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Abstract

Central counterparties (CCPs) are designed to be robust enough to withstand generally at least the simultaneous default of their largest two clearing members in extreme but plausible market conditions. This is called a 'cover 2' CCP. However, the extreme-and-implausible case cannot be excluded i.e. where the CCP would exhaust all funded financial resources (i.e. skin-in-the-game and the default fund D) to cover the default losses and would need to resort to unfunded recovery tools.

The aim of this paper is to consider the resilience of a CCP for both default losses and non-default losses. For the former case, it is shown under plausible assumptions that the assessment (or cash call) for the surviving members is sufficient to recover a cover 1 CCP provided that the total assessment powers under the CCP Rulebook equals $2D$. Given the extreme scenario we also take into account that some surviving clearing members might decide to leave the CCP. Some intuitive results for the cover 2 CCP case are provided as well.

For the latter case, it is demonstrated that under plausible assumptions, the likelihood that a non-default loss is larger than the CCP's capital including one year of profits, is equivalent to an AAA risk.

These observations together provide substantiation for the very low likelihood of a CCP's failure.

Keywords: CCP, G20 central clearing mandate, financial stability, CCP waterfall, non default losses.

JEL classifications: G02, G23, G28, G33

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1 Introduction

One of the most visible public policy responses to the Lehman crisis is the mandatory central clearing of over-the-counter derivative transactions. As a result the business of CCPs worldwide has increased substantially. For example, interest rate derivatives are now cleared with an average daily turnover on USD 5 trillion (notional amounts). This naturally leads to the question how well present-day CCPs are protected.

Central counterparties (CCPs) are designed to be robust enough to withstand at least the simultaneous default of their largest two clearing members in extreme but plausible market conditions. However, the extreme-and-implausible case cannot be excluded i.e. the scenario that the CCP would not have enough funded financial resources to cover the loss. Because of their contractual recovery mechanisms, it is possible for a CCP to allocate all losses to the surviving clearing members such that eventually no residual unallocated losses remain for the CCP. Central counterparties are required by their regulators to have such comprehensive arrangement in place which is able to fully allocate uncovered credit losses which may remain after one or more clearing members have been declared in default.[1] To achieve this goal, a CCP cannot only rely on its prefunded financial buffers (margin of the defaulters, skin-in-the-game and the default fund D). An additional but unfunded financial buffer is the assessment (or cash call) where each surviving clearing member is obliged under the CCP Rulebook to provide additional funds to the CCP. That contribution amounts typically to one, two or three times the original default fund contribution of each survivor. The maximum number of assessments under the Rulebook of a CCP will be denoted by a_{max}. However, the CCP also needs powers in its rulebook that are comprehensive i.e. such tools can address the excess loss to clearing members which happen to have a positive mark-to-market portfolio position (known as variation margin gains haircutting) or by tearing up derivative contracts to extinguish the loss. In so doing a CCP is able to allocate all default losses eventually.[2]

The aim of this article is twofold. First, to analyze the 'end of the prefunded waterfall case' where the default losses are so large that all prefunded financial buffers of the CCP are exhausted and there is still a residual loss. Using a simple theoretical model and some basic statistical results from Extreme Value Theory, we derive some qualitative results which are formulated as observations throughout this paper. Second, to estimate the probability

[1] See Principle 4 (credit risk), key consideration 7 which reads "A [CCP] should establish explicit rules and procedures that address fully any credit losses it may face as a result of any individual or combined default among its participants ..." in CPMI-IOSCO (2012).

[2] In FSB (2017), it is stated that the authorities in their consideration to intervene or not should assume the full application of the CCP's rules and arrangements for loss allocation.

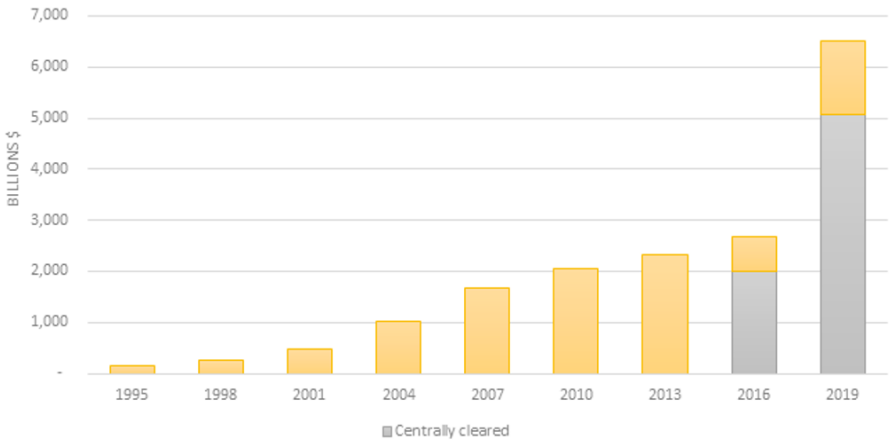

Figure 1: Cleared Volumes of OTC Interest Rate Derivatives 1995- 2019

Source: BIS. Total figures are aggregated across all currencies daily average turnover in USD bn. Centrally cleared volume share is on IRS notional breakdown by counterparty type (available only from 2016 onwards).

of a non-default loss exceeding the sum of the CCP's capital and one year of its profits.

The plan of the paper is as follows. In section 2 we show the historical evidence in the literature of CCPs in severe stress. This is 'the end of the prefunded waterfall case' described above. Section 3 establishes that the powers of a CCP under its Rulebook are sufficient to allocate any loss from member defaults among the surviving clearing members. In section 4 we study the cover 1 CCP which contains the main results of this paper for the default losses case. Section 5 considers the non-default loss case which is rarely studied in the literature. We provide an estimate of how unlikely it would be for a CCP to burn through the Regulatory Capital Requirement for non-default losses together with one year of profits. Section 6 concludes.

2 Historical cases of CCPs in severe stress

Mandatory central clearing of standardized OTC transactions has resulted in large increases of cleared volumes with CCPs (see Figure 1). This naturally raises the issue of the robustness of CCPs. The historical evidence is presented in Table 1.[3] There have been four cases where the CCP itself experienced severe stress which we define here to mean that the prefunded waterfall has been exhausted.[4] The first two cases involved CCPs that were

[3] Adopted from Berndsen (2020).

[4] Some near-misses involving CCPs can be found in (Gregory, 2014, pp. 267-270). Note that the successful handling of a clearing member default (the main purpose of a CCP) does not constitute a CCP in severe stress. LCH has managed eight such defaults since 1990.

not systemically important as they served some specific commodity markets (in sugar and palm oil) and the solution was liquidation eventually. The last two cases pertain to systemically important CCPs. The Hong Kong case was directly related to the largest stock market crash to date (October 1987) which caused a trade suspension of a week. During that time the solution attained for ending the stress at the CCP was to raise extra funds from shareholders, in effect comparable to what now would be called an assessment or cash call. Once trading and clearing was resumed it turned out that the rescue package was sufficient.[5] The New Zealand case involved fraud and two very large positions.[6] Because of the large build-up positions, the CCP chose for the solution of a partial tear up of the contracts of the defaulter i.e. it closed out (a compulsory liquidation) the opposing contracts at a price below the prevailing market prices (Budding et al., 2016).

The relatively short list in Table 1 shows that liquidation of a CCP is a very rare event and that systemically-important CCPs have not failed to date. Furthermore, it is important to realize that internationally agreed minimum standards for CCPs have only been established by central banks and securities regulators in 2004. After the Lehman default (which CCPs worldwide were able to manage without recourse to the default fund) the bar for CCPs has been raised and sharpened standards have been introduced in 2012.[7] For example, for credit risk the cover 2 standard has been introduced as well as more rigorous (reverse) stress-testing requirements. In the EU (but also in other jurisdictions) the PFMI in the case of CCPs have been put into law so these are now legally binding.[8]

3 The End of the CCP Prefunded Loss Waterfall

Notwithstanding the above relatively favorable historical evidence, it is prudent to prepare for the unprecedented.[9] In this section, we explore the scenario where a CCP reaches the end of the prefunded loss waterfall. This happens when the loss caused by one or more defaults is larger than the size of the prefunded waterfall. The Rulebook powers of a CCP to handle losses arising from member defaults(s) have the following characteristics:

- Members are required to post margins bilaterally with the CCP to cover their risk.
- Members are also required to post a contribution to the Default Fund (or Guarantee Fund), which the CCP can access if the bilateral mar-

[5] See Cox (2015) for a thorough analysis of this case.

[6] One position involved 71 % of the short side of the open interest Budding et al. (2016)

[7] See Recommendations for Central Counterparties in CPSS-IOSCO (2004) and Principles for Financial Market Infrastructures (PFMI) in CPMI-IOSCO (2012).

[8] The relevant legislation EU/648/2012 is called EMIR.

[9] See also the recent guidance of the FSB on CCP Resolution in FSB (2020)

CCP name (country), contracts involved, reference	year	root causes	solution
Caisse de Liquidation des Affaires en Marchandises (France) White sugar contracts (Bignon and Vuillemey, 2020)	1974	Unauthorized trading by clearing members and insufficient margin	liquidation (CCP not systemically important)
Kuala Lumpur Commodity Clearing House (Malaysia) Palm oil contracts (Hills et al., 1999)	1983	Six brokers into default, accumulation uncovered positions at one trader, and management's inaction	liquidation (CCP not systemically important)
Hong Kong Futures Exchange (Hong Kong) Futures contracts (Cox, 2015)	1987	Flawed governance and insufficient margin and default fund	cash call
International Commodities Clearing House (New Zealand) Commodities contracts (Budding et al., 2016)	1989	Forgery of customer documentation and very large positions of two largest clearing members	partial tear up

Table 1: Cases of Severe CCP Stress

gins posted are not enough to cover market losses stemming from a member default during market stress. In the EU, the default fund is sized to the cover two i.e. be able to withstand the default of the two largest clearing members and their affiliates. In this way, members are said to have mutualized the tail risk through the CCP.

- To properly align incentive structures between clearing members and the CCP, EMIR requires a layer of capital known as skin in the game (SITG), which the CCP must use up prior to accessing the default fund contributions of the non-defaulted members.

- If the combination of bilateral margins, skin in the game and default fund contributions are not enough to cover the losses due to clearing member defaults the CCP has reached the end of the prefunded waterfall. From that point onwards, the CCP has powers in its Rule Book to call additional resources from members equal to a multiple of member default fund contributions, and, if that is still not enough, by haircutting Variation Margin (VM) gains to the "winners" while still requiring the VM payments from the "losers". This process is called Variation Margin Gains Haircutting (VMGH).[10]

- Finally, if all these resources are not enough to meet the losses generated by the clearing member(s) default, the CCP can tear up the contracts (for foreign exchange and interest rate derivative contracts).[11]

The consequence of these Rulebook powers taken together leads to the first result of this paper:

Observation 1 *In the event of member default(s), all losses are eventually allocated if the CCP follows the rulebook allocation "mechanically".*

4 Assessing the Strength of the CCP Waterfall: the Cover 1 Case

In this section we assess the strength of the prefunded CCP Waterfall by going through the multiple lines of defence of the CCP.

The first line of defence for the CCP is the membership criteria used to assess whether a given counterparty is allowed to join the membership. Clearly the stronger the credit quality of the counterparty, the less likely they will default and the less likely the CCP waterfall will be used in the first place. Some CCPs (particularly for OTC derivatives) have very high

[10] In the case of equity or repo clearing (where VM calling is absent) an alternative loss arrangement is in place.

[11] At LCH, clearing members can vote for continuity of the service ("membership ballots") before tear up.

credit standards for membership which may be supplemented by requiring applicants to meet stringent operational capabilities in processing margin payments several times a day.

The second line of defence for the CCP is the quantum of margin called from each member. This is paid by the member to cover their cleared positions and can be seized by the CCP under the Rulebook if the member is declared in default. The CCP has absolute priority on this margin above all other creditors of the defaulted member. There are minimum regulatory standards which require that the margin coverage is set at a high confidence level. This ensures that if a member defaults, there are sufficient margins available to cover the loss in most circumstances. In other words, the credit quality of each member is enhanced by the margin held by the CCP for that member and the resulting credit rating of the member portfolio is of higher quality. This level of credit enhancement can be measured. Suppose the expected counterparty exposure at default is E_{cp}, the probability of default is P_d and L_{gd} denotes the Loss Given Default. Then the expected default loss $E(L_d)$ equals $P_d E_{cp} L_{gd}$. So for example, if the Loss Given Default is 100% ($L_{gd} = 1$) then $E(L_d) = P_d E_{cp}$. If the counterparty posts margin to a minimum regulatory standard of 99.5% for OTC derivatives (which is the legal requirement in the EU), then the Expected Default Loss greatly reduces to

$$E(L_d) = P_d E_{cp}(1 - 0.995) \tag{1}$$

This is equivalent to the expected loss from a unmargined counterparty with the same exposure E_{cp}, but with a probability of default equal to 0.005. So for example, if the counterparty has a credit rating corresponding to CCC, then S&P published statistics show an empirical probability of default of about 32% for such a rating.[12] The effect of the 99.5% margin is then to improve the effective counterparty rating (called 'facility rating')[13] to 0.005 x 32% = 0.16% as a new probability of loss for the member portfolio. Now a P_d of 16 bps is equivalent to a rating in the BBB range, so the overall rating of the CCC counterparty has been greatly enhanced to a prime expected Loss rating in the BBB range.

Practically speaking, it is unlikely that members will be admitted to the CCP if they are rated CCC and near default, as the other healthy members may object to having standards which would allow this. A more likely situation is when the healthy member has a B rating, as would be found in lower rated economies. According to S&P, a B rating has an empirical default rate of about 5%, so the credit enhancement of the 99.5% margin is .005 x 5% = 2.5 bps. This is firmly in the AAA to AA+ high prime rating

[12]Default, Transition and Recovery: 2019 Annual Global Corporate Default and Rating Transition Study, S&P Global.

[13]Here the facility rating refers to the credit rating including the collateral pledged to the CCP

band i.e. the probability of loss from a member default (regardless of the member rating) is very low and is equivalent to a high prime rating.

Observation 2 *The minimum regulatory standards for CCP margin requirements enhance the facility rating of a cleared member portfolio to a prime rating equivalent.*

The third line of defence in the CCP Waterfall is the 'Skin In The Game' (SITG). This is the amount of CCP Capital which must be used directly after the defaulted members resources, but before any non-defaulted member resources are exposed. It exists to align the incentives of CCP management and CCP membership and to encourage the CCP to put in place policies/procedures to ensure that margin levels are adequate. It is particularly effective as an alignment mechanism if linked directly to compensation. Generally, the quantum of SITG held by CCPs is not large and there is an active debate as to whether it should be increased substantially. This is discussed in McLaughlin (2018), where it is shown that a mandatory increase in regulatory requirements for SITG would eventually result in the CCP being unable to return the cost of capital. This in turn would result in the withdrawal of private funding from CCPs and leave public funding as the only viable option, unless there was to be a substantial increase in clearing fees across the industry to compensate. For the purposes of this discussion, the SITG layer will be ignored as it does not contribute substantially to loss absorbing capital in the CCP Waterfall under current regulations.

The fourth line of defence in the CCP Waterfall is the Default Fund (aka Guarantee Fund). This comes directly after SITG is exhausted. The Default Fund is constructed from member contributions which are pooled and held by the CCP to be used in the event that losses from member defaults exceed bilateral margins posted by the defaulters plus the SITG. It is in effect mutualizing the tail losses resulting from extreme but plausible market scenarios. The Default Fund is fully funded in cash. Hence by construction, the Default Fund in a Cover 1 CCP will fully cover the default of the member with the largest exposure to the CCP in the most extreme but plausible scenario. By definition this is the cost to liquidate the member portfolio in the most extreme but plausible market scenario net of all margins posted by the member.

If the Default Fund has been partly or wholly consumed to address the resulting loss after a member default, each surviving clearing member must make a formal decision to either: Replenish the Default Fund and continue membership, or leave the CCP altogether.[14] If the decision of the clearing

[14]There may also be a formal ballot by the membership to determine whether in aggregate the CCP needs to "wind down", but this will not be considered here as a separate capital buffer is already explicitly held to absorb such wind-down cost. In addition, for systemically important CCPs wind down is usually not preferred because of the systemic risk

member is to retain membership and not to exit the CCP then it will be required to post another contribution to replenish the Default Fund. Typically the member contribution to the Default Fund (D) is determined by the risk brought to the CCP and a reasonable assumption here is that this contribution for each member is given by the proportion of margin requirements for member i. Other such risk-based allocation schemes are also possible, but here we focus on this simple scheme as it adequately illustrates the essential arguments to be made. If there are N members in the CCP at the outset, then the replenishment of the Default Fund will fall to the surviving $N-1$ members. A new Default Fund in the cover 1 CCP will be sized to the uncovered loss of the second largest member and this could be quite close to (but slightly less than) the uncovered loss of the first member who defaulted. In other words, D will remain a conservative assumption for the size of the new Default Fund, but this time it needs to be allocated out among the remaining N-1 survivors. This means that for the replenishment, member i will have to fund the amount

$$\frac{M_i}{\sum_{i=1}^{N-1} M_i} D \tag{2}$$

where the sum is taken over all $N-1$ surviving members and M_i is the margin requirement for member i. If there are many members this number will be approximately equal to the original Default Fund contribution. More precisely, M_i is some historic margin average requirement as Default Funds are only rebalanced periodically (e.g. monthly) but this subtlety will not be pursued here. In summary, a severe member default in a Cover 1 CCP will mean that each member's original (prefunded) contribution will be consumed and will then need to replenish for an amount almost equal to its original default contribution, but at least the member will have the choice to retain membership of the CCP, or have a say in whether it continues operations before replenishing.

So far, the discussion has concerned the protection afforded by the funded part of the Loss Waterfall. However the possibility must also be considered that in an extreme but plausible scenario, there is a common shock to clearing members which could it make more likely that another member might also default. If this were to happen in a Cover 1 CCP, the Default Fund might be fully depleted after addressing the loss from the first default. The CCP would then have no choice but to resort to calling for potentially two further assessments under the Rulebook. The maximum number of potential assessments (a_{max}) is limited in the Rulebook to a small multiple of the original Default Fund contribution. So, the first assessment as discussed above is to replenish the fund from the default of the first member. The

implications so the CCP will most likely be put into resolution by a competent Resolution Authority.

second assessment is to cover the loss due to the default of the second member which was not covered by prefunded,in-house funds. Again it is possible that the uncovered loss from the second member default could be close to (but slightly less than) D if both defaulting members had uncovered losses of comparable size. In this most conservative case, a surviving member will have lost their original Default Fund contribution and be called for two assessments of total value

$$2\frac{M_i}{\sum_{i=1}^{N-2} M_i}D \tag{3}$$

where the sum is now over the $N-2$ surviving members. As the unfunded assessment is now larger if the member were to continue in the CCP, it is less likely to be honoured than in the case of a single default, where the loss was pre-funded and the member had a choice of whether to exit. A member not meeting a contractual assessment under the Rulebook would be considered an event of default at the CCP. In that event, the repudiating member would be declared in Default of the CCP Rulebook and the assessment owed would be added to the total loss to be allocated out among the remaining $N-3$ surviving members, thereby marginally increasing their assessment owed. More generally, if $k > 0$ members were to repudiate the call for assessments to meet the uncovered resources ($\approx$ D) from the default of the second large member, the amount not collected would be added to the resources to be allocated out among the surviving $N-2-k$ members. However, this additional amount to be allocated will be a smaller order of magnitude than the original amount D. So that addressing the default of the second large member in a Cover 1 CCP involves an element of credit risk, as the full uncovered loss required may not in fact be collected. If there is a large number of members, this absorption process will work without difficulty for two basic reasons. First, there will be many surviving members with a vested interest in continuing with membership of the CCP, so it would not be in danger of a wind down. Second, as the missing assessments from the relatively small number of members who repudiated the call is of an order of magnitude smaller than the total requirement to be filled ($\approx D$), and will be allocated out over a relatively large number of survivors thereby increasing their assessment only marginally to compensate. In summary, the result is:

Observation 3 *In a Cover 1 CCP with many members and $a_{max} \geq 2$, the simultaneous default of two large members can be absorbed by assessments on the survivors without going to VMGH.*

For a better understanding of this Observation it is instructive to consider when this loss absorption from the second member default might fail in a Cover 1 CCP. From the above discussion, a failure will be linked to a small membership (small N), for in that case there is potentially less interest

in the surviving members keeping the CCP operational for future clearing services and in dealing with the relatively large costs which will only be shared among very few survivors. For example, suppose that the number of members in the Cover 1 CCP service initially is N=4. If two were then to default simultaneously, that would only leave two survivors to share the losses. For simplicity suppose that the members are of approximate equal size (homogeneous CCP assumption). As discussed above, the first default is fully covered by the (funded) Default Fund of size D, so that each surviving member will lose $D/4$ in original contribution. The loss from the second member default is also $\approx D$ and the two survivors would then need to contribute an amount of $D/2$ if this was to be covered. In other words, they would need to contribute double their original default fund contribution to absorb the loss ($2D$). If the two survivors were to agree to continue clearing operations, this would require a new Default Fund of approximate size D, and each survivor would need to contribute $D/2$. The costs on surviving members are then as follows:

1. If the survivors chose to continue as members in good standing at the CCP, the total cost to each survivor is approx. an order of magnitude equal to the initial Default Fund size prior to default of the two members: $D/4 + D/2 + D/2 = \frac{5}{4}D$

2. If one survivor decides not to continue clearing, the CCP will fail as it cannot function with only one surviving member. The cost to each member is then: $D/4 + D/2 = \frac{3}{4}D$

3. If one survivor decides to repudiate the assessment call, then the CCP will not survive for future operations and the cost to the surviving member in good stead would need to be $D/4 + D$ to compensate for the unmet assessment of $D/2$ on the other member. But this would mean an assessment of four times the original default fund contribution on a surviving member which given that a_{max} is usually smaller than four, would not be allowed to assess this much from a member under the CCP Rulebook.

Even if case 1. prevails and the CCP were to continue clearing operations, this is not a stable situation and is effectively equivalent to the mechanism of bilateral margining without a CCP. Case 2. might cause Regulatory concern if the Competent Authorities felt that a cleared market solution was required and that bilateral trading as the only functioning trading mechanism was against the public interest. Case 3 is the most interesting. In the other cases a market price can be established as there are two functioning market participants left, but one of the participants is not in good standing and has repudiated its obligations to the CCP and effectively to the other remaining member. If the CCP were able to mark the positions to market, then the

required resources could be raised from the mechanism of VMGH. But that works only as long as the portfolio of the repudiating member remains in profit. If it were in a loss position, then under the CCP Rulebook, the only option left is full contract tear-up. But this only allocates the loss to the surviving member who did not repudiate the CCP assessment. In this case, the Resolution Authority would have to intervene to resolve the situation following the No Creditor Worse Principle and this would result in the loss being forced back onto the repudiating member in the end. Hence, a CCP can absorb losses from several members defaulting without applying VMGH and contract tear-ups so long as the total quantum of default losses L_d to be assessed against surviving members (after using the Default Fund) does not exceed the assessment powers in the CCP Rulebook (a_{max} rounds of default fund contributions).

We now can establish the strength of the waterfall for a cover 1 CCP with no repudiating members as follows. Assume the cover 1 CCP has N homogeneous members, Default Fund size D, with each member having the same ratio of Default Fund contribution $\frac{D}{N}$ and no repudiating members. If n members were to default then the resources over and above the amount D held which is needed to handle the uncovered loss is approximately $(n-1)D$ and this will be less than the amount $\frac{N-n}{N}D$ available for assessments on survivors as long as $n \leq \frac{2N}{N+1}$.[15] This fraction is very close to a_{max} for a sizeable membership (large N), so if no surviving member repudiates the assessment call, then the CCP can cover the losses from a second member default provided that $a_{max} \geq 2$.

Subsequently, we show the strength of the waterfall where we relax the assumption of no repudiators. So assuming $k > 0$ repudiators we arrive at the following conclusion:

Observation 4 *In a Cover 1 homogeneous CCP of N members with Default Fund D, n members in default, and k members who repudiate the CCP assessments, the total assessments then paid up would be $\frac{(N-n-k)D}{N}$. This CCP would not have to resort to VMGH if this number was greater than the uncovered loss $(n-1)D$, which would be the case as long as $n \leq \frac{2N-k)}{N+1}$. This is approximately $2+\frac{k}{N+1}$ and for large enough membership N would be very close to two. Since $(n-1)D$ was a conservative estimate for the resources required to cure the loss, these assessments raised would be enough for the CCP to handle the loss without resorting to VMGH under an extreme but plausible market scenario.*

Of course if the CCP were to handle the loss without resorting to VMGH, it could pursue the repudiating members by declaring them in default of the CCP Rulebook, seize any positive Variation Gains and if none are available pursue the repudiating member in the courts for the monies owed. This

[15] This follows from solving the inequality $(n-1)D < \frac{N-n}{N}D$ for n.

result implicitly assumes that the Default Fund has been sized and modelled correctly in the first place to cover the worst extreme but plausible exposure.

All these arguments can be adapted to a Cover 2 CCP with a sizeable membership base, where the Default Fund is sized to cover the maximum exposure to the CCP from the default of two members under an extreme but plausible market scenario, but the arguments involve advanced statistics and are beyond the scope of this paper. However, a Cover 2 CCP by definition, has a stronger prefunded waterfall than a Cover 1 CCP, so the above results hold as a special case.

The assumption that the CCP is homogeneous can be removed and a more general statement is possible. Again suppose the CCP is cover 1 with N members and n defaults and k repudiations. Then the loss which must be covered is again $(n-1)D$, but in the heterogeneous case the assessments available from survivors could be a lot less as there may be concentrations among the defaulters. If the n defaulted members had contributed the fraction q of the original Default Fund, the CCP would contractually be able to raise $2(1-q)D$ from the remaining $N-n$ members. Suppose $a_{max} = 2$ then this would be enough to cover the loss provided $q \leq (3-n)/2$. For two defaults in the CCP, $n = 2$ and this inequality is manifestly true as long as these two defaulters do not together contribute more than 50% to the original Default Fund.

Next if the k repudiating members had an original Default Fund contribution of $q\prime$, this inequality would be modified slightly to read that the CCP powers of two assessments are enough to absorb the loss of the n defaulting members, so long as $q + q\prime \leq (3-n)/2$. For $n = 2$ defaults, this is true as long as $q + q\prime$ together are less than 50%. Otherwise the CCP must resort to other powers such as VMGH or contract tear-ups. In summary, this discussion shows that the ability of the CCP to handle the default of any two members is linked to the extent of the concentration inside the CCP:

Observation 5 *For a heterogeneous Cover 1 CCP, the default of any two members under the worst extreme but plausible market scenario can be covered by the maximum of two assessments under the CCP Rulebook powers and the CCP can avoid VMGH and contract tear-ups altogether so long as the two defaulters and the assessment repudiators do not together contribute more than 50% of the original Default Fund.*

Each member should have planned and set aside capital to reserve against the maximum number of CCP assessments, so the risk of repudiations should not be material. This result identifies when the Cover 1 CCP might enter the VMGH stage of the Loss Waterfall, linking this to the degree of concentrations, the number of defaulters, the number of assessments allowed under the CCP Rulebook and the number of repudiators. But the result highlights that if the CCP has many members, is not very concentrated and has two assessment powers, it is very unlikely to enter into the VMGH phase

of the Loss Waterfall in the event that there are two defaults; the first default is covered by the existing Default Fund, the second default is covered by the first assessment and the Default Fund is reconstituted by a second assessment. If there are 3 simultaneous defaults in the CCP taking place under extreme but plausible conditions there will likely be no resources left (funded or unfunded) to meet the resulting loss and the CCP will need to impose VMGH. At this point, a surviving member will have lost the original default fund contribution and paid two more default fund contributions and will also have suffered a VMGH loss. It is unlikely that such a member would want to continue membership in the CCP and it is very likely that the CCP will be discontinued, with all contracts being torn up. Summarizing, this gives a sense of the strength of the Loss Waterfall:

Observation 6 *A cover 1 CCP having many members, no dominant concentrations and a_{max} assessment powers, will likely exhaust the entire prefunded Loss Waterfall in an extreme but plausible market scenario in the event that a_{max} members default with uncovered loss of approximately a_{max} times the original default fund.*

5 Non Default Losses

We have seen so far in this paper that losses due to member defaults can be allocated back to surviving members through the CCP Loss Waterfall and have discussed the strength of this mechanism. The natural remaining question is what about losses that are not due to member defaults, the so called non-default losses (L_{nd}). By very definition, these are not covered by the CCP Waterfall and cannot be allocated back to members without prior agreement and so they are to be ultimately covered by CCP Capital. Non-default losses are rarely studied[16]. They can broadly be classified as follows:

Investment Losses Here the activity of "storing" member margins posted to cover member defaults can give rise to Market Risk for the CCP; for example, under the EMIR regulatory constraints, a CCP is unable to store (on average) more than 5% of margins in unsecured deposits with commercial banks, and due to liquidity concerns is also not allowed to use Money Market Funds. If the CCP does not have access to the Central Bank relevant for the particular cash margin, this leaves only the options to buy bonds outright or reverse repo the cash to a commercial counterparty. Of course there will be tight liquidity and credit standards inside the CCP for which type of repo counterparties are allowable and for the liquidity and credit quality of the underlying bonds. However, it will still be the case that such a CCP will be

[16]Two exceptions are LCH (2014) and Lewis and McPartland (2017).

(reluctantly) exposed to Investment Risk on these activities. This shows in particular the key role that a Central Bank account can play in reducing this risk.

ICSD Failures When margin is posted in securities, they must be stored at a custodian and there is a risk they cannot be recovered when required if the ICSD fails. This will be more a liquidity risk rather than a solvency risk as the margins are legally segregated and will eventually be recovered.

Operational or Business Failures This covers a wide variety of loss types including those from cyber attacks, potential litigations, fraud, or IT system failures.

Under EMIR, Regulators capitalize explicitly for non-default losses. Currently they require a charge of 15% of annual net revenues (R_n) calculated as the average of the past 3 years annual figures. This is intended to be a conservative proxy for coverage up to a high quantile (99.9%) of the loss distribution. In other words, a 1 in a thousand chance (or .001) serves as a proxy for the probability of experiencing a non-default loss larger than the requirement ($Pr(L_{nd} > .15R_n)$). Moreover a CCP would typically report profit margins around 50%, so the annual profit of the CCP would be of the order magnitude of $.5R_n$. So now consider a significant CCP with $500 million of net revenues. The regulatory capital charge is then $75 million (15%) and the order of magnitude of annual profit is $250 million under the above assumptions. It is known theoretically by Extreme Value Theory, e.g. De Koker (2006), that losses at high confidence levels in excess of some large enough threshold U will follow a Pareto Law, with linear tail growth given asymptotically by:

$$Pr(LossX > U) \approx C.X^{-\alpha} \tag{4}$$

for some constant α. In a recent paper (McLaughlin, 2020) it is argued that the parameter p:= $\frac{1}{\alpha}$ is about 0.78 for a wide range of firm size and is consistent with heavy tails of the severity distribution as one might expect. This is also consistent with Moscadelli (2004), where the index is estimated for various business activities. If the regulatory capital requirement is interpreted at 99.9%, this is certainly a high confidence level and equation 4 would then give:

$$Pr(Loss > RegCap) = .001 \approx C \cdot (RegCap)^{-1.28} \tag{5}$$

And using Reg Cap = $.15 \cdot R_n$, allows to solve for C as

$$C = .001(.15 \cdot R_n)^{1.28} = \$12.48 million = 0.02496 \cdot R_n \tag{6}$$

This value of C can then be used in equation 4 to answer the critical question: What is the probability of observing an NDL in excess of the CCP annual

profits and the Regulatory Capital actually held? In other words we must calculate

$$Pr(LossX > (.5 \cdot R_n + .15 \cdot R_n)) \approx 12.480,000 \cdot (0.65 \cdot R_n)^{-1.28} = .000153 \quad (7)$$

In other words, an NDL loss event which exhausts both the Regulatory Capital held by the CCP and the annual profits held by the CCP has a very rare chance of occurring of about 1.5bps. This is considered AAA risk equivalent according to the Rating Agencies and is even under the Basel floor of 3bps. To summarize, this is really a statement on the Resilience of a CCP to NDLs:

Observation 7 *Assuming the power law implicit in the current Regulatory Capital Framework, the risk that a CCP might incur an NDL in excess of Regulatory Capital held which also wipes out one year of profits, is a AAA risk, whose likelihood of occurrence is approximately 1.5bps.*

Note that this result agrees with the earlier empirical observation in Table 1 that there has been only 2 CCP failures due to a non-default loss (with fraud as the root cause) in 50 years which is a frequency of 2 chances in 255 days x 50 years = 2 chances in 12,750 days or approx 1.5bps.

6 Concluding Remarks

This paper has recalled the main historical events where CCPs have got into severe stress, defined as the exhaustion of the prefunded default waterfall of a CCP. This is a rare event in itself and there have been no instances of a systemically-important CCP itself defaulting to date. We argue that this is due to the various lines of defence which are legally required and which have been raised to a higher bar following the Lehman crisis. This paper contributes to the CCP literature in two ways.

On default losses, we derive a number of observations regarding the strength of the waterfall for a Cover 1 CCP.[17] We show how the margining process improves the credit quality of any clearing member to a prime rating equivalent, decreasing the likelihood of a clearing member in the first place. In addition, we derive under plausible assumptions that two assessments (cash calls) are sufficient to cover the simultaneous default of two large members. In case there are assessment repudiating members (i.e. clearing members which cannot or do not deliver the extra funds) this changes to the condition that the two defaulters plus the assessment repudiators contributed no more than half of the original default fund.

On non-default losses, we show that a CCP is resilient to non-default losses. Based on some insights from Extreme Value theory, we show that

[17] To derive the results for a Cover 2 would require advanced statistics which is beyond the scope of this paper.

the probability of a non-default loss exceeding the sum of regulatory capital and one year of profit amounts to 1.5 bps, a rare event equivalent to a prime rating risk.

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