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FIVE FUNDAMENTAL QUESTIONS ON CENTRAL COUNTERPARTIES

By

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Five Fundamental Questions
on Central Counterparties*

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Abstract

Central counterparties (CCPs) are designed to reduce aggregate counterparty credit risk and function as market infrastructures for capital markets in securities and derivatives. Although CCPs, also known as clearing houses, exist for well over a century, they have gained prominence since they became the main international public policy response to the Lehman crisis of making over-the-counter derivative transactions safer. This G20's response to the Lehman crisis of making central clearing mandatory for standardized over-the-counter derivative transactions has been translated into law, Dodd-Frank for the US and EMIR for the EU. However, CCPs remain to some extent controversial with adversaries claiming that they potentially increase systemic risk and proponents viewing them as systemic risk reducing when properly designed and maintained. In this article I review the booming literature on CCPs, of which about 60% is published in the last five years, by asking five fundamental questions about CCPs. The aim is to construct a broad, academically substantiated, synthesis about CCPs and to propose directions for future research in what can be considered as the most important niche of financial economics.

Keywords: Central counterparty, clearing, OTC derivatives, financial stability, G20 central clearing mandate, recovery and resolution

JEL classifications: G01, G23, G28

1 Introduction

The first central counterparty (CCP) was opened in 1882 in Le Havre (France), named Caisse de Liquidation des Affaires en Marchandises, clearing coffee futures (Vuillemey, 2018). There were clearing houses long in operation before that date but they did not perform novation (legally interposing themselves between every buyer and seller of the relevant market) nor did they offer the explicit guarantee to execute the contract in case of a member default. At present there are world-wide about 60 CCPs.[1]

The aim of this article is to capture the collective knowledge embedded in the academic literature about CCPs. To be precise, I study central counterparties that serve capital markets in tradable financial instruments.[2] Sometimes the term clearinghouse is used, especially in the earlier literature. I will use in the remainder of this article only the term central counterparty to avoid confusion with an Automated Clearing House (ACH) which clears retail payments in bulk and performs multilateral netting but does not interpose itself between two trading counterparties (no counterparty substitution). The ACH is not in the scope of this article.

The scope of this review on CCPs is to some extent subjective, as is any literature review. Here, the ambition is to be exhaustive with respect to the peer-reviewed articles, at present the counter stands at 162 articles.[3] To be precise, the scope of the review encompasses all articles published in peer-reviewed, academic journals in the English language with at least a quarter of the text devoted to CCPs. I have used the following databases and search engines: EconLit, RePEc (EconPapers), SSRN (Social Science Research Network), WorldCat and Google Scholar. The cut-off date of the literature review is April 2020.

Many articles which are ultimately accepted for journal publication, first start out as a working paper. In conducting the review, these working papers have been collected by the author (presently 186 working papers have been identified). These are used to see if any recent but important insights are missing from the published articles. These papers together with some other relevant articles can be found in Appendix B.

Out of scope of this article are the numerous documents published by

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[1] The BIS Comparative Payment and Financial Market Infrastructure Statistics lists about 50 CCPs while the global association of CCPs, called CCP12, has 37 members which run 60 CCPs. Other dimensions could be to count the number of separate default funds or to look at the different business lines within a CCP. This would raise the number beyond 60 in both cases.

[2] In Chamorro-Courtland (2012a), interestingly but not in our scope, a non-financial central counterparty is discussed which clears payments among airline carriers world-wide using the legal notions of open offer and novation.

[3] See Appendix A for the full list. In case I have missed an article on CCPs published in the academic literature or as a working paper, please send the reference to r.j.berndsen@tilburguniversity.edu, so the database can be kept up-to-date.

the official or government sector (financial regulators, central banks, international standard setting bodies) and the financial industry. The former are not part of the review as the purpose of their work related to CCPs is to regulate or influence them through their public policy objectives of pursuing financial stability or promoting the safety and efficiency of the financial infrastructure. The latter are not in scope as they can be seen as advocating the interests of a particular CCP, clearing member or the wider industry. So, those publications are out of scope but not for the reason that they would not provide us with useful insights as they often do including some influential speeches by central bankers. Of course, articles of individuals or co-authors working in those sectors who have published in peer-reviewed, academic journals, are in scope.

It is assumed that the reader is familiar with the basic notions of a central counterparty such as the prefunded waterfall, the different asset classes a CCP may clear (equities, repos, and derivatives such as swaps, options and futures) and its default management process.[4]

The motivation for this literature study is the ongoing debate on the systemic benefits and risks of CCPs. CCPs remain to some extent controversial with adversaries claiming that they potentially increase systemic risk and proponents viewing them as systemic risk reducing when properly designed and maintained. To the best of my knowledge, there is no encompassing review article on CCPs summarizing what we know about them based on peer-reviewed, academic articles. This article is intended to fill that gap.

At the time of the cut-off date 87 different academic journals have been identified as containing one or more articles on CCPs that are in scope. In Table 1 those journals are listed in alphabetical order. From that table it emerges that the CCP literature is widely dispersed in terms of journals with one exception, The Journal of Financial Market Infrastructures, which is a journal that is specialized in CCPs.

2   A Simplified Chronological View

In this section, I provide a simple, chronological view on the CCP literature in three parts:

Pre-Lehman Crisis This covers a small part of the literature which reflects the lack of academic interest in CCPs prior to the Lehman crisis. There are only 9 articles published in the period 1983-2008 in academic journals and 15 working papers. Most articles are focused on explaining the why, what and how of CCPs and were assessing the benefits and costs of CCPs including lessons learned from the 19 October 1987 Crash such as in Bernanke (1990). The oldest reference in

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[4]Otherwise, useful introductory texts are: Norman (2015); Gregory (2014); Berndsen (2018).

Peer-reviewed Journal	# articles
Banking and Finance Law Review	3
European Journal of Finance	2
International Journal of Modern Physics C	3
Journal of Financial Market Infrastructures	48
Journal of Banking and Finance	6
Journal of Financial Economics	4
Journal of Financial Intermediation	3
Journal of Financial Regulation	2
Journal of Financial Services Research	2
Journal of Futures Markets	4
Journal of Money, Credit and Banking	3
Journal of Risk Management in Financial Institutions	3
Operations Research	3
Review of Asset Pricing Studies	2
Virginia Law and Business Review	2
Other academic journals with exactly one CCP article	72
Total number of articles in scope	162

Table 1: Academic journals containing more than one article on CCPs

our scope is Edwards (1983) in which fundamental questions are discussed still relevant as of today such as the optimal number of CCPs per asset class and the role of the government and central banks vis-à-vis CCPs. Given the fact that CCPs were established at the end of the nineteenth century, it is to be expected that earlier references exist from before 1983 which could meet the requirements for the scope of the review. To date they have not been found by the author. However, their relevance for this review would most likely be limited as CCPs are nowadays much better protected against member defaults because of international standards which have been published first in CPSS-IOSCO (2004).

G20's Mandatory Central Clearing Policy This part of the literature (2009-2015) discusses the policy response to the Lehman crisis i.e. mandatory clearing via a CCP of standardized over-the-counter (OTC) derivative contracts. This response is part of the G20's policy of 'Strengthening the International Financial Regulatory System', the major policy response to the Great Financial Crisis as evidenced in the declaration of the G20 at their 3rd Summit (G20 Pittsburgh, 2009). It caused an enormous increase of the literature with 54 articles and 68 working papers. It is safe to say that mandatory clearing by CCPs is controversial. This is evidenced by some of the titles e.g. *Clearing-*

house overconfidence in Roe (2013), *The problematic case of clearing-houses in complex markets* in Yadav (2013) or *A bill of goods: central counterparties and systemic risk* in Pirrong (2014)) while others are more positive e.g. *OTC central counterparty clearing: Myths and reality* in Milne (2012), *Financial Markets Uncertainty and the Rawlsian Argument for Central Counterparty Clearing of OTC Derivatives* in McNamara (2014) or *Credit Default Swap Clearinghouses and Systemic Risk: Why Centralized Counterparties Must Have Access to Central Bank Liquidity* in Kress (2011). Most notable issue is whether systemic risk would increase or decrease when Credit Default Swaps (CDS) would be centrally cleared by CCPs.[5]

(End-of-the) Waterfall Adequacy With the notional amount of centrally cleared contracts rising rapidly and hence also the amounts of margin called by CCPs worldwide, the focus shifted quite naturally to questions regarding the adequacy of the pre-funded waterfall and CCP's tools at the end of the waterfall. A recent reminder of the relevance of resource adequacy was the default of a clearing member at Nasdaq Clearing (Swedish CCP), on 11 September 2018. The default loss consumed not only the defaulter's resources but also hit the other clearing member's default fund contributions. This part of the literature covers the period from 2015 to the present (as mentioned before, cut-off date is April 2020) and the literature consists of 99 articles and 103 working papers.

This simple chronological analysis of the CCP literature reveals the clear surge in articles after the Lehman crisis while the academic interest is still continuing to the present day.

3 Citation Graph Analysis

It is customary in a literature review to analyse the citation graph i.e. the directed graph of articles pointing to its references where each article is a node. Such graph is usually acyclic, possibly disconnected and there is a directed link from node i to j if article i refers to article j. The citation graph is acyclic if there are no simultaneous references which is usually the case in the peer-reviewed literature because of the lead times to publication.[6]

Our citation graph is shown in Figure 1. There are 162 nodes and almost

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[5]See Stulz (2010) for a discussion on CDSs, which itself is not part of the CCP literature but often cited in the CCP literature (and therefore listed in Appendix B).

[6]Cyclical references could happen for example in a special issue of a journal as a result of a conference where participants reference each other. However, that is not the case here.
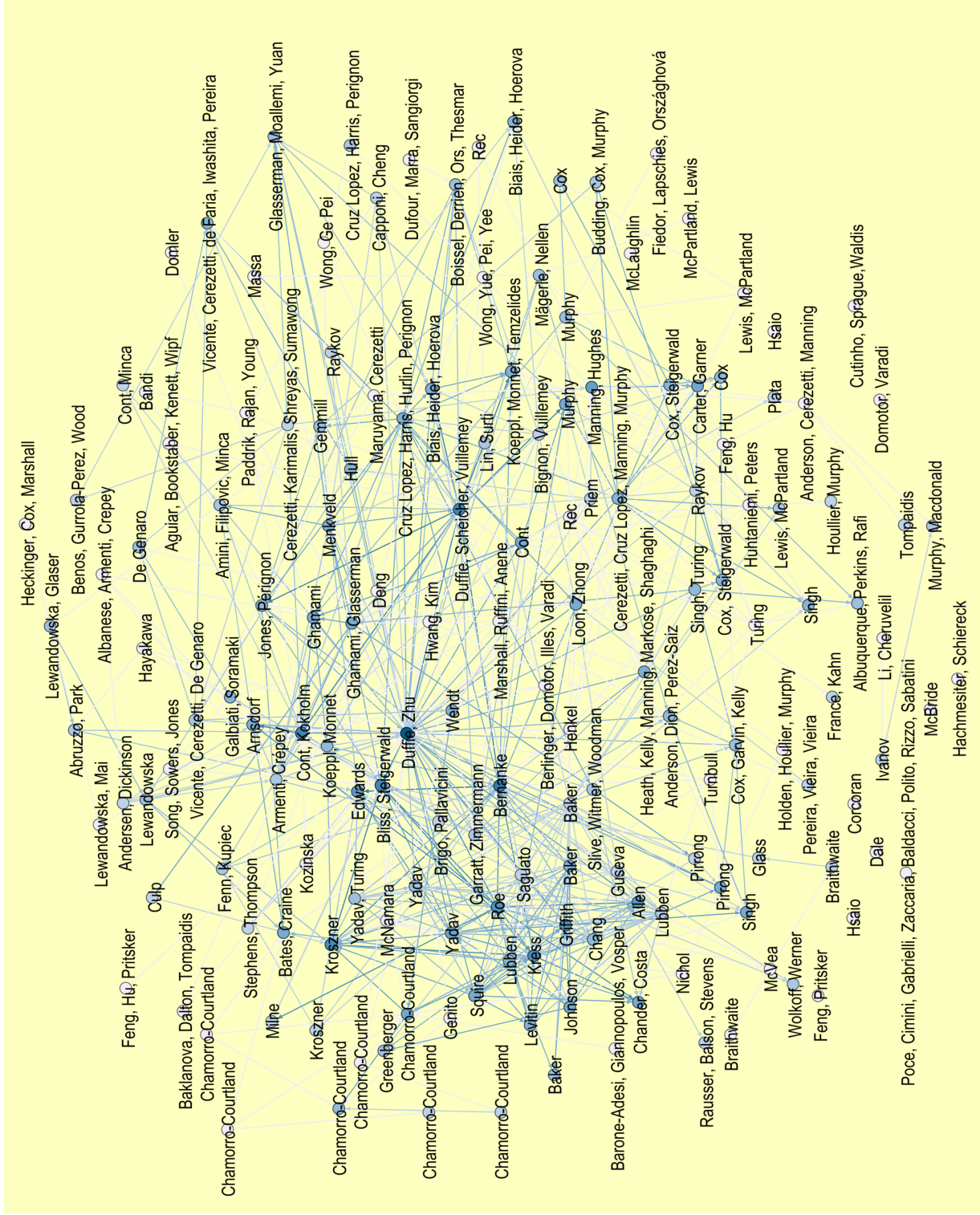
Figure 1: Citation Graph CCP Literature (162 nodes, coloured by in-degree)

600 links.[7] Furthermore, the graph is acyclic as I have not included, as mentioned above, working papers nor references to working papers. There is one exception to this rule: if a working paper is published later on as a journal article, I have included such working paper references as a proper reference in the citation graph provided that both documents have the same author(s) and title. Our graph is also disconnected as there are eleven articles which do not reference another article nor are referenced by any other articles in the peer-reviewed literature. They mostly contain references to working papers including many official sector and industry documents. The explanation for these nodes to be isolated varies from papers where the CCP is the object of applying a particular statistical technique, or where the author discusses proposed legislation such as Dodd-Frank in the US, EMIR in the EU or legislation in other jurisdictions.

The citation graph can be used to analyse the importance of an article in the CCP-literature by calculating several centrality measures. The simplest measure is degree centrality which is simply the number of incoming links of a node (indegree) which equals the number of references to that article by all other $(162 - 1)$ articles in the CCP literature. The top references, in our citation graph defined as nodes with in-degree ≥ 10, are listed in Table 2 in order of declining degree centrality i.e. declining importance. There are 12 such articles. Also two other centrality measures, authority centrality and PageRank centrality, have been included in Table 2 where a lower number implies a higher influence. Both measures are suitable for analysing directed graphs and take longer paths in the citation graph into account than indegree centrality which only uses paths of length equal to one.

From Table 2 it is clear that the most influential paper in the CCP literature is the contribution of Darrell Duffie and Haoxiang Zhu (Stanford University) from 2011 which poses the fundamental question of whether a CCP reduces counterparty risk. It is referenced 69 times and comes out first also on the basis of the other two centrality measures. The second most influential article is the classical reference written two decades earlier (1990) by former Federal Reserve Chairman Ben Bernanke (at Princeton University) on the behaviour of financial markets during the stock market crash of 1987. The oldest reference in the scope of the review (hence in the citation graph with zero out-degree), Franklin Edwards (1983), is also in the top references list. He makes a comparison between the various major CCPs clearing futures in the US and the UK. The newest top reference dates from 2016 of Mark Manning and David Hughes in which they discuss the different risk profiles of CCPs and commercial banks and other important differences between CCPs and banks. Most articles in Table 2 are influential

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[7]The graph is constructed using the latest available version (0.9.2) of the Gephi software described in Bastian et al. (2009).

across all three centrality measures but there are some exceptions where either the PageRank measure or the authority centrality measure is relatively high, indicating relatively low importance. A special mention is needed here for three working papers, one written by David Murphy and Paul Nahai-Williamson and two written by Craig Pirrong. Strictly speaking working papers are out of scope. However if they would have been published in a peer-reviewed journal they would have been included as a top reference in Table 2.[8]

In general a citation graph can also be used to perform a cluster analysis. Intuitively, a node belongs to a certain cluster if it shares more links with other nodes in that cluster then with nodes outside that cluster. Although various partitions of the graph in Figure 1 have been tried by the author, the results were disappointing in that no useful, stable partitions were generated. Varying the number of clusters did not lead to a better insight either.[9]

Another way to describe the CCP literature is to look at the method of analysis (see Table 3). The results in that table are based on the most influential articles according to the three centrality measures mentioned before, accounting for approximately half of the CCP literature. The dominant method, here called argumentation (57%), does not make use of a model which means they derive their strength from the quality of the arguments put forward . Model-based analysis account for little over one-third, divided over theoretical models (20%), statistical models (13%) and network models (3%). Some theoretical models are also calibrated (8%) using mainly the aggregate BIS Derivatives Statistics or the Public Quantitative Disclosure figures that CCPs publish in accordance with guidance from CPMI-IOSCO. Statistical models use more granular data or use certain probability assumptions. Network models explicitly model the interconnections between CCP and clearing members and typically calculate centrality measures. Some articles (7%) contain a case study which range from a certain event (such as the failure of a CCP), implementation of specific legislation in a jurisdiction, or a historical perspective on CCPs.

4   The CCP literature in five fundamental questions

As the chronological perspective above only provides a very rough insight and the cluster analysis does not yield useful results, it seems more produc-

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[8]Murphy and Nahai-Williamson (2014); Pirrong (2009, 2011) are respectively 25, 20, and 38 times referenced.

[9]The modularity class feature in the Gephi software was used with parameters set such that the main connected component of the citation graph was partitioned into 2,3,5 or 7 clusters. It was also observed that the partitions were not identical when repeating the analysis with the same parameters.

Author(s)	Title	Indegree	Auth.	PR
Duffie and Zhu (2011)	Does a Central Clearing Counterparty Reduce Counterparty Risk?	69	1	1
Bernanke (1990)	Clearing and Settlement during the Crash	25	2	7
Bliss and Steigerwald (2006)	Derivatives Clearing and Settlement: A Comparison of Central Counterparties and Alternative Structures	19	8	2
Duffie, Scheicher and Vuillemey (2015)	Central Clearing and Collateral Demand	19	10	3
Cont and Kokholm (2014)	Central clearing of OTC derivatives: Bilateral vs multilateral netting	19	9	6
Kroszner (1999)	Can the Financial Markets privately regulate risk? The development of derivatives clearing houses and recent over-the-counter innovations	16	6	17
Kress (2011)	Default Swaps, Clearinghouses, and Systemic Risk: Why Centralized Counterparties Must Have Access to Central Bank Liquidity	16	3	19
Roe (2013)	Clearinghouse Overconfidence	14	5	9
Griffith (2012)	Governing Systemic Risk: Towards a Governance Structure for Derivatives Clearinghouses	14	4	55
Edwards (1983)	The Clearing Association in Futures Markets: Guarantor and Regulator	11	15	32
Allen (2012)	Derivatives Clearinghouses and Systemic Risk: A Bankruptcy and Dodd-Frank Analysis	11	7	47
Manning and Hughes (2016)	Central counterparties and banks: vive la difference	10	42	24

Articles are ordered on indegree $\geq$ 10 in column 3. Columns 4 (Auth.) and 5 (PR) show the rank number according to the authority centrality measure respectively the PageRank measure

Table 2: Various Influence Measures of CCP Articles

Method of Analysis	Share (% of total)	
Argumentation	57	
Theoretical model	20	
of which with calibration		8
Statistical model	13	
Network model	3	
Case study	7	
Total	100	

Table 3: Methods used in the CCP Literature

tive to discuss the literature in the form of answers to fundamental questions. As it turns out, the questions are easy enough to formulate, although it is necessary to apply careful attention to the details, but the answers are hard to get. In my opinion, the most relevant questions pertaining to CCPs from a financial markets or financial stability point of view are as follows:

To clear centrally or not to clear centrally? Does the introduction of a CCP in a market which was 100 % bilaterally cleared before (this is also called the 'uncleared' space) reduce counterparty credit risk or not? If the answer to the question is 'not to clear centrally' it simply means that that market continues with bilateral clearing. If aggregate counterparty risk is taken as a proxy for systemic risk (as is often done in the CCP literature) this question turns into: do CCPs reduce systemic risk or not? An answer to this question would also provide an answer to whether mandatory central clearing as a response to the Lehman crisis is appropriate or not.

If there is already 1 CCP, what is the optimal number? If the answer of the previous question in a particular case is answered in favour of CCP clearing rather than bilateral clearing, the logical next question is what the optimal number of CCPs is for that case. The analysis then needed here is the effect on aggregate counterparty risk of the introduction of another CCP in a market where there is already a CCP. If it can be shown that the introduction of another CCP in that market is not an improvement, then the optimal number is one. Otherwise, the analysis needs to determine at which number of CCPs the aggregate counterparty risk reaches a minimum.

Is the size of the prefunded waterfall sufficient? The G20 policy of mandatory central clearing of standardized OTC derivative contracts have increased the reliance on CCPs of the financial sector as well as

the broader economy. The relevant question is therefore which extreme events can a CCP withstand using its prefunded resources (also called the prefunded part of the waterfall or 'resilience mode') and how many simultaneous defaults can it handle.

What happens at the end of the waterfall? No matter how extreme the scenarios are on which a CCP has based its waterfall, it is always possible to consider an even more extreme scenario or even a larger number of simultaneous defaults such that the prefunded waterfall proves to be insufficient after all. Which other resources or tools are then available in the rulebook (recovery mode) and what if even that is not sufficient (resolution mode)?

What is the role of Skin-in-the-Game? The fifth and last fundamental question I will consider in this article pertains to the governance of a CCP, more specifically the role of Skin-in-the-Game. In general, failed financial institutions often have experienced governance problems in the run up to their demise. It is therefore important that the right incentives are given to management. In case of CCPs, a lot of attention is paid to Skin-in-the-Game (SITG), the part of a CCPs own capital that is at risk in case of a member default before surviving clearing members suffer a potential loss.

Of course, these five questions do not cover every topic in the literature but the fundamental, main themes are covered. In the remainder of this section I elaborate on these fundamental questions, henceforth in short referred to as F1 through F5, and their answers.

[F1] To Clear Centrally or not to Clear Centrally?

For a proper answer to F1 it is necessary to make it more specific as there are various ways to answer it. The dominant way in the literature is to consider the effect on systemic risk of bilateral clearing versus central clearing. The proxy used for systemic risk is aggregate counterparty risk exposures. The literature can be divided in three approaches. The first approach is the effect on netting efficiency which is the reduction of the amount of aggregate counterparty risk exposure compared to the gross amount (i.e. before any clearing). The second approach is to consider the effect of collateral posted (for initial margin and/or variation margin as the case may be) on aggregate counterparty risk exposures. These two approaches have both qualitative and theoretical model-based articles and are general in nature. The third approach is to study a specific case. Articles in this approach provide more detail and sharper conclusions but are partial by nature.

The first approach on netting efficiency[10] is focused on the issue whether multilateral clearing within a single asset class reduces counterparty risk exposures compared to bilateral clearing across different asset classes.[11] In bilateral positions of OTC derivatives, counterparty risk exposures are usually netted across different asset classes between the two, bilateral, counterparties. In central clearing, exposures are not netted across different asset classes but are multilaterally netted within an asset class. The multilateral netting happens automatically because of the counterparty substitution through novation.[12] This is the point at which the CCP becomes the seller to every buyer and the buyer to every seller as transactions come in, transforming the network of bilateral exposures into a star-like network with the CCP at the centre. It is important to note that the original bilateral transactions do not exist anymore and hence a clearing member has only exposures on the CCP (assuming viability of the CCP). To compare fairly it is needed in both cases to consider the same set of market participants $N = \{2, \ldots n\}$ and the same set of transactions in $K = \{1, \ldots, m\}$ asset classes on a gross basis (before any netting).[13]

The simplest case is the homogeneous, complete network where every counterparty is trading with the $N-1$ other counterparties in all asset classes K which are equally risky, not correlated, and with the amount of trading taken as a random Gaussian variable. Introducing such homogeneous CCP means here that one asset class is cleared by the CCP and the $K-1$ other asset classes remain bilaterally cleared. This is the original case of Duffie and Zhu (2011) and their result is that central clearing reduces counterparty risk exposure if and only if $K < \frac{N^2}{4(N-1)}$. This means that with a few asset classes (e.g. K = 3) central clearing becomes beneficial at a small number of counterparties ($N \geq 11$). However, the authors also show that relaxing the assumption of identical standard deviations of the exposure for all K asset classes changes this outcome dramatically for the case of a CCP clearing only a relatively small asset class. In their numerical example in the context of mandatory clearing after the Lehman crisis, introducing a CCP for CDS (representing circa 10% of the exposure) would require 461 participants to be beneficial.

In Cont and Kokholm (2014), F1 is further examined. They generalize the result of Duffie and Zhu (2011) to a heterogeneous CCP by allowing

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[10]Alternatively, it is possible for equity CCPs to take settlement cost in a broad sense as the key variable of interest, see Koeppl et al. (2012).

[11]It is trivial to prove that multilateral clearing outperforms bilateral clearing on the same set of cyclical gross exposures.

[12]A similar legal device, called open offer, has the same end result in terms of exposures as novation. See Chamorro-Courtland (2010) for a legal analysis of novation and open offer.

[13]I am following the same notation convention in this strand of the CCP literature starting with the seminal article by Duffie and Zhu (2011) followed by Cont and Kokholm (2014); Garratt and Zimmerman (2017) and Hwang and Kim (2020).

non-zero correlations among the exposures of the different asset classes and heterogeneity in exposures. They show that for plausible values of correlation and heterogeneity, the minimum number of market participants for a CCP to be exposure reducing comes out much lower, in the range of 10 - 20. They also show that the above mentioned results of Duffie and Zhu (2011) with regards to CDS clearing are a particular case.

The next contribution in the first approach (Garratt and Zimmerman, 2017) looks at exposures from a network perspective as in reality the assumptions of a homogeneous network do not hold. Lewandowska and Mai (2018) show, based on actual data from three large CCPs, that the distribution of clearing members is indeed heterogeneous, resembling an exponential distribution. As shown in Garratt and Zimmerman (2017), financial networks are likely to grow over time in such a way that they become scale-free or exhibit the core-periphery property. The underlying reason may be that large participants are more likely to attract more trades because of economies of scale or bundling of services. If the N market participants trading K asset classes form a scale-free network, it means that there is a small number of large participants who trade with many other market participants and that there are a large number of small participants who trade with a few other market participants. In a core-periphery network the core is formed by the large market participants which may trade with any other participant while the periphery consists of small market participants that only trade with the core but not with other peripheral participants.

In addition, Garratt and Zimmerman (2017) not only study the mean but also include the variance of the exposures as a potential dimension of answering F1, with lower variance being more desirable. They show for both kind of networks that there are three regions to consider in the (N,K) space: one in which both the mean and variance decrease favouring CCP clearing unambiguously (for small K and relatively large N), one in which both the mean and variance increase, favouring bilateral clearing unambiguously (for large K) and an in-between region with higher mean but lower variance. In the latter region central clearing may be preferred if lower variance of netted exposures is sufficiently considered more important by the regulator.

The second approach (effect of collateral posted) recognizes that the remaining netted exposure needs to be covered by collateral.[14] In other words, whether counterparty risk exposure is measured on a gross (no collateral exchanged) or a net basis (collateral is posted). Before the Lehman crisis it was not customary to exchange initial margin bilaterally for OTC derivative transactions. The regulatory response was therefore not only focused on mandatory central clearing but also reducing the bilateral exposures in the uncleared space by raising collateral requirements for initial margin.

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[14]Aguiar et al. (2016) provide an insightful map of collateral flows in the CCP landscape.

The latter are called uncleared margin rules (UMR). These entail a phased multi-year approach where progressively smaller market participants (measured according to their derivatives portfolio) will be subject to the UMR.

In the literature [15] there has been considerable attention for the effect on collateral use of these two related, regulatory changes. Two early contributions for discussing this are (Pirrong, 2012; Singh, 2013) which both provide a critical assessment of the issue at end 2012/early 2013 as most of the effects of the Dodd-Frank Act still had to come. They conclude that the effect of the increase in collateralisation will turn out negatively in the sense that more assets become encumbered and that market and funding liquidity will suffer. In addition, Singh (2013) provides an alternative policy recommendation of a tax on net derivative liabilities (i.e. after bilateral netting and posting of collateral).

A rather different conclusion is reached in Squire (2014) which takes the view that the Lehman crisis was a liquidity crisis prompted by creditor's lack of confidence. He emphasizes the fact that after a member default a CCP distributes the liquid assets of the defaulter (margin) very quickly (same day or within a few days) to the surviving market participants, avoiding contagion via the liquidity channel. In a bankruptcy estate the cash can be trapped for years (Squire, 2014).

It is also important to realise that cash collateral posted as margin and default fund contribution to the CCP needs to be invested by the CCP. In Holden et al. (2016) this role is discussed and some stylized facts are presented. They discuss the four main approaches: reverse repos, central bank deposit, commercial bank deposit and high-quality asset purchases. It is obvious that the investment of the CCP has to be secure and readily available. This limits the use of commercial bank deposits and even more so if that commercial bank is also a clearing member. In times of financial crisis the repo market may dry up and the flight to quality (government bonds) reduces the possibility of high quality asset purchases.[16] This leaves the central bank deposit as a crucial investment instrument for the CCP, just when it matters most. This well-known argument is clearly advocated in Kress (2011) and was also a lesson learned from the October 1987 crisis (Bernanke, 1990).

In Duffie et al. (2015) we find a model-based contribution to the CCP literature in the second approach. In that article bilateral CDS data of fourteen large dealers is used for calibration of their margin model. They analyse a couple of different scenarios. They conclude that margins for CDS go up considerably compared to pre-crisis levels (from 10% to 17% of net

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[15] Pirrong (2012); Singh (2013); Squire (2014); Duffie et al. (2015); Holden et al. (2016); Dufour et al. (2019); Heath et al. (2016)

[16] See Brunnermeier and Pedersen (2009) which is an influential article on funding liquidity and market liquidity often cited in the CCP literature but itself not a part of that literature (and hence listed in Appendix B).

notional) when the 14 large dealers start to charge initial margin to each other in bilateral clearing but collateral demand goes down to 13% when two CCPs are introduced (US and EU). In case four overlapping CCPs would be introduced collateral demand comes out at 16%. In that sense they complement the earlier work of Duffie and Zhu (2011) that adding CCPs to a market with an existing CCP does not improve the situation. Adding client clearing (i.e. indirect participants that are not directly connected to the CCP but take clearing services from direct participants of the CCP) further reduces collateral demand to 10%. Marshall et al. (2018) is another model-based contribution which concentrates on variation margin payments and concludes that in some cases CCPs do not enhance market stability. However, they also state that their results are limited by the fact that they do not incorporate initial margins in their analysis.

The third approach taken in the literature are specific studies where data from a single event or CCP, country or legal aspect are analysed. I discuss six case studies:

- Dufour et al. (2019) and Boissel et al. (2017) analyse the Italian repo market, trading on MTS, which interestingly has both CCP clearing (in CC&G, clearing circa 80% of total daily notional of EUR 6.1 bn) and bilateral clearing (20%) in the morning of each trading day. They find, based on hourly data from 2010 - 2015 incorporating the European Sovereign Debt Crisis, that in (relatively) normal times repo spreads (against the ECB deposit rate) of trades centrally cleared are lower than those cleared bilaterally. This reflects the lower counterparty risk attained by the CCP. However, during the European Sovereign Debt Crisis, CCP repo spreads rose more than bilateral repo spreads, reversing the situation. This is attributed by the authors to the increase in costs of clearing as margins went up considerably.

- (Loon and Zhong, 2014) conducted an event study where the introduction of mandatory clearing is examined in a CCP (ICE Clear Credit in the US) which cleared CDS contracts voluntarily before (individual names, since Dec 2009). They use daily data before and after the event day when clearing became mandatory. They find evidence that central clearing reduces counterparty risk in comparison to bilateral clearing.

- Hachmeister and Schiereck (2010) examined the introduction of a CCP (Eurex Clearing) for equity trading on order-driven platform XETRA of Deutsche Börse in 2003. The focus in this event study was on the relation between post-trade anonymity which an equity CCP provides and market liquidity. Based on daily data the authors find a significant improvement in market liquidity as spread width declined and order

15

book depth increased.

- Bandi (2009) contains a qualitative study with a careful discussion of benefits and costs of central clearing in the context of India. The author concludes on balance in favour of introducing a CCP for India. There are at present several CCPs operating in India.

- Roe (2013) puts forward forcefully an argument against central clearing using US bankruptcy law analysis. The author and other scholars[17] focus on the effect that the CCP through novation has in practice a preferential creditor status vis-à-vis the defaulter compared to other creditors that are outside the CCP. These outsiders could be potentially worse off given a member default compared to the situation where they would have had a bilateral relationship with that defaulting bank. In the latter case they could setoff the bilateral exposure as allowed by US bankruptcy law increasing the average recovery rate of each creditor. This is termed the 'risk transfer principle' in Roe (2013).

- Biais et al. (2016) study optimal CDS contracts with moral hazard. On the basis of a theoretical model they conclude that a CCP for CDS can reduce counterparty risk if margins lead to better risk-prevention within protection sellers.

On the basis of the three approaches identified in the literature and discussed above, it seems very likely that a general answer to F1 is not possible at all i.e. the answer depends on a number of factors where and when central clearing of one asset class is reducing counterparty credit risk compared to bilateral clearing of multiple asset classes. For a fair quantitative answer one would need 1) a given set of bilateral exposures among a given set of financial institutions, 2) calculate the aggregate counterparty risk allowing netting in the bilateral case over all asset classes but with exchange of bilateral margin, 3) calculate for the CCP case the aggregate counterparty risk by netting multilaterally with full margining but with limited netting within asses classes (and as far as regulatory requirements allow), and 4) compare the two aggregates with the lower number as the superior outcome.

All in all, four factors which have been identified in the literature are shown in Table 4. The qualitative answer to the F1 question 'To Clear Centrally or Not to Clear Centrally' can now be answered as follows: central clearing for a given market or product is preferable from a systemic risk perspective if the number of clearing members is relatively high, or the number of asset classes is relatively low, or the bilateral margin requirements are relatively

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[17]See for example Levitin (2013) and Pirrong (2014) including Pirrong's earlier work published in working papers before 2013.

Factor	Bilateral clearing	Central clearing
Number of participants (N)	relatively low	relatively high
Number of asset classes (K)	relative high	relatively low
Bilateral margining requirements (i.e. uncleared margin rules)	relatively low	relatively high
Outside SIFIs	higher number	lower number

Table 4: Four factors influencing the answer to F1

high, or the number of systemically important financial institutions (SIFIs) that stays outside the CCP is relatively low[18], or a combination of those factors. Note that mandatory central clearing in combination with tougher uncleared margin rules (as is the current G20/FSB policy) is a self-fulfilling case because it induces changes in all four factors that favour central clearing.

[F2] If there is a CCP, what is the optimal number?

Given the nuanced answer to F1, it is obvious that the second fundamental question F2 should be asked only in the context of a particular case, as it does not make sense to answer it in general. F2 refers to the situation where a market or product already has at least one CCP and asks what the optimal number of CCPs is. To be precise, the context here is again systemic risk. This issue has been studied in a number of articles mentioned before and it seems that the literature[19] has reached a clear consensus on the issue: the optimal number of CCPs in a market or asset class is equal to one in case there is already a CCP. The underlying mechanism is the multilateral netting effect on counterparty risk exposures. If a market is cleared by $n > 1$ CCPs, the netting set will be broken up over n CCPs. The n subsets when added up would come out at much higher total counterparty risk credit. For example, Heath et al. (2016) show that going from five CCPs to one CCP reduced the total amount of collateral needed by 34%, based on actual data of 41 banks and five CCPs.

A related issue to answering F2 is interoperability of CCPs which can be seen as a way to consolidate the number of CCPs. Interoperability allows the clearing of transactions between two participants on the same market that are a member of two different CCPs i.e. given two CCPs C_1 and C_2 and two clearing members m_1 and m_2 the following holds: $(m_1 \in C_1, m_1 \notin C_2) \wedge (m_2 \notin C_1, m_2 \in C_2)$. Instead of a merger, interoperability connects two

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[18]This factor is derived from the risk transfer principle as stated in Roe (2013).

[19]See proposition 2 in Duffie and Zhu (2011), Tables 6 and 7 in Cont and Kokholm (2014), proposition 6 in Garratt and Zimmerman (2017), and Tables 7 and 9 in Heath et al. (2016).

or more CCPs which can be interpreted as a move towards the optimum of a single CCP (in terms of systemic risk). The CCP literature consists of seven articles which have been published in a very narrow time span, 2013-2016. This suggests a high academic interest, probably caused by the EU legal provisions in EMIR which came into force in 2012 which themselves are a consequence of the earlier, voluntary European Code of Conduct for Clearing and Settlement of 2006 aimed at increasing competition and transparency.

The evidence in the literature for allowing interoperability is mixed. For CCP clearing OTC derivatives, interoperability is generally not advised because of the operational risk implications (see McPartland and Lewis (2016)). Such interoperable links do indeed not exist worldwide. For CCPs clearing equity (for which interoperable CCPs do exist in Europe) some studies based on theoretical work or network analysis[20] find that the benefits of further multilateral netting across multiple CCPs outweigh the increase in cost of collateral in the case of interoperability ('horizontal links') including the introduction of a meta-CCP, a CCP with other CCPs as members ('vertical links'). One article discusses the potential negative distributional effects for smaller market participants which may end up contributing more margin compared to the case without interoperability (Massa, 2016). Another article investigates the feasibility of a small, local CCP linking to a large, international CCP (Anderson et al., 2013). They find on the basis of a two-country model that in general it is not beneficial to link up to the large CCP, as exposures for the local CCP will increase following establishment of the link, unless the favourable multilateral netting effect for the domestic participants is large enough (decreasing exposures) to compensate.

However, given the answer to F2 of favouring one CCP over multiple CCPs per market, there is at least one other angle that needs to be taken into account, competition. From a competition viewpoint, it may not be optimal to have only one CCP per market. Yet, as far as the author is aware, there are only very few working papers which address F2 from a competition angle. Fontaine et al. (2012, 2013) have done some work on the trade off between competition and counterparty risk in over-the-counter markets but this relates to competition among dealers where a CCP can improve this trade-off if there is wide access of market participants to the CCP. And Zhu (2011) analyses competition in the context of interoperability among equity clearing CCPs. She finds that in this case of a three-CCP-interoperability arrangement, clearing fees decline substantially, yet there is no evidence of a race to the bottom in terms of relaxing risk management.

All in all, to answer F2 it can be concluded that from a systemic risk view the optimal number of CCPs is one in the case where central clearing is ben-

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[20]See Cox et al. (2014); Feng et al. (2014); Feng and Pritsker (2014); Feng and Hu (2015); Mägerle and Nellen (2015); Lewandowska (2015).

eficial anyway. Where multiple CCPs clear the same product (because of multiple trading venues) reducing the number of CCPs should be preferred according to the academic literature mentioned earlier. The alternative of linking multiple equity-clearing CCPs through interoperability links may also lead to lower systemic risk under certain conditions.

[F3] Is the size of the prefunded waterfall sufficient?

The third fundamental question goes to the heart of the CCP's risk management. The complete waterfall consists of a prefunded part and an unfunded part. The former consists of all funds that are directly available to and manageable by the CCP for default losses i.e. all types of margin (such as initial margin, variation margin, liquidity and concentration risk margin, various other margin add-ons and any excess margin posted by clearing members), default fund, skin-in-the-game, and other own financial resources of the CCP. The latter, unfunded part, is defined in the rulebook of the CCP and it gives the CCP a set of recovery tools to cover remaining default losses (see question F4).

The literature relevant for F3 is very broad and diverse but can be divided in a few parts: historical look-back on the 1987 crisis, methodology of setting margins, procyclicality, stress-testing and improvements in the default management process.

1. *Historical perspective* Some historical perspective on the adequacy of the prefunded waterfall is provided by a number of articles containing lessons learned from the 1987 crisis. These papers generally consider that futures CCP's were up to their task although recommending some improvements (Fenn and Kupiec, 1993; Gemmill, 1994; Bates and Craine, 1999; Kroszner, 2000). A recent and authoritative account of the history of setting initial margin, the largest component in the prefunded waterfall, can be found in Heckinger et al. (2017). A historical view focusing on the US is given in Wolkoff and Werner (2011).

2. *Margin-setting methodology* There are two main approaches to margin modelling (Cutinho et al., 2017): fully automated models employing some statistical approach which produce frequent adjustments and are mainly backward-looking and margin models that incorporate expert judgement into the outcome of underlying models which can add a forward-looking capability towards events that are 'known unknowns' (such as general elections or referenda). In practice both approaches may be used by a CCP depending on the products cleared. Most empirical articles in the literature focus on the first approach[21] often with a recommendation to take into account in the margin calculations a specific issue or technique such as wrong-way risks (Brigo

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[21]e.g. Capponi and Cheng (2018); Ghamami (2015)

and Pallavicini, 2014), crowded trades (Menkveld, 2017), default risk among clearing members within the same financial group (Cruz Lopez et al., 2010, 2017) and filtered historical simulation (Barone-Adesi et al., 2018). Two studies focus on initial margin calculations and the impact of time-varying correlations for CDS clearing (Ivanov, 2017; Li and Cheruvelil, 2019). A qualitative but encompassing view on margin setting can be found in Cont (2015).

Given the omnipresent margin model risk, some articles investigate the performance of such models through back testing, e.g. Wong and Ge Pei (2017); Houllier and Murphy (2017).

The aspect of client margins is studied mainly from a legal angle in Canada and the US (Chamorro-Courtland, 2016a,b, 2017) where the issue is the protection of one client against the default of another ('fellow client risk').

3. *Procyclicality* An important aspect, also from a systemic risk perspective, is the issue of procyclicality of initial margin setting.[22] Procyclicality means a disproportionate increase in initial margin required by the CCP from clearing members in volatile times potentially exacerbating liquidity and funding problems they may have because of the crisis.[23] Generally speaking, a CCP has as anti-procyclicality tools: erodible margin buffers consumable under stress, margin floors and outright margin relief. It seems there is no consensus with some scholars finding evidence for procyclical margin setting (Abruzzo and Park, 2016) and some do not (Lewandowska and Glaser, 2017).

4. *stress testing* In (Yue et al., 2017; Paddrik et al., 2020; Murphy and Macdonald, 2016; Wong and Ge Pei, 2017; Anderson et al., 2019) the importance of stress-testing is discussed, both from an individual CCP perspective as well from the view point of stress-testing multiple CCPs at the same time ('regulatory stress testing').

5. *Default management procedures* In answering F3, one could also envisage to minimize the loss given the default of a clearing member, as an alternative to increase margin, as this would increase the probability of sufficiency of resources. This means improving the default management procedure: hedging, auctioning and closing out the defaulter's

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[22]See e.g. (Abruzzo and Park, 2016; Lewandowska and Glaser, 2017; Raykov, 2018a; Maruyama and Cerezetti, 2019)

[23]Such increases in initial margin requirement could also come from increases in collateral haircuts. Variation margins will also increase in volatile times but are not considered as procyclical as they are marked-to-market and zero-sum for the market as the CCP acts as a pass-through. Also note that for a proper measurement of procyclicality one should consider the same portfolio of each clearing member before and after the change in the margin model as the amount of trading or the direction of the portfolios are likely to change as well.

portfolio. Chamorro-Courtland (2010) studies the legal concepts of novation and open offer and recommends to CCPs to precisely specify in their rulebooks the moment when novation takes place to reduce legal risk. Cerezetti et al. (2019b) finds that hedging costs vary more than commonly thought and there are multiple ways of attaining the minimum cost. Vicente et al. (2015) offer a statistical model for a close out strategy for multi asset class CCPs. Finally, Vicente et al. (2017) show on the basis of a calibrated, theoretical model how to hedge better, so losses can be reduced.

From discussing this part of the literature it becomes clear that F3 is not analytically answerable for all CCPs for all times. As far as the author is aware, all academic literature on the adequacy of resources is CCP specific. What is needed for a real answer is a benchmark. How this benchmark should look like is an open question.[24] Margin setting in practice depends on many factors such as margin models with and without expert judgement, model risk, liquidity of the portfolio in stressed conditions, credit quality of clearing members, which extreme scenarios to include for sizing the default fund, the proper length of the look back period and the margin period of risk, etc.

So far only a normative, minimum answer can be provided by taking the perspective of the international standard setting bodies CPMI-IOSCO (2012). In their principle-based approach, the requirement for sizing the pre-funded waterfall is to cover at least the loss on the portfolio of the largest (two) defaulting clearing member(s) in extreme but plausible market circumstances. Let $D(D > 0)$ denote the number of simultaneous defaulting largest clearing member groups (also known as cover D). Simultaneous means here on the same day or until replenishment of the first default has been completed. Principle 4 on Credit Risk of the PFMI states that CCPs should size their prefunded waterfall to $D = 1$ and for CCPs clearing more-complex derivatives or internationally active CCPs, $D = 2$. According to EMIR, a CCP in the EU must be able to withstand $D = 2$. D is formulated in terms of financial groups containing one or more clearing members rather than in terms of the number of clearing members. Hence, correlated intra-group credit risk is taken into account in sizing the prefunded waterfall. So cover D may imply that the default of more than D clearing members is covered. The standard is also normative in the sense that the regulator has to approve of the suit of extreme-but-plausible stress scenarios. The severity of the stress scenarios is therefore also a major determinant of the size of the default fund and hence the prefunded waterfall. Note that the CCP is not meant to prevent the default of the D largest members (or a few more than D smaller clearing members), however it is designed to minimize losses

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[24]However, a useful contribution in this context is Murphy and Nahai-Williamson (2014).

for its members as a consequence of those defaults and in so doing prevent any subsequent defaults of its members.

The matter of simultaneity is particularly relevant in the context of extreme but plausible market circumstances. Because normally speaking i.e. assuming the CCP is compliant with all regulations and risk management is properly executed, a CCP with cover $D = 2$ can only get into major problems itself, in the sense of exhausting its prefunded waterfall, if at least the largest two clearing members default on the same day. Although this has never happened to date, it is important to include such extremes into the sizing of the waterfall as these market circumstances could be precisely the common factor causing such simultaneous defaults.

Another way for a CCP to get into difficulties are the so-called non-default losses. These are financial losses of the CCP that are unrelated to the default of a clearing member. They are mostly caused by the manifestation of legal, operational or cyber risks. Compared to the systemic risk of 10^{12} (EUR or USD), this financial risk is a few orders of magnitude lower but so are the buffers for non-default losses. This is rarely studied but see Lewis and McPartland (2017) where the authors recommend increasing the financial buffer for such losses, which is a financial buffer separate from the prefunded waterfall.

All in all, to answer F3 there are three answers. The first answer is from the literature above which, for lack of a benchmark, provides a relative answer by recommending improvements in the prefunded waterfall which all point toward, or imply, higher financial resources. The second answer provides a normative benchmark (cover D) which has been toughened in response to the Lehman crisis by an increase in D from one to two for the most systemically important CCPs. So, as long as a specific CCP adheres to the cover D (specified by its regulator or by law) financial resources are adequate in that normative sense.

The third answer is a retrospective one: financial resources have been adequate as long as no CCP has gone into resolution after a multiple member default. This last and unsatisfactory answer leads quite naturally to our next fundamental question, F4.

[F4] What happens at the end of the prefunded waterfall?

With the ongoing uptake in cleared volumes of OTC trading in the last decades, accelerated by the central clearing mandate (see e.g. OTC interest rate derivatives volumes in Figure 2), F4 asks about the ultimate robustness of CCPs in the most extreme circumstances. In line with the third answer to F3 given above it is therefore appropriate to look at the historical evidence of CCPs under stress.

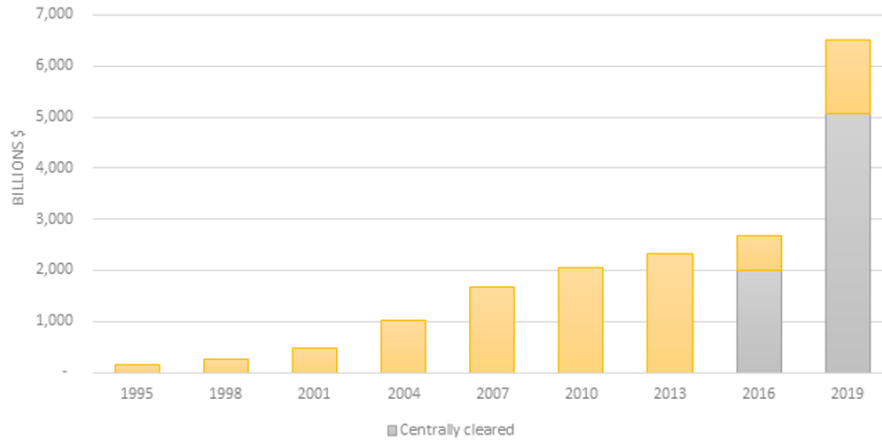As the prefunded waterfall is defined to handle at least D clearing mem-

Figure 2: 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).

ber defaults in extreme but plausible market circumstances, it is natural to define CCP stress as the point at which the prefunded waterfall is exhausted while there are still remaining default losses. There have been four historical cases of CCP stress thus defined and these are presented in Table 5. In the literature some other cases are mentioned but these did not end up as CCP stress i.e. the funds available at the CCP where eventually sufficient to cover the member default losses. Such cases are CME and OCC in the US during the 1987 Crash (Bernanke, 1990; Pirrong, 2014) and BM&F in Brazil during the large devaluation of the *real* after entering a floating exchange rate in January 1999 (Martins, 2020). Note that the successful handling of a clearing member default (the main purpose of a CCP) does not constitute a CCP in stress. For example, the London CCP LCH Ltd has managed eight such defaults since 1990.

In Table 5, the first two cases involved CCPs that were not systemically important as they served some specific commodity markets (in sugar and palm oil) and the solution was liquidation eventually (Bignon and Vuillemey, 2020; Hills et al., 1999). The last two cases pertain to systemically important CCPs. The Hong Kong Futures Exchange case was directly related to the largest US stock market crash to date (October 1987) which caused a trade suspension in Hong Kong 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 a cash call or voluntary assessment. Once trading and clearing was resumed it turned out that the rescue package was sufficient (Cox, 2015b). The ICCH New Zealand case in 1989 involved fraud and two very large positions of which one position involved 71% of the short side of the open interest. Because of the large

23

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).

So, the historical evidence shows that no systemically important CCP has failed to date, however we had two near-misses at the end of the 1980s where the two CCPs recovered using what we now would call recovery tools (voluntary cash call and partial tear up). It is also important to acknowledge the limited relevance of the last two cases for today's CCP risk management. Internationally agreed minimum standards for CCPs have only been established by central banks and securities regulators in 2004 (CPSS-IOSCO, 2004), fifteen years after those two events. In addition, 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 (CPMI-IOSCO, 2012). Not only the earlier mentioned cover 1/2 standard for credit risk and there is also a cover 1/2 standard for liquidity risk but also more rigorous (reverse) stress-testing requirements have been issued by the international standard setters. In the EU (but also in other jurisdictions) these international standards have been put into law so these are legally binding for CCPs.

Notwithstanding the above relatively favourable historical evidence, it is prudent to prepare for the unprecedented especially since the long-term effects of the central clearing mandate and the uncleared margin rules cannot be known yet. Lots of scholars have recognized this point (see below) and further guidance from the international standard setters as well as legislators has been published or is underway. This part of the literature which try to answer F4 is dealing with the topic of CCP Recovery and Resolution.

CCP recovery can be defined as the potential actions a CCP may undertake after exhaustion of its prefunded waterfall to handle the member default(s) as defined in its rulebook (so-called 'recovery tools') and as such pre-agreed with clearing members. The international standards (see Principle 3 on comprehensive risk management in CPMI-IOSCO (2012)) require that a recovery plan of a CCP should be comprehensive and effective i.e. be able to allocate all default losses that remain after full application of the prefunded waterfall. The three main elements of recovery are: 1) restore the matched book after a default (as the CCP still has part or all of the portfolios of the defaulter(s); 2) allocate remaining default losses with in general three possible candidates for absorbing those losses: the CCP, the surviving clearing members and the taxpayer; and 3) cover liquidity shortfalls that may arise;

This part of the literature is mostly of a qualitative nature and is largely focussed on policy recommendations.[25]. Raykov (2018b) is the exception to

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[25]Although many articles mention recovery and resolution in passing, the following

CCP name (country) and contracts involved	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, 2015b)	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 5: Cases of Severe CCP Stress

the rule where a theoretical, partial equilibrium, model is used.

The policy recommendations are concentrated on two of the three main elements for recovery: tools for allocating remaining losses and how to cover for liquidity shortfalls.

Firstly, some scholars recommend the use of the recovery tool Variation Margin Gains Haircutting (VMGH) [26] stressing the advantage that in theory it can always cover the remaining current losses and in that sense is a comprehensive recovery tool. Others point out that VMGH might expose clearing members with a hedged position outside the CCP, to losses on their out-of-the-money positions which would otherwise be a hedged position. This could produce unforeseen and random losses for clearing members.

Secondly, the cash call is advocated (also called 'assessment right') as a recovery tool of a CCP. This instrument consists of one or more calls by the CCP for a contribution from each surviving member equal to their default fund contribution just prior to the default. The advantage, as argued in some articles, is that losses are spread out over all clearing members in proportion to the risk that they pose to the CCP as the default fund contribution is risk-based. The main discussion here is whether the cash calls are capped or uncapped. In the former case the CCP can only call the number of times as specified in the rulebook while in the latter the tool becomes comprehensive from the perspective of the CCP as the CCP could call as many times as needed to fully cover the loss. However, the drawback is that for clearing members it becomes very hard or impossible to calculate their exposure to the CCP. This is problematic from a risk management and prudential banking perspective as a clearing member should be able to control its counterparty credit exposures.[27]

Thirdly, Initial Margin Haircutting (IMH) is discussed as a recovery tool which would mean that the initial margin of surviving clearing members would be used to cover any remaining loss caused by the defaulter(s). The advantage would be that a large financial resource becomes available which is also prefunded so there is no performance risk. However, most scholars do not recommend this tool as this jeopardizes a cornerstone of central clearing: initial margin posted by clearing member CM_i can solely be used by the CCP for the default of CM_i. If IMH would be allowed [28] then clearing members should consider their whole IM contribution as potentially risky

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articles have CCP recovery and resolution as there main topic (in chronological order): Culp (2010); Chamorro-Courtland (2012b); Singh (2015); Wendt (2015); Cont (2015); Lubben (2015); France and Kahn (2016); Lubben (2017); Plata (2017); Huhtaniemi and Peters (2017); Priem (2018); Singh and Turing (2018); Cox and Steigerwald (2018); Turing (2019); Henkel (2020); Bignon and Vuillemey (2020).

[26] Out-of-the-money positions (negative mark-to-market) pay variation margin to in-the-money positions (positive mark-to-market) to equalize the current profits and losses since the previous day (assuming a daily process)

[27] See Arnsdorf (2012) and Armenti and Crépey (2017).

[28] For example, in the EU it is forbidden by law.

and it would attract a capital charge.

Fourthly, to cover for liquidity shortfalls in these extreme circumstances several scholars have argued in favour of CCPs having access to the central bank (see among others Kress (2011); Baker (2013); Wendt (2015) and the earlier discussion on e 14). The main argument is that against the background of - most likely - multiple defaults which got the CCP into exhausting its waterfall, it may be difficult to obtain the liquidity needed for allocating the remaining loss, precisely in such extreme market circumstances.

The last part in answering F4 is CCP Resolution which can be defined as the intervention by a designated CCP resolution authority where the Board of the CCP needs to hand over part or all of the control of the CCP to that public authority. The aim of that intervention is *"...the pursuit of financial stability and ensure the continuity of critical CCP functions in all jurisdictions where those functions are critical and without exposing taxpayers to risk of loss ..."* (see Financial Stability Board (2017)). So, resolution discusses the situation where recovery of the CCP seems unlikely or where the outcome of the recovery is undesirable from a financial stability perspective. The literature on CCP Resolution is of a qualitative nature which is understandable as CCP resolution is still *terra incognita* (Cox, 2015a). Some scholars argue for a return to the bilateral clearing world (Singh and Turing, 2018; Turing, 2019) following CCP resolution, favour nationalisation of a CCP upon its complete failure (Lubben, 2015), or call for extra financial resources when in resolution, either prefunded (but then we are back to question F3) or unfunded.

All in all, it is no surprise that the literature on CCP recovery and resolution is of a qualitative nature. Hence, the academic answer to F4 consists of policy recommendations where generally variation margin gains haircutting and cash calls are preferred over initial margin haircutting. In addition, having the possibility of obtaining liquidity from the central bank on the basis of eligible collateral can facilitate a CCP's recovery process.

[F5] What is the role of Skin-in-the-Game?

The academic literature has focused on incentives for the CCP to pursue the public goal of financial stability rather than the private goal of profit maximisation. In this context a debate with a particularly high profile is the so-called skin-in-the-game (SITG). This relates to a part or the whole of a CCP's own capital which is incorporated in the waterfall. By definition skin-in-the-game forms part of the prefunded waterfall and as such can absorb a loss which exceeds the full defaulter's contribution. In general, SITG can be junior to the survivor's part of the default fund or senior to that, or both (i.e. two layers of SITG). In the first case the CCP suffers a loss of its own resources prior to any surviving clearing member while

in the second case the loss is only incurred by the CCP after the default fund is exhausted. The reason for not discussing SITG under F3, but here under F5, is that in practice it cannot quantitatively be considered as a meaningful loss-absorbing component given its small size.[29] This does not mean that SITG lacks a useful function. On the contrary, it is considered by many authors to provide a powerful incentive to the Board and senior management to take risk management seriously (Cox and Steigerwald, 2016; Rec, 2019a; Albuquerque and Perkins, 2016; Cerezetti et al., 2019a; Lewis and McPartland, 2018; Cox, 2015a; McLaughlin, 2018), especially a prudent setting of initial margin as that protects consumption of the SITG in the case of a member default. In general, the recommendation in the literature is to increase skin-in-the-game such that it is material in terms of a CCP's capital. However, this is nuanced by Carter and Garner (2016) which point at the diminished incentives for clearing members to fulfil their role in the default management process properly if SITG becomes too large. Furthermore, Cox (2015a) argues and (Murphy, 2017; McLaughlin, 2018) show on the basis of a theoretical model that with higher SITG the clearing fees are likely to increase, which would increase the cost of clearing across the financial sector. Hence, there is a trade-off between higher SITG and clearing costs.

Another part of the governance literature concentrates on the role of the clearing members. The relevant articles (Cox and Steigerwald, 2016; Saguato, 2017) argue for a remutualization of CCP's ownership i.e. to return to the governance model where the users of the CCP are also the owners of the CCP (this is called mutualized governance)[30] Finally, some scholars argue that the best way to incentivize CCP's management is to include independent directors in the Board of the CCP or a separate Supervisory Board (Greenberger, 2012; Griffith, 2012; Johnson, 2013).

All in all, Skin-in-the-game (F5) is important for providing to a CCP the right incentive to pursue a prudent risk management strategy which aligns with the public policy preference that systemically important CCPs should continue to operate in even the most extreme scenarios. SITG is not meaningful in terms of loss absorbing capacity. However, there is a trade-off between increasing the level of SITG and the cost of clearing.

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[29]For example in the EU, skin-in-the-game accounts for only 0.2% of the average prefunded waterfall of the 16 CCPs considered in the 3rd EU-wide stress test conducted by ESMA, published in July 2020 on its website.

[30]See Cox and Steigerwald (2016) for an overview of the various governance models that can be found worldwide.

5 Conclusions and topics fur further research

In this article, I have performed a literature review on central counterparties (CCPs) in three ways: a simple chronological review, a citation graph analysis (see Figure 1), and on the basis of a Q&A consisting of five easy-but-fundamental questions with, as it turned out, hard answers. The precise scope of the review is limited to articles published in peer-reviewed, academic journals in the English language with at least a quarter of the text devoted to CCPs. The search yields 162 such articles (until the cut-off date of April 2020).

CCPs, i.e. clearing houses with a settlement guarantee function, have been around for more than a century, with a gradual increase of clearing members and extension of the range of products cleared over time. However, the literature on CCPs is booming with the bulk published only in the last five years. The growing interest can be attributed to the international regulatory response of the Lehman crisis (2008) which prompted a reform of the global over-the-counter (OTC) derivative markets by making clearing via the CCP mandatory for standardized OTC derivatives. Although many other regulatory changes have been implemented, the clearing mandate (of in particular credit default swaps) has become the symbol of response to the Great Financial Crisis (GFC). This spurs a range of critical academic papers questioning whether this is the right response to the GFC or if it is better to leave those markets bilaterally cleared ('uncleared'). A natural follow up is a stream of papers investigating whether CCPs are up to the task, so imposed by the G20. The debate is ongoing and the default of a clearing member at Nasdaq Clearing (Swedish CCP) which consumed not only the defaulter's resources but also hit the other clearing member's default fund contributions on 11 September 2018, served as a conspicuous reminder, even though it concerned the idiosyncratic case of a natural person acting as a clearing member and the loss was relatively small (EUR 115 million). This prompted Nasdaq Clearing to introduce some extra but temporary skin-in-the-game (SITG) in their waterfall. The incentives of SITG have also induced a body of CCP literature.

The fundamental questions F1 through F5 have been chosen to reflect the main parts of the literature. For ease of reference, they are summarized in Table 6 with some loss of nuance in the abbreviated answers (the full answers are in section 4).

The answers to the fundamental questions reveal that a lot of research on CCPs is of a qualitative nature or based on stylized, theoretical models that are calibrated on high-level data. Only a few articles use granular data. On the basis of the review in this article, I propose the following synthesis of the academic knowledge on CCPs:

- It is an empirical matter whether heterogeneous CCPs reduce aggre-

F1 To Clear Centrally or not to Clear Centrally? From a systemic risk perspective, central clearing is preferable to bilateral clearing in cases where the number of clearing members is relatively high, the number of asset classes relatively low, bilateral margin requirements relatively high, or the number of systemically important financial institutions that stay outside the CCP is relatively low or a combination of those factors (see Table 4).

F2 If there is a CCP, what is the optimal number of CCPs? From a systemic risk view, the optimal number of CCPs is one in the case where F1 has been answered in favour of central clearing.

F3 Is the size of the prefunded waterfall sufficient? A three-pronged answer: 1) The literature does not provide a quantitative answer but a relative qualitative answer by recommending higher financial resources; 2) the normative answer is at least the simultaneous default of the largest or two largest clearing member groups (in terms of exposure in extreme but plausible market circumstances; 3) the retrospective answer is that financial resources have been adequate to date for systemically-important CCPs except for two cases in the 1980s (but these were recovered eventually).

F4 What happens at the end of the prefunded waterfall? CCP Resolution being *terra incognita* the answer in the literature is of qualitative nature consisting of policy recommendations where generally initial margin haircutting is discarded and central bank access for CCPs is prescribed.

F5 What is the role of Skin-in-the-Game? Skin-in-the-game is important for providing to a CCP the right incentive to pursue a prudent risk management strategy but not meaningful in terms of loss absorbing capacity. There is a trade-off between Skin-in-the-Game and the cost of clearing.

Table 6: Five Fundamental Questions and Shortened Answers

gate counterparty exposures in comparison to the bilateral clearing case. In other words, it is not possible to say *in general* that CCPs increase or decrease such exposures. This needs to be established from time to time, on a case by case basis;

- Mandatory central clearing in combination with sharpened uncleared margin rules as per the current G20/FSB policy is a self-fulfilling policy in the sense that once the market has moved to central clearing, it becomes optimal to keep it that way in comparison with bilateral clearing as all four influencing factors change in favour of central clearing (Table 4);

- In case there is already central clearing in a financial market, it is optimal to have only one CCP from a systemic risk viewpoint;

- The financial adequacy of the prefunded waterfall is most likely a normative matter ('cover D') as an empirical benchmark seems to be missing and it is hard to construct. In assessing the adequacy, it is also important to take the range of extreme scenarios into account.

Following the synthesis, I propose some topics for further research, both qualitative and quantitative topics, with an emphasis on using more granular data or - when not feasible - to use agent-based modelling based on data that is available:

1. It would be interesting to analyse the reverse of F1, as now there are CCPs clearing asset classes that fall under the mandatory clearing mandate. The research question could be under which assumptions regarding the clearing member distribution, multi-asset netting, and uncleared margin rules, a hypothetical return to bilateral clearing would lead to lower (if any) aggregate counterparty exposure taking the effect on collateral into account and by how much. It would require granular daily data on (anonymised) clearing member and client portfolio data and margin/default fund contributions of a single CCP. This work could then provide a quantitative answer to F1 for a number of specific CCPs and products over a particular time frame. This could provide an ex post review of this international policy;

2. On the basis of the same data mentioned under 1., it could be worthwhile to study the impact of clearing fragmentation i.e. what would be the effect on liquidity if the business line of an existing CCP would also be cleared by another CCP, breaking up the existing netting set. The sign of the effect would be negative according to the answer on F2 (as it would add a second CCP to the optimal number of one) but obviously the interesting part would be the quantitative estimate of that effect in certain specific cases, so the cost of fragmentation becomes transparent;

3. The competition angle is largely missing in the CCP literature regarding the answer to F2 (see discussion on page 18). An explanation could be that the systemic risk argument outweighs the competition argument as the proof of the pudding for CCPs is in times of financial crises rather than in fine weather. This opens up the interesting issue which paradigm actually should be used to analyse F2: decision-making under fundamental uncertainty or classical cost-benefit analysis;[31]

4. One potential scenario for a major financial crisis that has not happened yet, is the impact on global financial stability of more than two globally systemically important banks going into default simultaneously where those banks are a clearing member of multiple CCPs. This would require granular data of multiple CCPs which in turn needs to be non-anonymised in order to construct the correct network of multiple CCP memberships. In the absence of such non-anonymous data, one could consider agent-based modelling with multiple CCPs, multiple assets and heterogeneous agents (clearing members and clients) with appropriate simplifying assumptions. A further challenge would be to gauge the effect on that scenario by allowing for an adaptive response of agents to the multiple defaults which could shed some light on hidden paths of contagion in the global financial network.[32] This could be helpful in the search for a quantitative answer of F3;

5. The issue of a CCP's coverage of non-default losses is a neglected area in the CCP literature (see page 22). So far, little academic work has been done on the likelihood and magnitude of such losses for a CCP and the amount of capital needed to cover non-default losses risks. This naturally extends the discussion on the amount of capital including skin-in-the-game;

6. At present, the academic literature is relatively silent on the issue of the boundary between CCP recovery and CCP resolution: given the comprehensiveness of the CCP's Rulebook (see F4 in section 4) it would be useful to analyse the timing of a potential intervention of the CCP Resolution Authority and the optimal deviation from the CCP's Rulebook in a variety of scenarios.

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[31]See e.g. McNamara (2014) for arguing in favour of the former.

[32]For a related problem i.e. application of granular TARGET2 data to liquidity risk contagion with and without response of other participants to an initial liquidity coverage ratio shock, see Heuver and Berndsen (2020).

Appendix A The CCP Literature

In this appendix all 162 articles identified as falling within scope of the review (see section 1) are listed below in chronological order. The full reference can be found in the bibliography.

1983 - 2010
Edwards (1983); Bernanke (1990); Fenn and Kupiec (1993); Gemmill (1994); Dale (1998); Bates and Craine (1999); Kroszner (1999, 2000); Bliss and Steigerwald (2006); Bandi (2009); Glass (2009); Culp (2010); Hachmeister and Schiereck (2010); Chander and Costa (2010); Chamorro-Courtland (2010); McBride (2010); Rausser et al. (2010); Cruz Lopez et al. (2010);

2011 - 2015
Duffie and Zhu (2011); Kress (2011); Wolkoff and Werner (2011); Braithwaite (2011); Galbiati and Soramaki (2012); Hull (2012); Griffith (2012); Greenberger (2012); Allen (2012); Chamorro-Courtland (2012b); Pirrong (2012); Milne (2012); Biais et al. (2012); Arnsdorf (2012); Koeppl et al. (2012); Murphy (2012); Koeppl and Monnet (2013); Singh (2013); Anderson et al. (2013); Slive et al. (2013); Dømler (2013); Yadav (2013); Johnson (2013); Nichol (2013); Corcoran (2013); Roe (2013); Jones and Perignon (2013); Levitin (2013); Baker (2013); Hsiao (2013); Cox et al. (2014); Pirrong (2014); Stephens and Thompson (2014); Feng et al. (2014); Cont and Kokholm (2014); Feng and Pritsker (2014); Brigo and Pallavicini (2014); Turnbull (2014); McNamara (2014); Lin and Surti (2014); Hsiao (2014); Chang (2014); Loon and Zhong (2014); Song et al. (2014); Yadav (2014); Squire (2014); Singh (2015); Cox (2015a); Wendt (2015); Mägerle and Nellen (2015); Cox (2015b); Vicente et al. (2015); Duffie et al. (2015); Lewandowska (2015); Feng and Hu (2015); Lubben (2015); Ghamami (2015); Cont (2015);

2016 - 2020
Chamorro-Courtland (2016a); Cont and Minca (2016); Manning and Hughes (2016); Cox and Steigerwald (2016); Carter and Garner (2016); Albuquerque and Perkins (2016); Budding et al. (2016); Murphy and Macdonald (2016); McPartland and Lewis (2016); Holden et al. (2016); Aguiar et al. (2016); Abruzzo and Park (2016); De Genaro (2016); Glasserman et al. (2016); France and Kahn (2016); Heath et al. (2016); Mcvea (2016); Massa (2016); Chamorro-Courtland (2016b); Amini et al. (2016); Berlinger et al. (2016); Biais et al. (2016); Braithwaite (2016); Yadav and Turing (2016); Guseva (2016); Baker (2016); Lewandowska and Glaser (2017); Yue et al. (2017); Murphy (2017); Heckinger et al. (2017); Ivanov (2017); Wong and Ge Pei (2017); Houllier and Murphy (2017); Benos et al. (2017); Cutinho et al. (2017); Vicente et al. (2017); Lewis and McPartland (2017); Huhtaniemi and Peters (2017); Boissel et al. (2017); Cruz Lopez et al. (2017); Ghamami and Glasserman (2017); Deng (2017); Menkveld (2017); Lubben (2017); Chamorro-Courtland (2017); Garratt and Zimmerman (2017); Armenti and Crépey (2017); Plata (2017); Saguato (2017); Hayakawa (2017); Marshall et al. (2018); Raykov (2018b); Singh and Turing (2018); Baklanova et al. (2018); McLaughlin (2018); Fiedor et al. (2018); Lewandowska and Mai (2018); Raykov (2018a); Cox and Steigerwald (2018); Lewis and McPartland (2018); Tompaidis (2018); Barone-Adesi et al. (2018); Poce et al. (2018); Kozinska (2018); Capponi and Cheng (2018); Silva et al. (2018);

Cerezetti et al. (2019a); Maruyama and Cerezetti (2019); Andersen and Dickinson (2019); Anderson et al. (2019); Turing (2019); Li and Cheruvelil (2019); Dömötör and Váradi (2019); Cerezetti et al. (2019b); Genito (2019); Dufour et al. (2019); Priem (2018); Chamorro-Courtland (2019); Rec (2019a); Baker (2019); Rec (2019b); Henkel (2020); Paddrik et al. (2020); Hwang and Kim (2020); Bignon and Vuillemey (2020); Albanese et al. (2020);

Appendix B Other Relevant Papers

In this appendix, some important papers are listed that, strictly speaking, are out of scope as defined in section 1. Nevertheless they are either relevant for understanding the CCP literature or 'just outside' of the scope. As such, the latter category provide an overview of the 'false negatives' of my scope definition. The papers are listed in alphabetical order. The full reference can be found in the bibliography.

Acharya and Bisin (2014)
Brunnermeier and Pedersen (2009)
Heckinger et al. (2016)
Heller and Vause (2011)
Hills et al. (1999)
McPartland and Lewis (2017)
Murphy and Nahai-Williamson (2014)
Pirrong (2009)
Pirrong (2011)
Stulz (2010)

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