad (55)$$

All the parameters in (55) could be considered known or relatively easy to approximate except for the concentration ratio γ and the confidence level $\tilde{\alpha}$ associated with the guarantee fund. As reflected in the denominator of r_2 , the collateral and capital costs associated with a bank's guarantee fund contributions to CCPs are proportional to $\gamma(z_{\tilde{\alpha}} - z_\alpha)$. This cost increases as the confidence level $\tilde{\alpha}$ and the concentration ratio $0 < \gamma \leq 1$ increase. Recall that the concentration ratio is a measure of the adequacy of the Cover 2 rule, given the portfolios cleared through a CCP.

We cannot estimate concentration ratios directly because we do not have the exposures of all clearing members of the CCPs — we have data only on a small number of banks. Instead, we build on the relationship (26) relating initial margin, guarantee fund contribution and the parameters γ and $\tilde{\alpha}$. For any bank i , consider the ratio of its total CCP initial margin $\text{IM}_i = \sum_k \text{IM}_{ik}$ to its aggregate guarantee fund contribution $\text{DF}_i = \sum_k \text{DF}_{ik}$. Assuming a common concentration ratio γ , (26) yields

$$\frac{\text{IM}_i}{\text{DF}_i} = \frac{1}{\gamma} \frac{z_\alpha}{z_{\tilde{\alpha}} - z_\alpha}. \quad (56)$$

Table 4: Baseline values for parameters used in the numerical results. Source: Authors’ analysis.

Variable	Definition	Value
c_l	marginal cost of collateral	0.7%
c_p	marginal cost of capital	6.7%
c_r	Cooke ratio	8%
p_b	bank risk weight	20%
p_c	CCP risk weight	2%
Δ_b	bilateral MPOR	10 days
Δ_c	central clearing MPOR	5 days
$\omega_1, \dots, \omega_5$	bilateral fractions for credit, interest rates, commodity, equity, and currency	0.81, 0.56, 0.85, 0.95, 0.99

We calculate time averages of IM to DF ratios in the sample period and use these as our estimates of these ratios. Viewing the left side above as observable in our data, we can approximate $\tilde{\alpha}$ assuming that γ is known, or approximate γ assuming that $\tilde{\alpha}$ is known. In other words, (56) reduces two unknown parameters to one, if IM/DF is held fixed.

We will see in the next section that IM to DF ratios vary widely in our data. We will vary the parameters γ and $\tilde{\alpha}$ to produce a range of ratios in (56) consistent with what we observe in the data. This will give us a range of plausible values for r_2 .

7 Numerical Results

We now report numerical results based on the methods of the previous section. Unless otherwise indicated, our results use the baseline parameter values in Table 4.

7.1 Estimating r_1

Table 5 summarizes our estimates of r_1 values for banks 1, 2, and 3. We will compare these estimates with values for r_2 to determine whether the cost incentives favor central clearing, based on the cost inequality in (36). In each column of Table 5, we report the means and standard errors from 1000 simulated paths. The two columns under “Constrained NGR” are based on the rejection sampling method in (49) with the net-to-gross ratio constrained to fall between $n_l = .05$ and $n_u = 0.25$. Our estimates of r_1 under “Constrained NGR” are based on 1000 accepted paths. For comparison, the columns under “Unconstrained” omit (49); they result in net-to-gross ratios of around 40 percent. In both cases, full netting means that we allow cross-asset netting between banks, as in (13); partial netting means we do not allow cross-asset netting, as in (14).

As is evident from Table 5, cross-asset netting has a dramatic impact on bilateral netting efficiency and thus on our estimates of r_1 . Indeed, with cross-asset netting, the values of r_1 are so large that no plausible

values of r_2 will satisfy (36): *if banks are able to net across asset classes in setting their bilateral margin requirements, the costs under bilateral trading are much lower than the costs under central clearing.* With cross-asset netting precluded, the estimates of r_1 are much lower, and the comparison between the two scenarios less immediate.

The results in Table 5 also indicate that the r_1 estimates are higher when banks experience a lower (and more realistic) net-to-gross ratio. To see why, consider the net-to-gross ratio between banks i and j as defined in (48). A lower net-to-gross ratio is achieved as σ_{ij} , the standard deviation of the cross-asset portfolio value in the numerator of the net-to-gross ratio, becomes smaller relative to the sum of σ_{ijk} 's over k , i.e., the sum of standard deviations of asset class specific portfolio values in the denominator. This occurs as the correlation among X_{ij}^k 's decreases.³⁴ With lower net-to-gross ratio constraints, our calibration scheme constructs X_{ij}^k 's that tend to have lower cross-asset correlations.

At the same time, the stochastic weights in our calibration scheme add up to one; that is, the $\omega_k X_{ij}^k(t)$'s add up to the observed cross-asset portfolio values $V_{ij}^\omega(t)$. Since the sample standard deviation of the observed V_{ij}^ω 's is fixed, lower net-to-gross ratio constraints, which impose lower cross-asset correlations among X_{ij}^k 's, result in higher estimates for the standard deviations of the X_{ij}^k 's and thus higher estimates of r_1 .

It also turns out that these X_{ij}^k 's simulated under lower net-to-gross ratios result in central clearing portfolios, $\sum_{j \neq i} X_{ij}^k(t)$, whose standard deviation parameters ν_{ik} are higher. This is due to the X_{ij}^k 's having higher standard deviations and higher cross-bank correlations. That is, a lower net-to-gross ratio results in higher σ_{ijk} 's, higher cross-bank correlations, and lower cross-asset correlations. As the net-to-gross ratio decreases, ν_{ik} 's increase at a higher rate when compared to that of σ_{ij} 's. The net effect is that r_1 estimates under lower realistic net-to-gross ratios are higher whether or not cross-asset netting is allowed.

The last two columns in Table 5 show estimates under the correlation restrictions (50) and (52), with the net-to-gross ratio again constrained to fall between 5 percent and 25 percent, based on (49). Compared with the estimates under ‘‘Constrained NGR,’’ the correlation restrictions result in lower values of r_1 under full (cross-asset) bilateral netting. In contrast, the correlation restrictions have virtually no effect in the absence of cross-asset bilateral netting. Reasons behind these comparative results are as follows.

Estimates of σ_{ij} 's turn out to be higher under the cross-asset correlation restriction (50), $\rho_{ij} \equiv \rho_{ij}^k$, compared to the case without this restriction. The left panel of Table 6 gives estimates of ρ_{ij} 's based on the simulation of 1000 accepted X_{ij}^k paths. On the other hand, estimates of ν_{ik} 's under the cross-bank correlation assumption (52), $\rho_{ijm} \equiv \rho_{ijm}^{kl}$, appear to be close to ν_{ik} estimates in the absence of the cross bank correlation assumption. Recall that r_1 is the ratio of $\sum_k \nu_{ik}$ to $\sum_{j \neq i} \sigma_{ij}$. Consequently, r_1 estimates

³⁴In fact, when $X_{ij}^k(t)$'s are mean zero normal random variables, the net-to-gross ratio becomes equal to $\sigma(\sum_k \omega_k X_{ij}^k(t)) / (\sigma(\omega_1 X_{ij}^1(t)) + \dots + \sigma(\omega_K X_{ij}^K(t)))$. And, when $X_{ij}^k(t)$'s have non-zero mean, it can be shown that the net-to-gross ratio becomes equal to the aforementioned ratio of standard deviations as $t \rightarrow \infty$.

Table 5: Estimates of r_1 for banks 1,2, and 3, based on 1000 simulation runs. The “Constrained NGR” estimates use (49) with $n_l = .05$ and $n_u = 0.25$. The “Unconstrained” estimates omit (49) from the sampling procedure, for comparison. Results with full netting allow cross-asset bilateral netting; results with partial netting do not. Estimates under “Restricted Correlation” impose (50) and (52), and use (49) as well. Source: Authors’ analysis.

	Constrained NGR		Unconstrained		Restricted ρ	
	Netting		Netting		Netting	
	full	partial	full	partial	full	partial
\bar{r}_{11}	5.43	.91	2.14	.65	3.66	.91
SE	.14	.01	.14	.01	.08	.01
\bar{r}_{21}	4.54	.84	2.69	.68	3.10	.86
SE	.20	.01	.14	.01	.08	.01
\bar{r}_{31}	5.18	.87	1.67	.58	3.37	.87
SE	.18	.01	.08	.01	.07	.01

Table 6: Estimated correlation parameters under restrictions (50) and (54). Left panel shows cross-asset correlations $\rho_{ij} \equiv \rho_{ij}^k$ in rows $i = 1-3$ and columns $j = 1-5$, $j \neq i$, for banks i and j . Right panel shows cross-bank correlations $\rho_{ijm}^k \equiv \rho_i^k$ in rows $i = 1-3$ and columns $k = 1-5$ for bank i and asset class k . Source: Authors’ analysis.

Estimated ρ_{ij}				Estimated ρ_i^k					
-.28	-.20	-.14	-.14	.00	.00	.00	.00	.00	
-.17		-.19	-.71	-.07	.00	-.01	.00	.00	-.01
-.32	-.08		-.34	-.13	.00	-.02	.01	.00	.02

under “Constrained NGR” become higher than r_1 estimates under “Restricted ρ ” when bilateral cross asset netting is allowed.

Now consider the case of partial netting (without bilateral cross-asset netting), where cross-asset correlations do not come into play in estimating σ_{ij} ’s. The estimates of σ_{ijk} ’s in the “Constrained NGR” and “Restricted ρ ” calibrations are similar. So, given that the two calibration schemes also give similar ν_{ik} estimates, their resulting r_1 estimates are very close as well.

7.2 Approximating r_2

We now turn to the calculation of r_2 , the expression on the right side of (36). As discussed in Section 6.2, the parameters in r_2 are generally known or can be approximated from public data, with the exception of the concentration ratio γ and the confidence interval $\tilde{\alpha}$ associated with CCP guarantee funds. Equation (56) establishes a link between these parameters and the ratio of IM to DF under central clearing. We will use (56) in exploring a range of plausible values for r_2 . We first vary $\tilde{\alpha}$ and γ and calculate the resulting IM/DF ratios and values for r_2 . We then vary parameters to match the range of IM/DF ratios we observe

across CCPs in our dataset.

In Table 7, we examine three values for $\tilde{\alpha}$ and three values for γ . The table also records values of the conditional confidence level $\tilde{\alpha} = (\tilde{\alpha} - \alpha)/(1 - \alpha)$ introduced in (21), which presents $\tilde{\alpha}$ relative to the IM confidence level α . We take a minimum adequacy standard for a Cover 2 guarantee fund to $\tilde{\alpha} \geq 0.9$, which gives $\tilde{\alpha} \geq .9 + .1\alpha$. This follows from (22). Recall from Section 4.3 that a low concentration ratio indicates that the guarantee fund covers a small fraction of the CCP’s potential exposure. In Table 7, we see that the value of r_2 decreases as either $\tilde{\alpha}$ or γ increases, suggesting that satisfying the cost incentive inequality (36) may be at odds with sound CCP risk management. Also, the lowest values of r_2 in the table are associated with the lowest IM/DF ratios.

In Table 8, we vary parameters to target the range of IM/DF ratios we observe in our dataset. The ratios we observe vary from 0.7 to 73 across the majority of the CCPs in the dataset. We vary the MPOR ratio Δ_b/Δ_c as well as the other parameters because this ratio provides a regulatory lever to adjust cost incentives. The rows with $\tilde{\alpha} < .9$ represent cases indicating potentially inadequate guarantee funds. These cases produce many of the larger values of r_2 , which are associated with larger observed IM/DF ratios, again indicating a tension between the cost incentive (36) and sound CCP resources. This pattern suggests that larger observed IM/DF ratios may indicate problematic guarantee fund risk management. In other words, while large IM/DF ratios could favor costs under central clearing, they might also indicate inadequate guarantee fund requirements. Given equation (56) and the proposed minimum adequacy standard for the guarantee fund confidence level $\tilde{\alpha} \geq .9 + .1\alpha$, if we take a view on acceptable levels for γ , we can then identify adequacy standards for observed IM/DF ratios. For instance, with $\alpha = .99$; if we require $\gamma \geq .5$, then IM/DF ratios above 6 would be an indication of CCPs questionable guarantee fund risk management. Or, when requiring $\gamma \geq .2$, acceptable levels for IM/DF ratios fall below 15.³⁵ Our dataset gives IM/DF ratios between 5 to 10 at the four largest derivatives CCPs. If we fix $\alpha = .99$ and $\tilde{\alpha} = .9$, requiring $\gamma \geq .5$ indicates inadequate guarantee fund resources at some of these CCPs. However, setting $\gamma \geq .2$ would change our assessment of guarantee fund resources at these 4 largest derivatives CCPs.

Remark 5 In estimating time averages of IM/DF, we have considered IM/DF both from the perspective of each individual bank and also across all 5 banks in the dataset. Table 11 gives time averages and standard deviations of IM/DF to 5 CCPs both from the perspective of 3 individual banks and across all 5 banks in the sample period. The average IM/DF ratios across all banks to the 12 remaining CCPs in the

³⁵A 2009 letter from the Federal Reserve Board to ICE Trust, a CDS CCP, states that “ICE Trust will collect (i) Margin, which consists of (a) daily two-way cash-variation margin and (b) 99 percent 5-day VaR-based initial margin, and (ii) 99.999999 percent VaR-based GF (guarantee fund) Contributions that will provide additional protection against the default of a major market participant.” The letter is available at http://www.federalreserve.gov/boarddocs/LegalInt/BHC_ChangeInControl/2009/20090605.pdf. In our formulation, the statements in the letter correspond to setting $\alpha = 99$ percent and $\tilde{\alpha} = 99.999999$ percent under a Cover 1 standard.

Table 7: Values for r_2 and IM/DF at various values of the guarantee fund confidence level $\tilde{\alpha}$ and concentration ratio γ , with the IM confidence level $\alpha = 0.99$. Other parameter values are given in Table 4. Rows in italics have either $\tilde{\alpha} < 0.9$ or $\gamma < 0.5$ and therefore potentially inadequate guarantee funds as also discussed in Table 8. Source: Authors' analysis.

$\tilde{\alpha}$	$\check{\alpha}$	γ	IM/DF	r_2
<i>.992</i>	<i>.2</i>	<i>1</i>	<i>28.2</i>	<i>1.36</i>
<i>.992</i>	<i>.2</i>	<i>.5</i>	<i>56.4</i>	<i>1.39</i>
<i>.992</i>	<i>.2</i>	<i>.01</i>	<i>2818</i>	<i>1.41</i>
<i>.997</i>	<i>.7</i>	<i>1</i>	<i>5.5</i>	<i>1.19</i>
<i>.997</i>	<i>.7</i>	<i>.5</i>	<i>11</i>	<i>1.29</i>
<i>.997</i>	<i>.7</i>	<i>.01</i>	<i>552</i>	<i>1.41</i>
.9995	.95	1	2.4	.99
.9995	.95	.5	4.8	1.17
<i>.9995</i>	<i>.95</i>	<i>.01</i>	<i>241.3</i>	<i>1.40</i>

dataset are, 3.98, 5.44, 6.85, 7.25, 7.71, 10.07, 11.37, 19.55, 25.98, 75.59; the last two CCPs have a very large average IM/DF ratios – for instance, excluding the observed zero DF contributions gives 90730 as the average IM/DF ratio for one of these two CCPs.

Sensitivity to Collateral and Capital Costs

Our baseline marginal collateral and capital cost estimates, $c_l = .7$ percent and $c_p = 6.7$ percent, follow BIS [2013b], which introduces and employs low, central (baseline), and high collateral and capital cost scenarios, (see Table 10 on p.38 of BIS [2013b]). Low and high collateral and capital cost scenarios are .55 percent, .94 percent and 6.3 percent, 7.3 percent, respectively. These cost estimates are used in Tables 10-12 to measure the sensitivity of r_2 to c_l and c_p . The boldface entries are BIS [2013b]'s different cost scenarios.

Our numerical examples indicate that when $\tilde{\alpha}$ and γ satisfy our proposed minimum adequacy standards, and the remaining parameters driving r_2 remain close to their baseline values set by regulators, r_2 decreases when the marginal cost of capital increases. This favors bilateral trading. In contrast to the impact of c_p on r_2 , increasing the marginal cost of collateral tends to increase r_2 , which favors central clearing. However, for values of $\tilde{\alpha}$ and γ deviating from the minimum adequacy standards, r_2 's variation with respect to that of c_p and c_l may change direction. For instance, Table 12, which uses inadequate $\tilde{\alpha} = .6$, and $\gamma = .1$, shows that r_2 increases when c_p increases, but it decreases when c_l increases. Overall, as can be seen from Tables 10-12, r_2 will not change materially unless there would be a significant change in the marginal collateral and capital costs.³⁶

³⁶For simplicity, we have used the same collateral costs for the centrally cleared and bilateral markets. In practice, the bilateral market accepts a much wider range of assets as collateral, so the marginal cost of collateral under central clearing

Table 8: Values for r_2 and IM/DF at various values of the IM confidence level α , guarantee fund confidence level $\tilde{\alpha}$ and concentration ratio γ . These parameters are varied to match the span of IM/DF ratios across 17 CCPs, which range from 0.7 to 73. Rows in italics have either $\tilde{\alpha} < 0.9$ or $\gamma < 0.5$ and therefore potentially inadequate guarantee funds. Source: Authors' analysis.

α	$\tilde{\alpha}$	$\check{\alpha}$	γ	Δ_b/Δ_c	IM/DF	r_2
.9	.999	.99	1	1	.7	.41
.9	.999	.99	1	2	.7	.58
.9	.999	.99	.5	1	1.4	.58
.9	.999	.99	.5	2	1.4	.83
.95	.995	.9	.8	1.5	2.2	.84
.95	.995	.9	.8	2	2.2	.97
.95	.995	.9	.5	1.2	3.5	.85
.95	.995	.9	.5	2	3.5	1.1
<i>.99</i>	<i>.997</i>	<i>.7</i>	<i>1</i>	<i>1</i>	<i>5.5</i>	<i>.84</i>
<i>.99</i>	<i>.997</i>	<i>.7</i>	<i>1</i>	<i>2</i>	<i>5.5</i>	<i>1.19</i>
<i>.9</i>	<i>.99</i>	<i>.9</i>	<i>.1</i>	<i>1.2</i>	<i>12.3</i>	<i>1.01</i>
<i>.9</i>	<i>.99</i>	<i>.9</i>	<i>.1</i>	<i>2</i>	<i>12.3</i>	<i>1.31</i>
<i>.99</i>	<i>.995</i>	<i>.5</i>	<i>.5</i>	<i>1</i>	<i>18.7</i>	<i>.95</i>
<i>.99</i>	<i>.995</i>	<i>.5</i>	<i>.5</i>	<i>2</i>	<i>18.7</i>	<i>1.34</i>
<i>.99</i>	<i>.995</i>	<i>.5</i>	<i>.3</i>	<i>2</i>	<i>31.1</i>	<i>1.37</i>
<i>.995</i>	<i>.999</i>	<i>.8</i>	<i>.1</i>	<i>1</i>	<i>50.1</i>	<i>.98</i>
<i>.997</i>	<i>.9995</i>	<i>.83</i>	<i>.07</i>	<i>1</i>	<i>72.3</i>	<i>.98</i>
<i>.997</i>	<i>.9995</i>	<i>.83</i>	<i>.07</i>	<i>2</i>	<i>72.3</i>	<i>1.39</i>

7.3 Cost Comparison

Armed with estimates of r_1 and r_2 , we can revisit the cost comparison inequality in (36), which states that central clearing lowers capital and collateral costs when $r_1 < r_2$. We summarize our main observations as follows.

- With cross-asset bilateral netting, our estimates of r_1 are in the range of 3–5, meaning that the annualized total standard deviation under central clearing is 3–5 times larger than under fully bilateral trading. These values are substantially larger than any plausible values for r_2 , indicating that capital and collateral costs strongly favor bilateral trading when bilateral cross-asset netting is allowed.
- Without bilateral cross-asset netting, our estimates of r_1 fall to the range of 0.8–0.9. Our estimates of r_2 vary between 0.4 and 1.2, so no blanket comparison is possible.
 - If banks use more than one CCP per asset class, r_1 should be increased by a factor between 1 and $\sqrt{2}$; this eliminates most cases in which $r_1 < r_2$, which are the cases favoring central

should be somewhat higher.

Table 9: Time average and standard deviation of IM/DF of banks to 5 CCPs in the sample period. Source: Federal Reserve and authors' analysis.

	CCP 1	CCP 2	CCP 3	CCP 4	CCP 5
bank 1					
IM/DF Mean	.26	1.03	5.97	5.52	344.41
IM/DF SD	.18	.30	1.00	1.47	97.58
bank 2					
IM/DF Mean	.12	1.79	3.02	3.57	437.64
IM/DF SD	.09	1.39	1.11	1.02	173.73
bank 3					
IM/DF Mean	.61	2.59	4.81	6.13	434.78
IM/DF SD	.11	1.38	1.24	1.81	169.27
Across all banks					
IM/DF Mean	1.03	1.85	4.77	7.59	325.18
IM/DF SD	1.91	1.39	1.64	7.65	173.79

Table 10: Sensitivity of r_2 to marginal collateral and capital costs. $\alpha = .99$, $\tilde{\alpha} = .90$, and $\gamma = 1$. Source: Authors' analysis.

c_l	.55%	.55%	.55%	.55%	.7%	.7%	.7%	.7%	.94%	.94%	.94%	.94%	.94%
c_p	6.3%	6.7%	7.3%	10%	6.3%	6.7%	7.3%	10%	6.3%	6.7%	7.3%	10%	20%
r_2	1.06	1.06	1.06	1.05	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.05

clearing.

- Our estimates of r_1 do not decrease materially unless we have strong negative correlations between a bank's trades with different counterparties in the same asset class. We do not observe strong negative correlations in our data.
- Larger values of r_2 are associated with lower values of the concentration ratio γ and guarantee fund confidence level $\tilde{\alpha}$. In other words, when cost incentives favor central clearing, it may be because of inadequate guarantee fund resources.
- The MPOR ratio Δ_b/Δ_c is an important factor in tilting the cost comparison in favor of central clearing. Reducing this ratio from its current value of 2 would further weaken incentives for central clearing.

8 Discussion and Conclusions: Factors Driving the Cost Incentives

Our analysis points to three factors as the main drivers in the comparison of capital and collateral costs under bilateral and central clearing: netting efficiency, the margin period of risk, and the size of CCP

Table 11: Sensitivity of r_2 to marginal collateral and capital costs. $\alpha = .99$, $\check{\alpha} = .99$, and $\gamma = 1$. Source: Authors' analysis.

c_l	.55%	.55%	.55%	.55%	.7%	.7%	.7%	.7%	.94%	.94%	.94%	.94%	.94%
c_p	6.3%	6.7%	7.3%	10%	6.3%	6.7%	7.3%	10%	6.3%	6.7%	7.3%	10%	20%
r_2	.88	.88	.88	.87	.88	.88	.88	.88	.88	.88	.88	.88	.87

Table 12: Sensitivity of r_2 to marginal collateral and capital costs. $\alpha = .9$, $\check{\alpha} = .6$, and $\gamma = .1$. Source: Authors' analysis.

c_l	.55%	.55%	.55%	.55%	.7%	.7%	.7%	.7%	.94%	.94%	.94%	.94%	5%
c_p	6.3%	6.7%	7.3%	20%	6.3%	6.7%	7.3%	20%	6.3%	6.7%	7.3%	20%	20%
r_2	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37

guarantee funds. We discuss each of these factors in turn. We also discuss data gaps that limit our analysis and that limit supervisory monitoring of important features of OTC derivatives reform.

Netting

A reduction in counterparty risk through greater netting is often put forward as one of the main arguments in favor of central clearing. Since at least the work of Duffie and Zhu [2011], it has been recognized that central clearing may not enhance netting if different products are cleared through different CCPs or multiple CCPs clear the same product. The relative netting efficiency of bilateral and central clearing depends on the configuration of CCPs and also on whether counterparties are able to net across asset classes when they trade bilaterally. Indeed, without a prohibition on cross-asset netting in bilateral margin levels, our cost comparison would overwhelmingly favor bilateral trading. With this prohibition, our estimates of r_1 suggest a modest increase in netting efficiency in a market with full central clearing compared with a market with no central clearing, assuming no proliferation in the number of CCPs per asset class.

Using confidential data, Duffie et al. [2015] compare total collateral requirements in the credit default swaps market with and without central clearing. Their dataset reflects positions of nearly all participants, but it is limited to credit default swaps, so no direct comparison with our results is possible. A very rough comparison is provided through the ratio of total collateral required under full central clearing and a fully bilateral market; based on their Figure 1, this ratio is approximately 0.75, which could be compared to our estimates of 0.8–0.9 for the ratio r_1 . The analysis in Duffie et al. [2015] excludes guarantee fund contributions, which play a significant role in our comparison. Because they focus on collateral requirements they do not address capital requirements, which are also important in our comparison.

Margin Period of Risk

The ratio of lengths of the MPOR under bilateral trading ($\Delta_b = 10$ days) and central clearing ($\Delta_c = 5$ days) has a significant impact on our cost comparison. For values of r_1 in the range 0.8–0.9, it is easy to find parameter values for which the cost comparison favors central clearing if $\Delta_b = 2\Delta_c$ but favors a bilateral market if $\Delta_b = \Delta_c$; see Table 8.

In our model, increasing the MPOR by a factor of two increases costs by a factor of $\sqrt{2}$. As stated earlier (see footnote 12), while our baseline $\Delta_b = 2\Delta_c$ seems to follow the finalized MPOR’s associated with bilateral and central clearing initial margin calculations, counterparty and CCP risk capital rules may come into effect with $\Delta_b = \Delta_c$. That is, our baseline $\Delta_b = 2\Delta_c$ may overstate cost incentives for central clearing.

In their analysis of collateral requirements in the credit default swaps market, Duffie et al. [2015] (p.246) estimate that increasing the MPOR from five to ten days increases total collateral requirements by only 20–25 percent. Their analysis is specific to CDS and does not include guarantee fund contributions or capital requirements. Nevertheless, their estimates suggest that our factor of $\sqrt{2}$ may actually overestimate any cost incentive in favor of central clearing, even in the case $\Delta_b = 2\Delta_c$.

The longer MPOR adopted for bilateral trading has critics. In a December 2015 statement³⁷ accompanying approval of the final rule on bilateral margin requirements, Commissioner J. Christopher Giancarlo of the Commodity Futures Trading Commission stated that “I also continue to object to the ten-day liquidation horizon that must be incorporated into initial margin models for all types of uncleared swaps. The ten-day requirement is a made up number that is not tailored to the true liquidity profile of the underlying swap instruments. I call upon my fellow regulators to revisit this issue as we gain more experience with initial margin models.” In the same statement, he objected to “punitive levels of margin to drive hedging market participants toward cleared products.”

CCP Guarantee Funds

Costs associated with contributions to CCP guarantee funds are a significant factor in tipping incentives away from central clearing. As detailed in Section 4.3, guarantee fund contributions carry two types of costs: the collateral cost associated with the contributions themselves, and a capital charge resulting from the risk that the guarantee fund will be tapped upon the default of a clearing member.

Each of these costs depends, in part, on the size of the guarantee fund. As discussed in Section 4.3, under the Principles for Financial Market Infrastructure adopted by CPMI and IOSCO [2012], a systemically important CCP must size its guarantee fund to meet a Cover 2 standard. This principle-based approach

³⁷“Statement of Commissioner J. Christopher Giancarlo Regarding Final Rule on Margin Requirements for Uncleared Swaps,” December 16, 2015, available at <http://www.cftc.gov/PressRoom/SpeechesTestimony/giancarlostatement121615b>.

leaves substantial ambiguity about the appropriate size of the fund. In particular, the Cover 2 standard is intended to cover losses from the failure of two clearing members under stress conditions. The severity of the “extreme but plausible” stress, captured by our parameter $\tilde{\alpha}$, is unspecified. The adequacy of the Cover 2 standard, captured by our concentration ratio γ , may vary widely across CCPs, depending on the number of clearing members and the heterogeneity of their portfolios. One of the main conclusions of our analysis is that cost incentives that favor central clearing are in tension with maintaining sufficiently high guarantee fund levels.

Bank regulators have historically noted the importance of *comparability* across institutions as one component of a sound regulatory framework, (BCBS [2013]). Our study suggests that CCP regulation on guarantee fund requirements, which also directly affect CCP risk capital requirements, would also benefit from greater comparability.

Our analysis does not account for the business value of CCP membership, which often requires a minimum contribution to the guarantee fund. Membership enables a bank to clear on behalf of clients and to earn fees by doing so. In principle, these fees should partly offset the cost of the bank’s contribution to the guarantee fund. In practice, several large banks have exited or discussed exiting the client clearing business because leverage ratio capital requirements have made this business unprofitable. Omitting this consideration therefore seems unlikely to have a significant effect on our cost comparison.

Data Gaps

Our analysis points to gaps in the data available to the public and even regulators in understanding the impact of OTC derivatives reform. To the best of our knowledge, no regulatory authority has a comprehensive view of OTC derivatives transactions by market participant, both cleared and uncleared, with associated data on margin. The creation of swap data repositories, as mandated by the Dodd-Frank Wall Street Reform and Consumer Protection Act, has provided a mechanism for reporting swap data, but these repositories do not track margin associated with transactions.

The dataset we used in our analysis was collected under the *Guidelines for reporting institution-to-institution data* published by the BIS International Data Hub. This data collection addresses important information on counterparty credit exposures. But our analysis has also been limited by shortcomings of the BIS data collection template. In particular, the value of the reports would be greatly increased if institutions reported their exposures to other institutions by product category. We have also observed notable inconsistencies in reporting between pairs of institutions in cases where the value reported by one institution should mirror the value reported by the other.

Our analysis also points to the limited information available on the adequacy of CCP guarantee funds. The quantitative PFMI disclosures by CCPs, which took effect in February 2015, are an important step

Table 13: Summary of key notation. Source: Authors' analysis.

Notation	Description	Display
$X_{ij}^k(t)$	value to bank i of contracts with bank j in asset class k at time t	(39)
\bar{X}_{ij}^k	change in value of X_{ij}^k over the margin period of risk	(3)
$A_{ij}^k(t)$	sum of absolute values of contracts of type k between banks i and j	(42)
$Y_{ij}(t)$	total cross asset exposure of bank i to bank j at time t	(41)
\bar{V}_{ij}	change in value of V_{ij} over the margin period of risk	(4)
$V_{ij}^\omega(t)$	value to bank i of contracts with bank j at time t with weights $\omega_1, \dots, \omega_K$	(40)
\bar{U}_{ik}	change in value of U_{ik} over the margin period of risk	(15)
e_{ij}	exposure of bank i to bank j , net of collateral	(7)
e_{ik}	exposure of bank i to CCP k	(18)
e_{ki}	exposure of CCP k to bank i , net of collateral	(17)
IM_{ji}	initial margin posted by bank j to bank i	(5)
IM_{ik}	initial margin posted by bank i to CCP k	(16)
IM_i	total initial margin posted by bank i	
DF_{ik}	guarantee fund contribution from bank i to CCP k	(25)
DF_i	total guarantee fund contribution from bank i to CCPs	
$N_{ij}(t)$	ratio of net-to-gross value of obligations of bank j to bank i at time t	(48)
σ_{ijk}	standard deviation of 1-day change in $X_{ij}^k(t)$	
σ_{ij}	standard deviation of 1-day change in $V_{ij}(t)$	
ν_{ik}	standard deviation of 1-day change in $U_{ik}(t)$	
ρ_{ij}^{kl}	correlation of \bar{X}_{ij}^k and \bar{X}_{ij}^l	
ρ_{ijm}^k	correlation of \bar{X}_{ij}^k and \bar{X}_{im}^k	
β	constant defined in (12)	
z_α	α quantile of the standard normal distribution	
$\tilde{\beta}$	$z_{\tilde{\alpha}} - z_\alpha$	

toward greater transparency — they include information about the amounts collected by CCPs in initial margin and guarantee fund contributions. But they do not explain the wide range of IM/DF ratios we observe in our data.

Appendix

A Key Notation

Table 13 summarizes the definition of key notation used in the paper. Numerical values for some parameters were specified in Table 4.

B FSB estimates of ω

Table 14 gives estimates of the total fraction of OTC credit and interest rate derivatives that were centrally cleared over time by the end of June 2015. These estimates are based on the 5th-9th FSB progress reports on the implementation of the *OTC Derivatives Market Reforms*.³⁸ The quantitative impact study (QIS) used in BCBS and IOSCO [2012] (Section 4 of Appendix C) estimates that 13 percent of all OTC commodity derivatives, 2 percent of all OTC equity derivatives, and 0 percent of all foreign exchange derivatives had been cleared in 2012.³⁹ The 6th-9th FSB reports do not provide any estimates on central clearing of foreign exchange, equity, and commodity derivatives; they merely state that market participants do not expect significant clearing of these asset classes through CCPs in the near future. Table 8 (page 13) of the last FSB report indicates that in the U.S., 0 – 20 percent of new foreign exchange, equity, and commodity derivatives transactions can be centrally cleared.

We assume that ω_k 's are constant in our model calibration. We use a weighted average of ω 's for credit and interest rate derivatives. As reported in Table 4, we assume that fractions $(\omega_1, \omega_2, \omega_3, \omega_4, \omega_5) = (.81, .56, .85, .95, .99)$ of the credit, interest rate, commodity, equity, and foreign exchanges derivatives have been cleared bilaterally in our sample period.

Table 14: Percentage of the total credit and interest rate derivatives that have been centrally cleared by June 2015. Rows 1-5 show end-of-month estimates from the 5th to the 9th FSB reports. Source: FSB and authors' analysis.

	Fraction of Derivatives Cleared Centrally	
	Credit(%)	Interest Rate(%)
2/2013	12	41
6/2013	14	42
2/2014	19	46
9/2014	19	44
6/2015	21	48

C A Discussion of BIS [2014]

In contrast to the result of our study, BIS [2014] concluded that capital and collateral costs favor central clearing. Unlike our study, BIS [2014]'s cost incentive analysis was not based on a model of OTC clearing calibrated to derivatives exposure data. Instead, BIS [2014] used a quantitative impact study (QIS)

³⁸See Table 5-6 of Section 2.4.4 and Appendix II of FSB [April 2013], page 3 and Section 2.5 of FSB [September 2013], pages 2-3 and Section 2.2.3 of FSB [April 2014], page 4 and Section 2.2.3 of FSB [November 2014], and Section 2.3.2 and Tables 7-8 of FSB [July 2015].

³⁹This QIS predicts that *after the clearing mandate takes effect*, 10 percent, 57 percent, and 44 percent of all OTC foreign exchange, equity, and commodity derivatives would be centrally cleared.

through which it collected data on the collateral and capital costs associated with derivatives portfolios of 20 participating banks. At the time the QIS was conducted, some of the capital and collateral rules had not been finalized. So, bank participants themselves did not have a clear view on how the new capital and collateral rules should be calculated. This ambiguity is a significant limitation of the study.

For instance, BIS [2014] (page 8) asked participants to use an interim CCP risk capital rule that could have underestimated the finalized one captured by our study.⁴⁰ For bilateral and central clearing initial margin calculations, BIS [2014] (page 12) asked participants to use either their own internal models or the SA-CCR method (BCBS [2014b]). To the best of our knowledge, there was no consensus in 2014 (even among large bank holding companies) on how the new bilateral initial margin rules would be implemented or how bilateral IM requirements should be calculated. On the central clearing side, banks were asked to replicate CCP's IM requirements. For those banks that used the SA-CCR method for their IM calculations, IM was in fact underestimated; SA-CCR (which itself was not finalized at that time) provides an estimate of average derivatives exposures over a given time period. IM, being calculated based on a risk measure, should represent the tail of a distribution of derivatives exposures or portfolio values. So, it would be problematic to rely on QIS participants' IM calculations to estimate the collateral costs. Since bilateral margin requirements had not come into effect in 2014, there was no consensus among banks on how Basel counterparty risk capital charges should be calculated under variation and initial margin requirements. QIS participants whose IM were underestimated by the SA-CCR method could report unrealistically high capital charges under margin requirements. So, bilateral capital costs could be overestimated favoring central clearing cost incentives. To estimate the guarantee fund contribution of participants to hypothetical CCPs, BIS [2014] assumed a constant DF/IM ratio and scaled the estimated IM to arrive at an estimate of banks' guarantee fund contributions. So, DF calculations also seem to be unreliable.

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⁴⁰See Ghamami [2015] for a detailed description and analysis of various versions of CCP risk capital rules.

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