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Research Paper

I've got you under my skin: large central counterparty financial resources and the incentives they create

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ABSTRACT

This paper introduces a simple model of the default waterfall of a central counterparty (CCP) clearing service to provide an objective analysis of its composition. The three commonly found elements of the waterfall (initial margin, CCP capital at risk or "skin-in-the-game" (SITG), and default fund (DF)) are introduced, and the impact of varying the proportions of each element is discussed. The model suggests that, under reasonable assumptions, CCPs want SITG to be as low as possible, while clearing members prefer services where it plays a larger role in the default waterfall. In our setting, lower levels of SITG lead to a higher CCP return on equity but reduced levels of clearing. Moreover, CCPs have an incentive to keep initial margin higher than the required minimum, as this reduces the risk of DF losses without putting CCP capital at risk. The analysis presented suggests that a regulatory minimum requirement for SITG could play a role in incentivizing the use of CCPs where a clearing mandate does not apply and regulatory capital incentives to clear do not bite.

Keywords: central clearing; CCP capital requirements; CCP financial resources; default fund (DF); default waterfall; skin-in-the-game (SITG).

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1 INTRODUCTION

Central counterparties (CCPs) play a key role in postcrisis derivatives reforms. As such, they are systemically important, and thus the question of their soundness is an important one: see Rehlon and Nixon (2013) for a further discussion of the nature and role of CCPs in the postcrisis financial system. Robustness to default risk is a CCP's raison d'être, so the sufficiency of the resources in a clearing service's default waterfall and the burdens borne by the different contributors to it are key unknowns. Default waterfall resources are typically composed of three elements:[1]

(1) initial margin (IM), provided on each cleared account by the risk taker (we assume that IM is proportional to the risk of the relevant portfolio);

(2) some of the CCP's own capital, its skin-in-the-game (SITG);

(3) the service's default fund (DF), a mutualized layer of resources provided by clearing members.

The sum of these constitutes the service's total (funded) financial resources (TFR). Each clearing service's IM is typically floored at some minimum amount by regulatory requirements, IM_{min}, and there is often additional IM above this level. We denote the resources above IM_{min} as "RAIM". Using our terminology, a typical clearing service default waterfall can be illustrated as in Figure 1.[2]

Many CCPs are privately (as opposed to user) owned, so the question of the relative contributions of CCP owners and CCP users naturally arises. This is particularly contested, as the different tranches in the waterfall have different risks.

- IM is provided by the risk taker, and it is typically only at risk if that party defaults (or sometimes if the CCP defaults).

- The CCP's owners provide the SITG, and this is at risk if the margin is not sufficient to absorb the costs of managing a clearing member default.

[1] The end-of-day variation margin (VM) forms a flow across the clearing house from losers to winners, so it does not represent funds available to the CCP in the default waterfall. Intraday VM does sometimes accumulate at the CCP, so these funds are temporarily available; but their lack of permanency means they are not counted as an element of the default waterfall.

[2] Waterfalls first became common in the capital markets through their use in mortgage-backed securities (MBSs). In early tranched structures, the risk that flowed down was prepayment risk: the top tranche was typically prepaid first. Latterly, private label MBSs were developed where default risk flowed in the other direction, ie, with defaults eroding tranches from the bottom up. Hence, the convention developed that the layer in a default waterfall that is most exposed to default risk is at the bottom, while the least exposed layer is at the top. This is the convention we adopt.

FIGURE 1 The default waterfall of a typical clearing service.

- The service's DF is provided jointly by clearing members, and all surviving clearing members' contributions are at risk if any default or series of defaults is not absorbed by the defaulter's margin, SITG and DF contribution.

For simplicity, it is assumed that the CCP's owners and its users are disjoint, and thus potentially have opposing incentives.

The conventional wisdom is that CCP SITG should be big enough that the threat of its loss provides an incentive to the CCP's owners to ensure that margins are set at a prudent level (and, thus, that it increases members' confidence in the clearing service).[3] The adherents to this position argue that ensuring there is enough SITG also ensures (or at least goes a long way to ensuring) that there is enough IM, ie, the risk of loss of SITG incentivizes the CCP to calculate IM prudently.

This paper is a contribution to the study of CCP financial resources. A simple model of a clearing service and its default waterfall is introduced: non-default risk is not discussed. The risks that arise in this situation and the costs and benefits to the CCP and to its clearing members are analyzed. This allows us to determine the optimal proportions of each element of the default waterfall from the perspective of each party, as well as the incentives present. In particular, we show that CCPs are incentivized to have as little SITG as possible, and that this leads to a lower take-up of clearing than would result from higher SITG levels. SITG does play a role in incentivizing prudence when margin is being set, but for more complex reasons than conventional wisdom. It has been found that the risk of loss of future earnings due to clearing members shunning a service that has breached its default fund is sometimes as important as (or more important than) the risk of loss of SITG.

[3] See, for instance, Carter and Garner (2015), who say "the amount of a CCP's own funds contributed to the default waterfall should therefore be material to the CCP, regardless of the materiality of this contribution to the total size of the default waterfall".

2 CLEARING SERVICE FINANCIAL RESOURCES

The key design decisions in our model of a clearing service default waterfall are as follows.

- A CCP with a single clearing service and a fixed set of potentially clearable portfolios is assumed.
- The TFR in the default waterfall are fixed. This is reasonable, as regulation (at both the Principles for Financial Market Infrastructures (PFMI) and European Market Infrastructure Regulation (EMIR) levels) sets TFR via the "Cover 2" standard (at least for CCPs that are systemically important in more than one jurisdiction, or which clear complex products).[4]
- TFR are composed of some amount of IM, SITG and a mutualized DF.
- The minimum level of IM, $\mathrm{IM}_{\mathrm{min}}$, is assumed to be set by regulation (such as EMIR's 99% confidence, two-day holding period for cleared exchange-traded derivatives in the house account); we assume that CCPs are free to set the actual level of IM required for cleared portfolios at any level above this, for instance, by setting a target confidence interval for their margin model above the regulatory minimum.
- RAIM is filled by some mixture of additional IM, SITG and DF. We assume that any of these three components can compose between 0% and 100% of RAIM, subject to

$$\mathrm{RAIM} = \text{additional IM} + \mathrm{DF} + \mathrm{SITG}, \qquad \mathrm{TFR} = \mathrm{IM}_{\mathrm{min}} + \mathrm{RAIM}.$$

This simple model allows us to study the choices available: should the RAIM be all IM, all SITG, all DF or some mixture of these?[5] One way of visualizing the choices here is to consider the fraction of RAIM that is IM, and the fraction that is SITG.

One objection to this idea is that it is often not possible to "trade" DF or SITG 1:1 for IM, as DF and SITG are mutualized resources but IM is not. That is, if we wish to reduce DF by, say, \$1 billion for fixed SITG, that implies reducing the stressed loss

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[4] The assumption here is that while individual clearing members might gain or lose market share, the size of the largest two clearing members (whoever they are) remains fixed. This is equivalent to the assumption in Murphy and Nahai Williamson (2014) that the power law, which describes how stressed loss over IM falls off from the largest to the smallest clearing member, is fixed. This is approximately true over the typical period between DF resizing.

[5] This focus on the choices available in the design of central clearing was advocated in Budding and Murphy (2014).

over IM by \$1 billion for the largest two members, which implies their IM increases by \$1 billion. However, it is neither fair nor prudent to just increase these members' IM and leave the IM for all other members constant, as the members who used to define Cover 2 are now being held to a higher standard than everyone else, and may no longer have the biggest two stressed losses over IM. Thus, IM for other members must rise too, and the waterfall increases in size by more than \$1 billion. The mutualization factor,

$$m = \frac{\text{IM}}{\text{IM of two largest members}},$$

defines the increase in size. TFR grow by \$1 billion $\times$ $(m - 1)$. The higher the mutualization factor is for a given clearing service, the more efficient it is to hold resources for that service in a mutualized form. It is assumed that m is a property of the market shares of participants in the market being cleared, so it is exogenously given rather than being under the control of the CCP.

The appealing simplicity of designing a waterfall using fixed-size TFR and 1:1 substitution between DF, SITG and additional IM can be retained by measuring additional IM as if it were a mutualized resource. We use an asterisk $(*)$ to indicate this convention, so

$$\text{additional IM}^* = \frac{\text{additional IM}}{m}, \qquad \text{RAIM}^* = \text{additional IM}^* + \text{SITG} + \text{DF}.$$

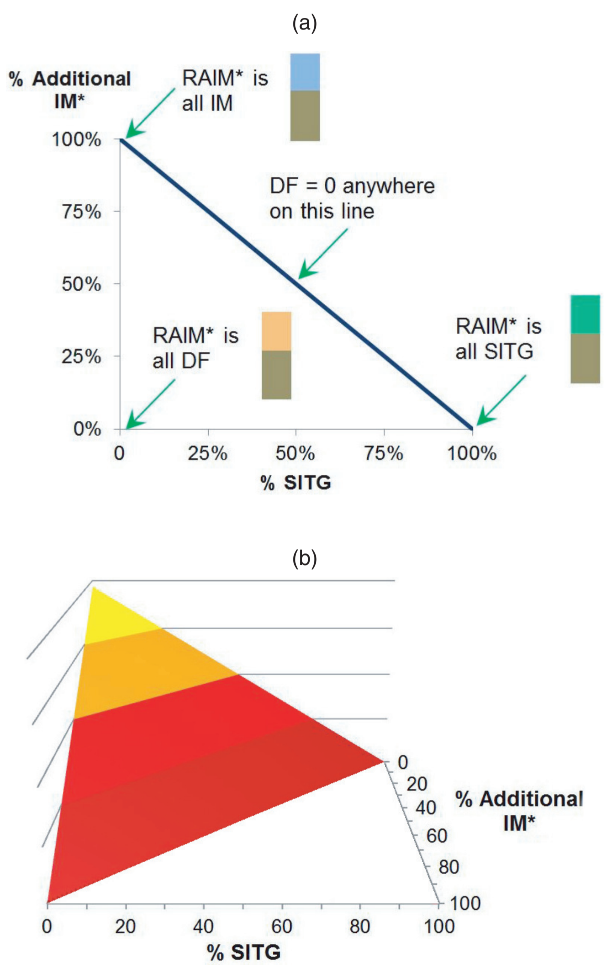
The total amount of IM held for a given amount of additional IM* is IM_{min} + additional IM* $\times\, m$. We revise our design space slightly, defining $\text{TFR}^* = \text{IM}_{\text{min}} + \text{RAIM}^*$. The financial resources design choices available are the percentage of RAIM* that is additional IM*, and the percentage that is SITG. Appendix A gives a worked example of how a particular clearing service can be represented using additional IM*, while Figure 2 illustrates the design space.[6]

3 DEFAULT FUND RISK

A key risk for clearing members is the risk that the CCP's default fund is used (or "breached") and, hence, that mutualized resources are lost. Clearly, in this setting we have the following.

[6] Note that the situation $\text{IM} < \text{IM}_{\text{min}}$ is not considered. The possibility of this, and the consequent role of SITG as an incentive for CCPs to avoid this design choice, is a common argument for regulatory minimum requirements on SITG. In practice, however, the regulation of margin models and clearing member oversight already form a substantial safeguard against imprudently low margins.

FIGURE 2 The design choices for CCP financial resources (part (a)) and the resulting levels of default fund (on the z-axis in part (b)).

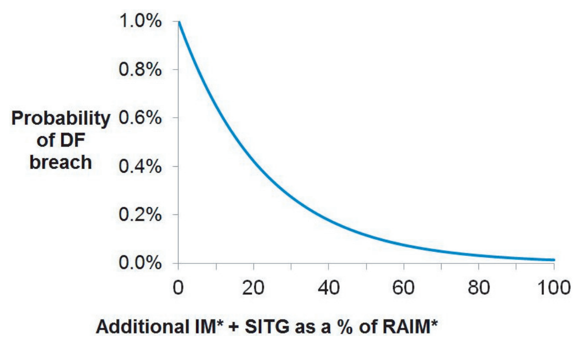


All three-dimensional surfaces have been edited for clarity.

- The higher DF is in the waterfall, ie, the bigger additional IM* + SITG is, the lower the probability that losses caused by clearing member defaults will breach DF.[7]

[7] Following Murphy and Nahai Williamson (2014), Armakola and Laurent (2015) and Ghamami (2015), we are thinking here of the central counterparty as centralized debt obligation (CCP-as-CDO) analogy, with DF as the senior tranche.

FIGURE 3 The probability of a DF breach contingent on two defaults as a function of the DF attachment point for a high m service.



- The probability of DF breach is concave in the resources below the DF. These are additional IM, SITG and the defaulters' DF contribution. Starting at zero, at first more resources reduce risk a lot, but then the rate of risk reduction slows.

To model this, we assume that the probability of a DF breach p_{DF} contingent on two clearing member defaults is a declining exponential in additional $\mathrm{IM}^* + \mathrm{SITG} + \mathrm{DF}/m$ (where the last term represents the defaulters' DF contributions: on average, if m is higher, these will be lower). This is illustrated in Figure 3. Formally, we would set

$$p_{\mathrm{DF}} = \alpha \exp\left(\beta \frac{\text{additional IM}^* + \mathrm{SITG} + \mathrm{DF}/m}{\mathrm{RAIM}^*}\right),$$

where α is a positive constant and β is negative.[8]

We will assume that DF breach is the only risk to clearing members, ie, that CCPs cannot default; hence, posted IM is risk-free for non-defaulters. For an alternative view, in which losses can extend beyond DF, see Nahai Williamson *et al* (2013).

[8] Here, we have set $p_{\mathrm{DF}} = \alpha = 1\%$ at $\mathrm{IM} = \mathrm{IM}_{\min}$, $\mathrm{SITG} = 0$ and $m = \infty$, corresponding to the minimum EMIR confidence interval for margin for exchange-traded clearing services. The possibility of making intraday margin calls and of calling for additional margin based on clearing member credit quality declines reduces p_{DF}, while the possibility that new trades intraday will cause portfolio risk to rise will increase it, so this is a conservative but not unreasonable calibration. For a given clearing service, β could be determined using the methods of Murphy and Nahai Williamson (2014).

4 CLEARING MEMBER COSTS

A clearing member has two costs associated with their membership of a given clearing service in our model:

- the cost of funding the CCP financial resources they contribute;[9]
- the extra return on equity that needs to be earned thanks to the risk of a DF breach.

The total amount of resources funded by the clearing members is IM + DF. Suppose that the average margin cost of funds for clearing members per dollar is f.[10] The total funding cost to the clearing members for the service is then

$$f \times (\mathrm{IM} + \mathrm{DF}) = f \times (\mathrm{IM}_{\min} + m \times \text{additional IM}^* + \mathrm{DF}).$$

Similarly, as discussed above, we assume some cost per risk-adjusted dollar of DF contributions e and define the cost of DF risk as $e \times \mathrm{DF} \times p_{\mathrm{DF}}$.[11]

The lowest cost to clearing members of any default waterfall design is for SITG = RAIM* (ie, additional IM* = 0, DF = 0), as this minimizes both elements of the cost. In our model, then, clearing members are incentivized to argue for SITG to be as large as possible.[12] Moreover, if SITG is fixed, they will argue for IM to be higher than the minimum for some financial resources designs.

The magnitude of these effects can be studied by choosing values for TFR*, $\mathrm{IM}_{\min}$, funding cost and cost of risk-adjusted DF. Appendix A sets out the values chosen here, and Figure 4 shows how clearing member costs vary for different allocations of RAIM* to IM and SITG using these parameters. The convexity of p_{DF} in resources below DF explains the shape here: at first, increasing IM quickly reduces risk, so the DF risk cost declines more rapidly than the funding cost of extra IM. This effect fades as IM increases further, and eventually the extra funding cost of IM outweighs the

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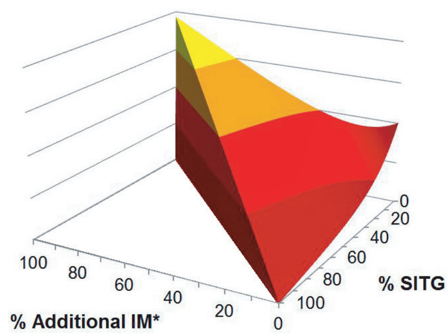
[9] Unfunded liabilities to the CCP such as DF "top up" calls are not included in the model.

[10] There is an argument that funding cost should be superlinear in IM rather than just linear. This is clearly true at some level of margin posting, but, in reality, total resources contributed to CCPs are much smaller for large banks (perhaps 1% or less of their available liquidity), so we are typically far from the "stress point", which is where CCP margin requirements might be so large that funding them requires paying a higher spread.

[11] In the small p_{D} limit, economic capital models for credit risk are typically linear in p_{D}, so this is reasonable. Note that as additional IM* + SITG increases, not only does p_{DF} decline, but the loss given DF breach declines too. Less realistically, we do not model this effect, nor do we capture the impact of the regulatory (as opposed to economic) capital requirements associated with CCP membership. See Appendix B for a further discussion of this issue.

[12] Arguments from clearing members seeking to increase minimum requirements for SITG from Citi and JP Morgan can be found in Albuquerque *et al* (2015) and Rosenberg (2014), respectively.

FIGURE 4 The costs to clearing members (on the z-axis) for different designs of clearing service financial resources.



DF risk reduction. Moreover, the safer the DF is, or the lower the cost of clearing member risk capital, the lesser this effect is.

5 THE AMOUNT CLEARED

Suppose that clearing members have a free choice about whether to clear a given transaction or not, and that they make the choice based only on the (risk-adjusted) cost of clearing.[13] In particular, suppose that amount cleared is proportional to $1/\text{cost}$. From the results of the last section, it follows that the amount cleared is maximized if RAIM is all SITG. This corresponds to a maximally safe clearing service, with no mutualization and all losses above IM_{min} being borne by shareholders. Figure 5 illustrates the amount cleared for various designs of clearing service financial resources.

Clearing members do not determine clearing service financial resources: they cannot get a desired level of SITG just by wanting it. Given this, the key question is what level of SITG CCPs would freely choose. The answer is the level that maximizes their return on equity (ROE). Both parts of this ratio are important: as SITG grows, so does CCP equity; but more SITG makes the DF safer, and thus encourages more clearing and, hence, higher returns. There will be an optimal balance that maximizes ROE. We look at this in two settings: a single-period one, where the CCP does not consider the repercussions of a DF breach on clearing, and a multiperiod one, where it does. The amount cleared will factor into this analysis in two ways.

[13] That is, we assume that regulatory capital differences between cleared and uncleared trades do not supervene, that no clearing mandate applies and that there is no CCP competition. The potential market power of a monopoly CCP to raise clearing fees is also not addressed in the model.

FIGURE 5 The amount cleared for various designs of clearing service financial resources.

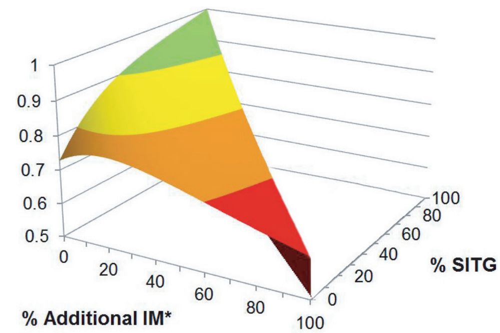
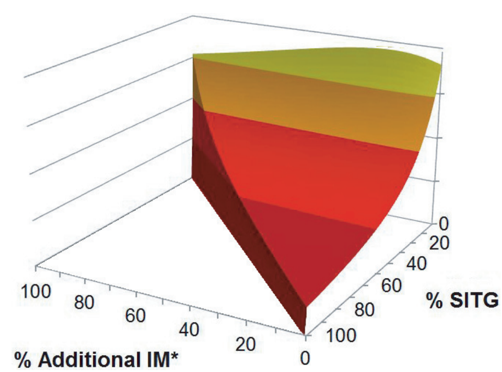


FIGURE 6 CCP ROE as a function of financial resources design: single-period model.



- It is assumed that the baseline design of financial resources (for instance, as set out in Appendix A) is for the maximum amount cleared, so any design that induces clearing members to clear less will require proportionately fewer TFR*. Thus, for instance, at additional IM* = SITG = 0, the amount cleared is roughly 75% of the total possible, so TFR* is three-quarters its baseline size.
- It is also assumed that CCP earnings are proportional to the amount cleared, so, for instance, at additional IM* = SITG = 0, the CCP earns three-quarters of the maximum amount possible.[14]

[14] In particular, there are no fixed costs in our model: a more realistic approach would include these, and thus show that CCPs had an incentive to encourage enough clearing to cover their costs.

6 OPTIMAL CENTRAL COUNTERPARTY SKIN-IN-THE-GAME: SINGLE-PERIOD SETTING

We assume that there is a minimum equity requirement for the clearing service (to provide capital against operational risk and to fund wind down of the CCP, for example), and that any SITG is in addition to this.[15] For each design of waterfall, the amount cleared is calculated. This determines the TFR and, hence, the absolute amount of SITG. From this, both the CCP's earnings and the total equity required can be determined.

Figure 6 illustrates the CCP's ROE as a function of the design of its financial resources using this methodology. The maximum is at zero SITG, with an additional IM^* of roughly 19% of RAIM^*.

It is important to note that the optimal ROE from the perspective of CCP does not maximize the amount cleared. This is because the effect of increasing SITG on CCP equity is more powerful than its effect on increasing CCP earnings: the highest ROE is usually achieved by having a reasonable (but not maximal) return at the lowest possible equity.[16] This is easiest to see from the example calibration: going from additional $\text{IM}^* = \text{SITG} = 0$ to additional $\text{IM}^* = 0$, but with $\text{SITG} = 1\%$, increases the amount cleared by 0.8% and, thus, increases the CCP's earnings by this amount. However, 1% of TFR^* is \$31 million, or roughly 8% of total CCP equity, so increasing SITG by 1% of TFR^* increases CCP returns roughly ten times more slowly than it increases total equity.

The high ROE of low SITG designs might perhaps help to explain some CCPs' contributions to the policy debate. For instance, CME Group (2015) says "it is unreasonable to conclude that CCPs should contribute excessive amounts of capital to the default waterfall", while LCH.Clearnet (2015) states that "a substantial increase of SITG would create a misalignment of clearing member incentives", a comment that, while reasonable in that low SITG puts clearing members at greater risk and, hence, encourages their participation in default management, ignores the counterveiling positive externalities of higher SITG.

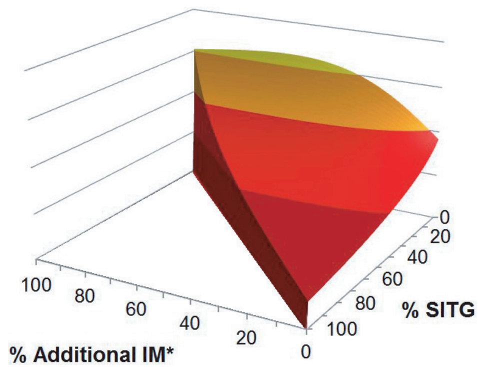
7 OPTIMAL CENTRAL COUNTERPARTY SKIN-IN-THE-GAME: MULTIPERIOD SETTING

In the previous section, the risk of a DF breach only affected CCPs through the amount clearing members chose to clear for a given composition of financial resources in

[15] The question of the right level of capital for non-default risks is not addressed here: see Murphy (2012) for a discussion of this issue.

[16] It is possible to find situations where maximum ROE occurs at nonzero SITG in the model, but this only happens when clearing fees are elevated. For most realistic calibrations, the maximum ROE is at zero SITG.

FIGURE 7 CCP ROE as a function of financial resources design: multiperiod model.



one period. The model can be improved by considering multiple periods. Here, a completely safe CCP would simply be an annuity earning a fixed clearing fee in each period, based on the amount cleared. For other CCPs, an additional assumption about the loss of CCP earnings after a DF breach must be made. We make the most stringent assumption: namely, that any DF breach causes clearing members to shun the service forever. This allows us to calculate a revised CCP ROE, discounting back future earnings (provided there has been no DF breach) and assuming a static design of financial resources.[17]

In this setting, DF breach risk becomes the dominant issue. CCPs react to this risk by designing their financial resources to be highly safe, as this increases the value of their future (risk-adjusted) earnings. However, as before, the optimal CCP ROE is obtained if they do so without making an equity contribution, ie, by setting SITG $=$ DF $= 0$. For our calibration, the maximum ROE is for additional IM* equal to 59% of RAIM*, as Figure 7 illustrates.

It should also be noted that in this model the risk of loss of SITG is comparatively minor compared with the risk of loss of future earnings. This is because a DF breach eliminates any possibility of future earnings, and the current low-rate environment makes discounted future earnings quite valuable. In this setting, clearing member reactions to a loss that is mutualized are a more significant motivation for CCPs than the risk of loss of SITG. Of course, this in turn depends on the assumption that clearing members will shun the CCP once there has been a DF breach: if they have to clear

[17] Specifically, we use a standard discrete time credit default swap pricing model, as in Arvanitis and Gregory (2001), with zero recovery, $p_{\mathrm{D}} = p_{\mathrm{DF}}$ and the single-period CCP earnings as the (risky) coupon.

some trades at a particular CCP despite a DF breach, then that CCP has less incentive to stay safe.

8 CONCLUSIONS

Our model suggests that, under reasonable simplifying assumptions, CCPs want SITG to be as low as possible, while clearing members consider services where it plays a larger role in the default waterfall to be safer. Low SITG leads to elevated returns for CCP equity holders but lower levels of clearing than those found when CCPs put more of their equity at risk in the default waterfall. These insights help to explain the comments of various parties in the SITG debate.

We also find that both CCPs and clearing members prefer designs with IM higher than the minimum: clearing members because it reduces DF risk, and CCPs because it reduces the amount and risk of SITG and DF. Our model suggests that a regulatory minimum requirement for SITG could play a role in incentivizing clearing. An alternative to this is to get higher levels of clearing by regulatory fiat, for instance, via a clearing mandate or capital disincentives for bilateral trading.

The model also suggests that the risk of a race to the bottom on IM may not be significant, at least where there is a single dominant CCP clearing an asset class and TFR are fixed. Such CCPs not are incentivized to push IM down to the minimum level, and clearing members will clear less at a CCP with $\mathrm{IM} = \mathrm{IM}_{\min}$. Regulatory minimum requirements for SITG help here, too, as the incentive to increase margin (and, thus, create extra costs for clients as well as clearing members) is less powerful at higher levels of SITG.

The incentives for CCPs are different if there is competition. Here, the assumption of reciprocal elasticity in clearing is less reasonable, and CCPs may well decide to allocate safety costs to SITG as well as IM. This is a potential benefit that may offset the reduction in netting efficiency from multiple CCPs. See Huang (2016) for a further discussion of this as well as a more sophisticated model of clearing service financial resources structure.[18]

A prominent, unanswered question in the SITG debate is how much skin is enough to create good incentives for the CCP.[19] Our model suggests that regulators can answer that question by asking what level of SITG would be sufficient to generate the amount of clearing they consider necessary, were market participants free to choose whether or not to clear any particular trade.

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[18] Note that the assumption of fixed TFR may be unrealistic for a competitive CCP with low margin levels, as such a CCP might be tempted to skimp on its stress testing too.

[19] For instance, Cox (2015) suggests that the CCP's regulator "should have the responsibility to ensure that a sufficiently objective and balanced decision is reached" on CCP SITG, but he does not suggest a procedure for determining the amount required.

The mutualization factor m has been introduced as a measure of how efficient it is to hold resources in a mutualized form for a given clearing service. We have seen that once DF risk is included, total costs for clearing members are typically minimized for small (but nonzero) additional IM, but that CCPs may be incentivized to set additional IM at a higher level. This insight highlights a different question that has received less attention in the SITG debate: should there be any constraint on additional IM, especially for high m services, where holding resources in the form of DF is particularly efficient? Our analysis (and that of Carter *et al* (2016)) shows the importance of ensuring that CCPs' governance processes give sufficient regard to the views of all types of users as well as those of shareholders on the composition of clearing service financial resources, so that an appropriate balance is struck between their potentially differing views on issues such as this.

There have been various proposals for non-standard designs of CCP financial resources, for instance, where SITG is *pari passu* with the mutualized DF, or where there is an additional tranche of CCP equity above DF (Cox 2015). The methods presented here could easily be extended to analyze proposals such as these, or to design alternative waterfall arrangements.

APPENDIX A. NUMERICAL CALIBRATION

The results presented here are based on the following calibration for a representative large clearing service and clearing member risk and funding profile.

- We start with a typical clearing service with IM of \$30 billion, $\mathrm{IM}_{\min}$ of \$25 billion, DF of \$2 billion and SITG of \$100 million.
- The mutualization factor,
$$m = \frac{\mathrm{IM}}{\text{IM of two largest members}},$$
is determined to be 5.
- This means we can represent the service as $\mathrm{IM}_{\min}$ of \$25 billion, SITG of \$100 million and DF of \$2 billion, as before, with additional $\mathrm{IM}^* = (\mathrm{IM} - \mathrm{IM}_{\min})/m = \$1$ billion. Thus, in the fully mutualized representation, TFR^* in the service is $\$25\text{ billion} + \$1\text{ billion} + \$0.1\text{ billion} + \$2\text{ billion} = \$28.1$ billion and $\mathrm{RAIM}^* = \mathrm{TFR}^* - \mathrm{IM}_{\min} = \$3.1$ billion.[20]

[20] The fully mutualized representation of a clearing service provides a useful comparison tool. If each service is first put into this representation and then scaled so $\mathrm{TFR}^* = 1$ (or, depending on the application, so $\mathrm{IM}_{\min} = 1$), the relative extent of the mutualization and the risk absorption capacity of CCP SITG is more readily apparent.

- The maximum possible SITG, DF or additional IM* here is \$3.1 billion.
- The exponential fall off of p_{DF} is calibrated by setting p_{DF} =1% at SITG = additional IM* = 0 and $p_{\text{DF}} = 1.3$ basis points (bps; or a "one-in-thirty-years" standard), when RAIM is entirely composed of SITG and additional IM*.
- Clearing member funding cost f is set at 25bps, and the required (pretax) return on equity e is set at 15%.
- Required minimum capital (eg, for operational risk) for the service is set at \$400 million.
- The one-year discount factor for future earnings is set at 0.99.

APPENDIX B. INCORPORATING REGULATORY CAPITAL COSTS

The model in the body of the paper assigned costs to clearing members based on funding and an economic capital model of DF risk. In reality, regulatory rather than economic capital is often the decisive factor for some clearing members, so this appendix discusses a modification to our model in order to assign regulatory capital cost.

The governing framework here will often be rules based on the Basel Accords (specifically, Basel Committee on Banking Supervision (2014)). Here, the approach for the house account is to allocate capital for two risks.

- The risk of CCP failure (which does not appear in the model proposed in the body of this paper) is captured via a charge on trade exposures to CCPs. Broadly, the trade exposure is the current mark-to-market of the cleared portfolio, plus an adjustment for potential future exposure, plus initial margin and minus variation margin. The rationale here is that if the CCP defaults, the clearing member loses their portfolio (which in stress is worth the mark-to-market at default, plus the potential future exposure and minus the variation margin received) and they lose their IM (or at least the non-bankruptcy remote portion of it). Since the current mark-to-market is approximately equal to the variation margin, and the potential future exposure is a measure of the same risk as IM, trade exposure can be modeled as $2 \times$ IM. This then attracts a 2% risk weight in the Basel framework.
- The risk of DF loss is capitalized on a sliding scale, based on the attachment point of DF. Conceptually, the approach is similar to the one taken in the main body of this paper, but rather than calibrating the scale absolutely, a relative measure is used. Specifically, the DF would be compared with the capital

TABLE C.1 Summary of financial resources disclosures for four clearing services.

Resource characteristics (millions of USD)	Service			
	CME base	Eurex	ICE F&O	LCH Swapclear
DF	3 007	3 355	1 450	6 095
Total IM	96 094	36 523	21 659	98 771
SITG	100	106	100	63
m range	2.5–3.25	3.75–6	3.5–5	4.75–7
SITG as a % of DF	3.3%	3.2%	6.9%	1.0%
$\text{RAIM}^* + \text{IM}_{\text{min}}/m$ at max m	32 640	9 214	5 972	20 269
SITG as a % of this	0.3%	1.1%	1.7%	0.3%

required if all of the cleared exposures were capitalized using the bilateral exposure framework. The details of this are complicated, but one simple way to incorporate the effect would be to use the end points: the worst risk weight for exposures to a qualifying CCP's DF in the Basel framework is 20%, and the best is 2%, so it would be logical to take the capital requirement for the DF at SITG $=$ additional IM $= 0$ as 20% of DF and at SITG $= 100\%$ TFR* as 2% of it as well as to draw a smooth line between these two extremes using a negative exponential, as in Section 3.

APPENDIX C. SUMMARY OF DISCLOSURES FOR FOUR LARGE CLEARING SERVICES

The disclosures mandated by Committee on Payments and Market Infrastructures and Board of the International Organization of Securities Commissions for CCPs (see CPMI–IOSCO 2015) give some insight into the amounts of various tranches of financial resources in many clearing services. The first part of Table C.1 summarizes recent disclosures from four leading services. In the second part, the mutualization factor m is estimated for each service using data on the amount of margin contributed by the top five and ten clearing members. There is significant model risk in this process, so a range of estimates of m is given. Subsequent rows then show SITG as a percentage of DF. It is impossible to infer TFR* from the disclosures, as IM_{min} is not disclosed, but a related measure, $\text{RAIM}^* + \text{IM}_{\text{min}}/m$, can be calculated. This is estimated for the largest m, and SITG is shown as a percentage of it.

Table C.1 illustrates a variety of practice in the four services, although it should not be interpreted as indicating different levels of resilience. In particular, 100 000 000 seems to be an anchor point for SITG (€100 million is approximately US$106 million at the time of writing), with only SwapClear having a lower level of SITG than this. The different markets cleared have significantly different levels of mutualization, however, and this has an effect on SITG, considered as a fraction of resources in the * representation.

DECLARATION OF INTEREST

The views expressed in this paper are those of the author, and not necessarily those of the Bank of England.

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