Analysis of Central Clearing Interdependencies

9 August 2018

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Definitions

Many of the following terms are derived from the CPMI-IOSCO Public quantitative disclosure standards.[1]

Clearing service	A set of products cleared by a CCP that share resources from the same default fund. Some CCPs maintain a single default fund in which case there is no distinction between a CCP and a clearing service.
Initial margin	Includes 'base-line' initial margin, 'add-ons', and 'retained marked-to-market/variation margin' (where relevant), irrespective of whether the CCP offers gross omnibus client accounts, net omnibus client accounts or individual segregated client accounts.
Intraday liquidity / settlement line providers	Includes mandatory rules-based lines, the auto-collateralisation on flow function provided by some central securities depositories (CSDs), international central securities depositories (ICSDs) and in Target2 Securities, and liquidity provision from third-parties to the CCP. The use of the CCP's own liquid resources is excluded.
Prefunded default fund	The amount of collateral posted by each clearing member in order to meet its default fund contribution requirement, excluding the amount of Initial Margin.
Prefunded financial resources	The sum of prefunded default fund and initial margin.
Third-party investment managers	Third-party investment managers for the CCP's total investment portfolio, including investments of cash and/or other collateral as well as the CCP's own cash resources.

[1] CPMI-IOSCO *Public quantitative disclosure standards*, February 2015.

Introduction

In 2015 the Chairs of the FSB Standing Committee on Supervisory and Regulatory Cooperation (FSB SRC), the FSB Resolution Steering Group (FSB ReSG), the Committee on Payments and Market Infrastructure (CPMI), the International Organisation of Securities Commissions (IOSCO), and the Basel Committee on Banking Supervision (BCBS) (together "the Committees") constituted an ad hoc study group (the Study Group on Central Clearing Interdependencies (SGCCI)) to identify, quantify and analyse interdependencies between central counterparties (CCPs) and major clearing members and financial service providers, and the resulting systemic implications.

Given the rise of central clearing, in particular following post crisis reforms to derivatives markets, the Committees identified the need to better understand the interdependencies in central clearing. In many cases, CCP membership is drawn from a common group of large banks, many of which are also important providers of financial services to CCPs (such as liquidity provision, lines of credit, custodianship, settlement and cash management). These interdependencies are often cross-border.

To further understand and quantify the interconnections between CCPs and the rest of the financial system, the Committees launched work in 2016 to globally map interconnections between CCPs, clearing members and other financial institutions that provide financial services which are critical to the operations and viability of CCPs. Data was collected from 26 CCPs, across 15 jurisdictions in North America, South America, Europe and Asia-Pacific. This effort was aimed at providing a comprehensive overview of the connections between different aspects of the central clearing system while focusing, where possible, on the types of connections that could lead to potential contagion.

After reviewing the findings from the 2016 data collection, which were published in July 2017,[2] the Committees agreed to conduct another but more streamlined data collection to assess whether the findings from the 2016 analysis were stable over time. To enable comparability, the 2017 exercise collected data from the same group of 26 CCPs (see Annex A for a list of CCPs that participated in the 2016 and 2017 data collections).

In preparation for the second data collection, the study group held a roundtable with representatives from participating CCPs, clearing members, custodians and other financial service providers, as well as academics to solicit their perspectives on: (i) the findings presented in the July 2017 report, (ii) ways to improve the analysis, (iii) how to streamline the data collection template to reduce the burden on reporting CCPs while meeting the objective of the exercise, and (iv) whether they had any concerns over the data collection exercise. Industry representatives and academics generally agreed that the analysis confirmed what was largely intuited, while enabling market participants to visualise the extent and size of the interconnections in central clearing. A few roundtable participants suggested that the analysis could be improved by presenting more quantitative data when discussing the impact of default, rather than looking solely at the number of financial institutions impacted. As a result, the box plots used in the July 2017 report were replaced with scatter plot diagrams. And finally,

[2] BCBS, CPMI, FSB, IOSCO, *Analysis of Central Clearing Interdependencies*, 5 July 2017 (at https://www.bis.org/cpmi/publ/d164.htm; http://www.fsb.org/wp-content/uploads/P050717-2.pdf; http://www.iosco.org/library/pubdocs/pdf/IOSCOPD570.pdf).

discussions from the roundtable resulted in the following key changes to the 2017 data template:

- Changing the reference date for the data collection to 31 October 2017 from 30 September 2016. This was to avoid using a quarter-end date, which aligns with the CPMI and IOSCO public quantitative disclosure standards for CCPs,[3] and further reducing the potential to reverse engineer the identity of a CCP or financial service provider.
- Removing the spreadsheet tab that collects information related to the management of a clearing member default.
- Eliminating the columns that collect data on the currency denomination (e.g. in euro, dollars, yen, local currency) for intraday liquidity/settlement lines, credit facilities, cash investments and non-cash investments.
- Streamlining the collection of data for the type of default fund collateral to include cash and non-cash collateral, rather than type of government bonds.

The 2016 and 2017 studies of central clearing interdependencies are intended to inform the ongoing policy work on CCP resilience, recovery planning and resolution, and possibly provide useful inputs for designing a supervisory stress testing framework. In particular, these efforts are intended to:

- quantify, at a high level, the type and nature of connections between CCPs, their members, and other critical services providers such as custodians and investment counterparties;
- map relationships in central clearing at a global level;
- identify where risks may concentrate in the CCP network; and
- explore whether major providers of financial services to CCPs are also the most interconnected clearing members.

The remainder of this report is organised as follows. Section 1 summarises the key findings of the report. Section 2 provides an overview of the data used in the report. Sections 3 through 6 describe the interconnections between CCPs, their clearing members and several types of critical service providers. Section 7 concludes and provides some considerations for future work.

[3] CPMI-IOSCO, February 2015.

1. Key findings

This comprehensive data collection from 26 CCPs, across 15 jurisdictions in North America, South America, Europe and Asia-Pacific permits a global analysis of interdependencies in central clearing. The analysis addresses CCPs, their members and other financial institutions that are linked to CCPs such as custodians, settlement banks, credit and liquidity providers and investment counterparties. These data provide a unique view of the central clearing landscape that is not available elsewhere. The results from the SGCCI's analysis are varied and depend on the specific aspects of the central clearing system that are being analysed but some broad themes from the study can be made. In this study, analysis of clearing members and financial service providers was carried out at a group level rather than individual legal entity level. As such, throughout this report, the term 'entity' refers to a collection of firms belonging to the same group or parent.

The 2017 analyses of interdependencies in central clearing broadly confirm the high-level conclusions of the 2016 exercise; namely that:

1. Prefunded financial resources are concentrated at a small number of CCPs. The two largest CCPs (as measured by prefunded financial resources) account for nearly 40 per cent (32 per cent in 2016) of total prefunded financial resources provided to all CCPs, with the next group of eight CCPs accounting for an additional 50 per cent of total prefunded financial resources (56 per cent in 2016). The remaining CCPs in this study are considerably smaller.

2. Exposures to CCPs are concentrated among a small number of entities. The largest 11 out of 306 clearing members (as measured by prefunded financial resources contributions to the CCP) are connected to between 16 and 25 CCPs. This indicates that the default of a CCP's clearing member could result in defaults of the same entity or affiliates in up to 24 other CCPs included in this analysis.

3. The relationships mapped in this report are all characterised, to varying degrees, by a core of highly connected CCPs and entities and a periphery of less highly connected CCPs and entities. At the same time, even these less highly connected CCPs often maintain connections to at least one highly connected entity that indirectly connects the CCP to the central (more interconnected) part of the network structure.

4. Among the different types of relationships between CCPs and other financial institutions, a small number of entities tend to dominate each of the critical services required by CCPs. These concentrations suggest that a failure at one of these central elements of a CCP network would likely have significant consequences for the rest of the network.

5. Clearing members and clearing member affiliates are also important providers of other critical services required by CCPs and can maintain numerous types of relationships with several CCPs simultaneously. For instance, the largest clearing members often provide a number of additional services to CCPs, with many providing at least three and one providing six services. In addition, out of 306 clearing members, 27 per cent also provide credit to CCPs, 26 per cent provide investment services and 16 per cent provide intraday liquidity.

There are, however, some changes to highlight in the interdependencies in central clearing. For instance, compared with September 2016, as of October 2017, initial margins from clients are concentrated in two CCPs, compared to one in 2016. This seems to suggest that client clearing has increased substantially at one CCP between September 2016 and October 2017.

The results are a useful starting point for understanding potential sources of systemic risks in central clearing. It is important to note, however, that neither data collection exercise assesses second-round effects and endogenous feedback mechanisms that could amplify (or dampen) any initial stress.[4] Moreover, these exercises are limited to evaluating the level of *interconnectedness*. They do not seek to measure *risk*, in the sense of net exposures across CCPs. Also, the data do not include information about risk management within CCPs or on any entity other than CCPs with whom financial entities have relationships with. As a result, the analysis is not suited to support any conclusions related to the impact of entity default on the broader financial system or the real economy or to demonstrate transmission of risks through CCPs.

2. Data overview

The data were collected as of 31 October 2017 and represent a snapshot in time. The 26 CCPs included in the data collection vary significantly in terms of the products that they clear as well as their overall size and level of activity.

The data available to the SGCCI included a variety of proxies for the size of each entity corresponding to the different services provided to each CCP. These proxies appear in many of the figures that follow. Generally, the size of each CCP in each layer of the network is represented by the total level of resources or service provision provided to the CCP in that layer. Similarly, the size of each service provider in each layer of the network is represented by the total level of resources or services it provides to CCPs in that layer. For example, the amount of prefunded financial resources that are held by the CCP to manage counterparty exposures roughly approximates a CCP's estimate of the market risk posed to it by portfolios of its clearing members and their clients. While a clearing member's prefunded financial resources across multiple CCPs do not predict the aggregate clearing system's exposure to that clearing member – because some of those exposures may be offsetting, while others may be diverse – it does inform an understanding of the complexity of a default of that clearing member, as all of the house (i.e. proprietary) positions would need to be liquidated promptly, and client positions would need to be transferred to another clearing member (preferably) or liquidated. Hence, total prefunded financial resources are used to proxy for the size of CCPs in the central clearing network.

As in 2016, each CCP was asked to provide a variety of quantitative and qualitative data on several important characteristics relating to the CCP:[5]

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[4] The analysis does not represent a stress testing exercise.

[5] In addition to the broad categories noted above, the data collection also asked CCPs for information regarding entities that provide access to certain trading and settlement systems. These data are not included in this report as the data analysis team's assessment was that the quality of the data was not sufficient for inclusion in the report.

- **Clearing members:** Identified at the clearing service level. The default of a clearing member exposes a CCP to credit and liquidity risks, because the CCP guarantees the fulfilment of obligations to surviving clearing members.
- **Custodians:** Firms that hold cash and securities collateral on behalf of CCPs and their members. Disruptions at a custodian exposes a CCP to operational and liquidity risks, as the CCP may experience a delay in accessing its collateral. In case of cash collateral, the CCP may also face credit risks. I/CSDs are considered custodians.
- **Settlement banks:** Banks that process payments, settlements and collateral transfers between CCPs and their members. Disruptions at a settlement bank expose a CCP to operational risk (and possibly also credit and intraday liquidity risk) as it experiences delays in fulfilling payment and settlement obligations or transfers of collateral.
- **Intraday liquidity and settlement lines:** Providers of intraday liquidity and settlement lines to CCPs. Disruptions at an intraday liquidity provider exposes a CCP to operational and liquidity risks as payments and settlements may be delayed.
- **Credit and liquidity facilities:** Providers of overnight and term credit and liquidity facilities. Disruptions at a provider of credit and liquidity facilities expose a CCP to liquidity risks.
- **Cash investments:** Counterparties to investments such as repurchase agreements and deposits that are used by CCPs to invest cash resources. Disruptions at providers of cash investment services may expose a CCP to credit, operational and liquidity risks.
- **Non-cash investments:** Counterparties to investments for non-cash resources, typically securities lending services whereby CCPs lend out available non-cash collateral. Disruptions at these services providers exposes a CCP to operational and liquidity risks.
- **Total investment portfolio and non-cash collateral portfolio:** CCPs hold certain non-cash investment assets (e.g. government bonds) and investments facilitated by third-party investment managers. Failure of providers of investment services may expose a CCP to credit, operational and liquidity risks.

CCPs submitted anonymised information to the SGCCI data analysis team, which was reviewed by the CCP's national authority.[6] Consistent with last year, to reduce the potential to identify a CCP, CCPs were asked to provide exposures to their top 25 clearing members

[6] CCPs participating in the survey submitted a list of entities with whom they had a relevant relationship (e.g. clearing members, custodians, etc.) to the IOSCO Secretariat. The IOSCO Secretariat assigned aliases to these entities, consistent across all CCPs in the survey. The aliases were designed so that entities belonging to the same corporate group (where this could be established) have related aliases, but it was not possible to identify the actual entity to the group. Only the IOSCO Secretariat had access to the aliases and individual firm names, but they did not have access to the individual CCP data templates, The CCPs then submitted their data templates using the aliases (via national authorities to the BIS in Basel) and the data was analysed by the Data Analysis Team (DAT), comprising four people none of whom are or were members of any Secretariat. Only members of the DAT had access to the anonymised individual CCP data templates. Members of the SGCCI did not have access to the anonymised individual CCP templates or to the list of aliases and firm names. Also the CCP's home authority and the DAT made efforts to validate data contribution by CCPs, and beyond that, the SGCCI has worked under the assumption that the reported data did not contain any errors or omissions which may bias the results of data analysis.

for each clearing service.[7] While, on the one hand, this constraint may bias results related to CCP membership (e.g. commonality of membership, network statistics, overlap between CCP membership and provision of other services to CCPs), the largest 25 clearing members typically represent the majority of the prefunded financial resources to the CCPs included in the survey.

The bespoke data collection yielded information for 51 clearing services and 306 clearing members. Annex B lists the specific products cleared by each clearing service as described by each CCP, which is essentially unchanged compared with the 2016 exercise; the variety of products demonstrates that the underlying sample of CCPs and clearing services represents a broad cross section of the clearing landscape that is not concentrated in any specific product or asset class.

2.1 Interconnections across clearing members and financial service providers

CCPs maintain various relationships with other financial institutions. Entities may have relationships with CCPs as clearing members, custodians, settlement banks, credit and liquidity providers and investment counterparties. Moreover, a single entity often maintains different types of relationships with different CCPs. As an example, a financial institution might be member of one CCP, a custodian for a second CCP, while providing a credit line to a third CCP. Figure 1 below provides an overview of the ways in which these roles are fulfilled by the entities covered in this data collection. Diagonal elements of the table report the number of entities fulfilling any particular role as of 31 October 2017 (the figures as of 30 September 2016 are in parentheses). For example, the entry in the top-left corner of the table shows that across all 26 CCPs there are 306 distinct clearing members. Similarly, the bottom right entry of the table shows that there are 123 distinct entities that are investment counterparties across all 26 CCPs. Any given column of the table reports the ways in which each specific type of entity fulfils multiple roles. As an example, among the 306 clearing members, 29 are custodians for at least one CCP, 59 provide settlement services to at least one CCP, 49 provide intraday liquidity and settlement lines to at least one CCP, 82 provide credit and liquidity facilities to at least one CCP, 24 provide third-party investment management services to at least one CCP, 79 are investment counterparties to at least one CCP.

Figure 1 suggests that a high degree of interconnections remains in the different roles provided by entities that are connected to CCPs. As an example, 29 out of 56 (40 out of 65 in 2016) custodians are also CCP clearing members and 82 out of 101 (76 out of 95 in 2016) credit and liquidity facility providers are also clearing members. Similarly, among 56 distinct custodians, 30 of these provide credit and liquidity facilities while 39 of these custodians are also investment (e.g. repo) counterparties. Accordingly, the default of a clearing member or critical service provider could, in many cases, have an impact not only on the same service provided for other CCPs but also on the provision of other services and functions for other CCPs as well.

[7] CCPs were also asked to provide their exposures to their top 25 custodians, investment managers, intraday liquidity providers, credit and liquidity facilities and non-cash investment managers; their top 15 exposures to settlement banks, and their top 11 exposures to investment fund managers.

The entities that are connected to CCPs come from a variety of jurisdictions and many are banks, with 22 out of the 26 CCPs surveyed exposed to at least ten G-SIFIs, all of which are banks (see Annex C).

Figure 1: Total number of entities connected to any CCP

	Clearing members	Custodians*	Settlement banks**	Intraday liquidity / settlement line providers	Credit and liquidity facilities	Third-party investment managers	Invest-ment counter-parties
Clearing members	**306 (307)**						
Custodians*	29 (40)	**56 (65)**					
Settlement banks**	59 (56)	33 (38)	**88 (81)**				
Intraday liquidity / settlement line providers	49 (49)	30 (33)	54 (48)	**74 (66)**			
Credit and liquidity facilities	82 (76)	30 (38)	55 (52)	61 (54)	**101 (95)**		
Third-party investment managers	24 (25)	15 (15)	19 (20)	16 (18)	20 (22)	**29 (29)**	
Investment counter-parties	79 (83)	39 (44)	68 (65)	57 (53)	77 (74)	29 (29)	**123 (122)**

* The figure excludes central banks and I/CSDs offering custody services.

** The figure includes commercial banks offering settlement services and central banks.

Figure 2 shows the conditional probabilities of interconnections across clearing members and financial service providers. Each row gives the probability of having a link in the layer described by the row given that the entity provides the service described in the column. For instance, there are 29 custodians that are also clearing members and a total of 56 custodians; hence there is a 51.8 per cent (i.e. 29/56) probability of an institution being a clearing member, conditional on that institution being a custodian. On the other hand, there is a 9.5 per cent (i.e. 29/306) probability of an institution being a custodian, conditional on that institution being a clearing member.

Similarly, there are 82 credit and liquidity providers that are clearing members and a total of 101 credit and liquidity providers; as such, there is an 81.2 per cent (i.e. 82/101) probability

of an institution being a clearing member, conditional on that institution being a credit and liquidity provider.[8]

Figure 2: Conditional probabilities of interconnections across clearing members and financial service providers

	Clearing members	Custodians*	Settlement banks**	Intraday liquidity / settlement line providers	Credit and liquidity facilities	Third-party investment managers	Invest-ment counter-parties
Clearing Members	100	9.5	19.3	16.0	26.8	7.8	25.8
Custodians*	51.8	100	58.9	53.6	53.6	26.8	69.6
Settlement banks**	67.0	37.5	100	61.4	62.5	21.6	77.3
Intraday liquidity / settlement line providers	66.2	40.5	73.0	100	82.4	21.6	77.0
Credit and liquidity facilities	81.2	29.7	54.5	60.4	100	19.8	76.2
Third-party investment managers	82.8	51.7	65.5	55.2	69.0	100	100
Investment counter-parties	64.2	31.7	55.3	46.3	62.6	23.6	100

* The figure excludes central banks and I/CSDs offering custody services.

** The figure includes commercial banks offering settlement services and central banks.

3. Interdependencies between CCPs and their clearing members

The analysis presented in this section shows that there is a significant level of concentration in the central clearing system – both in terms of a relatively small number of CCPs that comprise most of the prefunded financial resources in the data used and a small number of highly interconnected clearing members whose default or financial distress would impact a large number of CCPs. Additionally, the comparison between the degree of interconnectedness in the 2016 and 2017 data suggests that the structural properties of the network have remained stable across the two data collections.

[8] This calculation was not performed on the 2016 figures.

3.1 The CCP-clearing member network

Clearing members maintain a network of relationships with a variety of CCPs. A common way of depicting these relationships is through a network graph where each node represents an entity in our system (e.g. clearing member, CCP, custodian, etc.).[9]

Network Charts

In all the network charts, the size of the node is a linear function of the financial input; for example, in Figure 3 the financial input is total prefunded financial resources and in Figure 8, the input is the total value of assets under custody and the total value of settlement flows, respectively. The weights (sizes) of nodes are calculated amongst the population of the same type. The population of CCPs is 26 and the population of clearing members is 306. To visualise the network, the size of the largest and smallest nodes is set arbitrarily. The area of some very small clearing members may have been increased to make them visible in the network graph. The largest and the smallest nodes have respectively a thinning and a magnifying effect and due to the large size differences between the largest and smallest nodes in the data, this makes directly-proportional network visualisation impossible across all nodes. In the network figures that follow, CCP nodes can be compared with each other, and clearing members can be compared with each other; however, CCP nodes cannot be compared with clearing member nodes. Additionally, in all network charts in this report, the distances between the core and the periphery of the network are automatically assigned by the software that generated the network chart and have no specific meaning. It is important to note that the size of the nodes in this report cannot be compared with the size of the nodes in last year's report as different settings were applied to the minimum node size in order to facilitate visualisation; hence larger node sizes in this report relative to last year's report do not necessarily imply higher activity.

Figure 3 represents a global and relatively comprehensive view of the CCP-clearing member network across several jurisdictions and asset classes. The chart depicts the CCP network for the top 25 clearing members[10] of each CCP. Each CCP is shown in red and each clearing member in blue. The size of a CCP node can be seen as a proxy for the CCP's credit risk exposure to all of its clearing members, while the size of a clearing member node is a measure of the total prefunded financial resources that the clearing member has posted or contributed among all CCPs of which it is a member.[11] The lines connecting CCPs and members depict the CCP-clearing member relationships in the network.

Figure 3 confirms the findings from the 2016 exercise: there is a high degree of interconnectedness across the CCP-clearing member network, with a few CCPs being connected to many clearing members, and a few clearing members being connected to many

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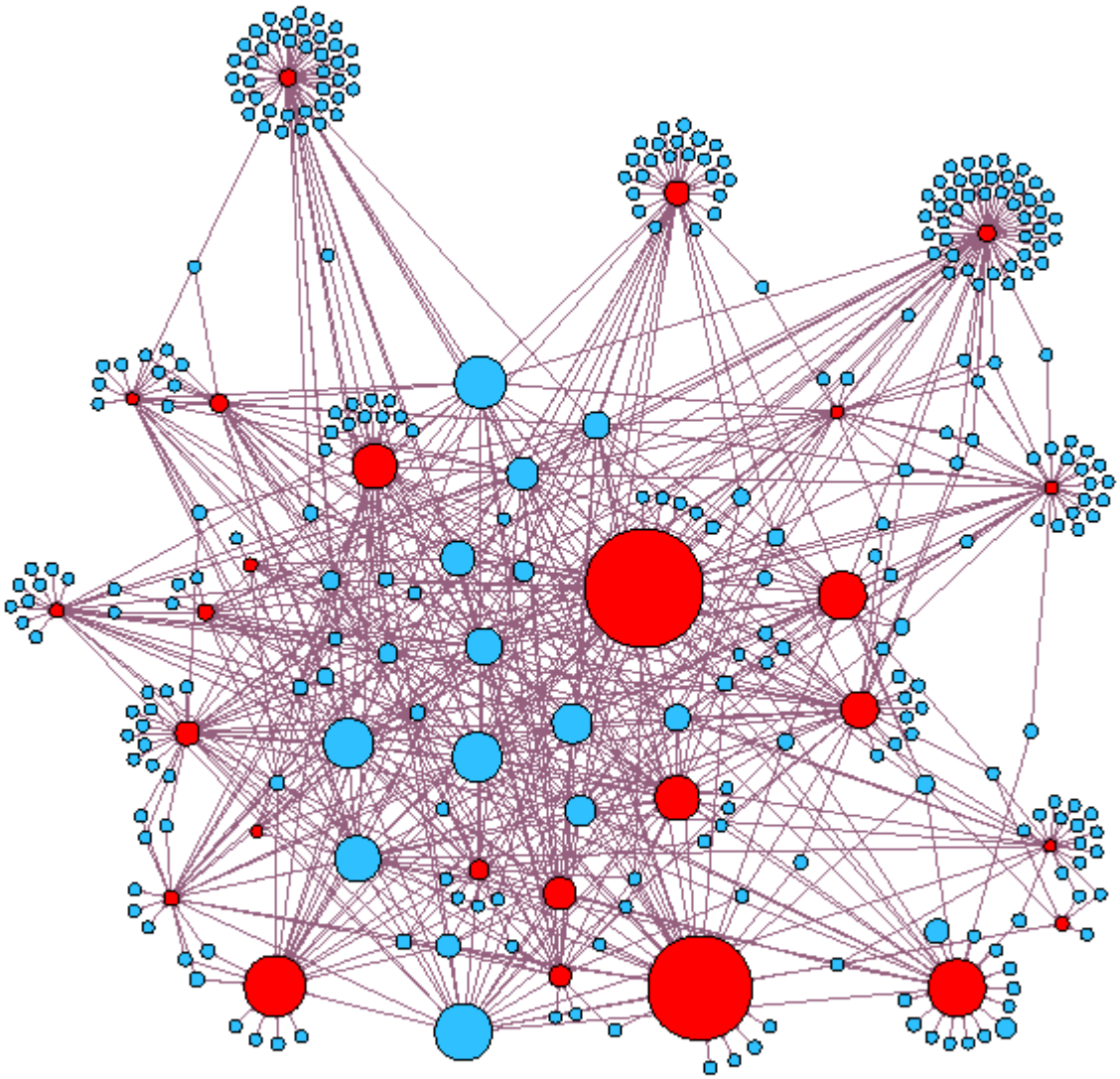
[9] P Gai, A Haldane and S Kapadia, "Complexity, concentration and contagion", *Journal of Monetary Economics*, vol 58, 2011, pp 453–470. M Billio, M Getmansky, A Lo and L Pelizzon, "Measuring Systemic Risk in the Finance and Insurance Sectors", MIT Sloan School Working Paper, no 4774-10, 2010.

[10] Although the network graph does not depict every CCP-clearing member relationship, the largest 25 clearing members typically represent the majority of the CCP's total financial resources.

[11] Although a clearing member's aggregate initial margin across CCPs is not a reliable measure of aggregate risk that clearing member poses to the system (because exposures at different CCPs may be offsetting), the size of the nodes (initial margin plus default fund contributions) provides some information about CCPs' potential future exposure to clearing member that is generally sufficient for the purposes of ranking and visual comparison.

CCPs.[12] This suggests that the default of a clearing member in the centre of the chart could have important consequences for a number of CCPs in the network due to cross-default provisions (and practical implications) that would result in the need to liquidate positions of the member or its affiliates at other CCPs. However, this analysis of interconnectedness cannot, on its own, conclude that such a default would have any material impact on CCPs at which the defaulter or its affiliates are not members, or on other members of that latter group of CCPs.

Figure 3: The CCP-clearing member network



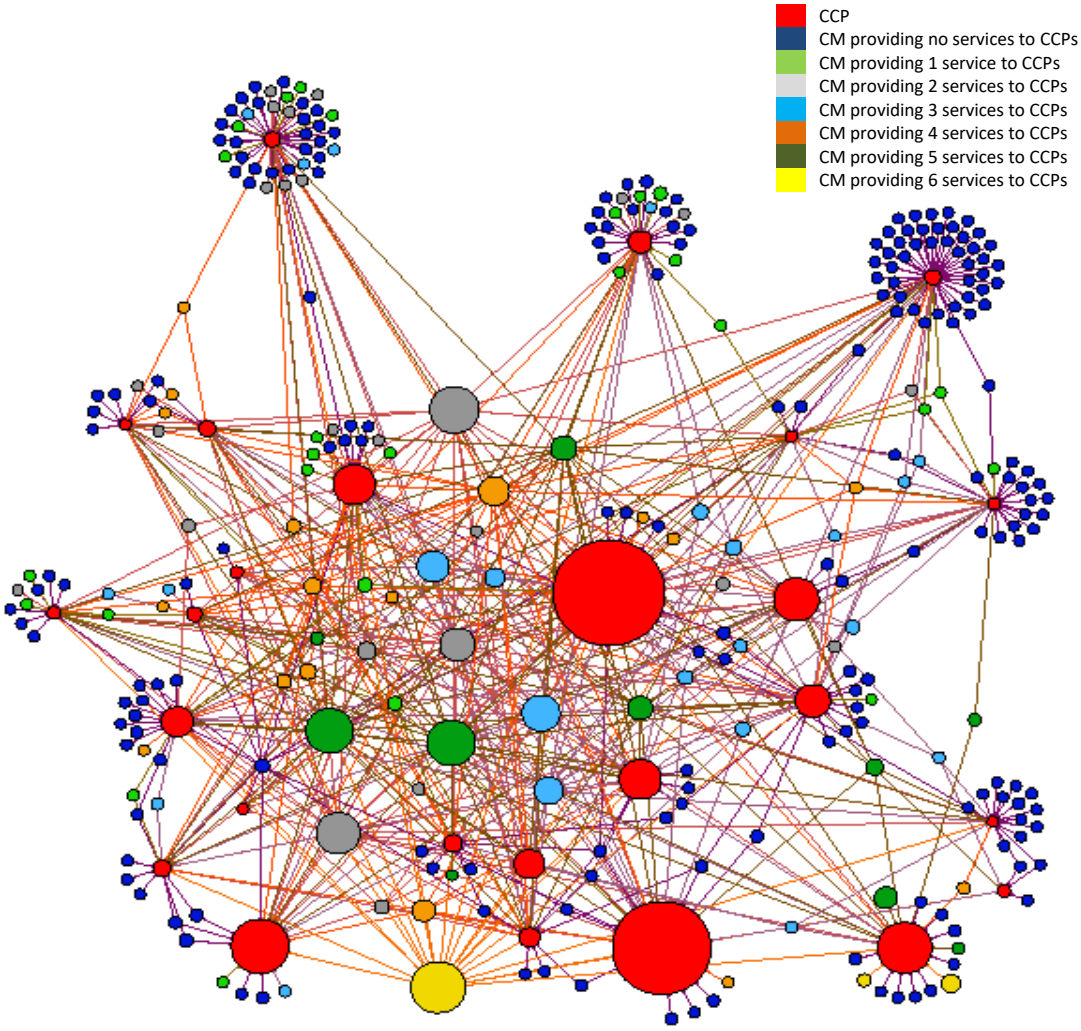
3.2 The multiple services provided by clearing members

CCPs maintain various relationships with other financial institutions. Figure 4 shows clearing members (non-red nodes) that provide one or more additional services (i.e. as a custodian, settlement bank, investment counterparty, intraday liquidity and settlement provider, credit or liquidity provider) to one or more CCPs. The colour of each clearing member node

[12] See Annex D for the tables displaying the main network measures as in October 2017 and September 2016.

corresponds to the number of different services that clearing member provides to CCPs in the sample, but not the types of services provided nor the size of provision of those services. Therefore, two identically-coloured nodes may represent clearing members that each provide a different set of services. In addition, node size is based on aggregate prefunded financial resources, so that the nodes representing clearing members are ranked according to their exposures to CCPs. Consistent with the 2016 exercise and other analyses undertaken in this report, the figure shows that the largest clearing members often provide a number of additional services to CCPs, with many providing at least three (pale blue, orange, jade green and yellow).

Figure 4: Clearing members providing multiple roles



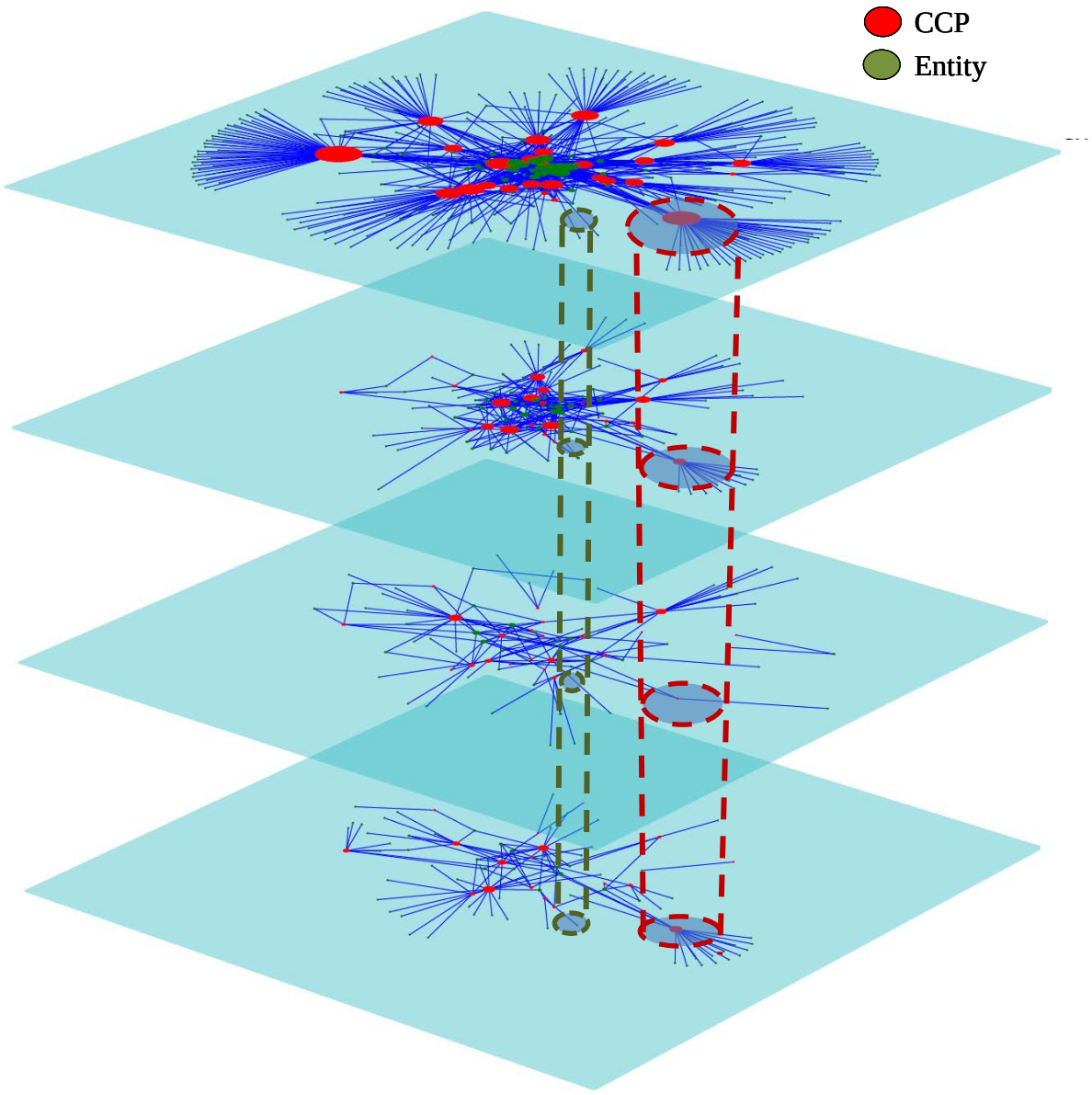
Other ways of observing the degree of interconnectedness is to examine the extent to which a clearing member of one CCP is also a service provider for other CCPs. Such systems are better described in terms of multiplex networks. For example, Figure 5 illustrates the different layers of the multiple networks that connect CCPs to entities.[13] Although there are seven ways in which an entity can be connected to a CCP (as described in Figure 4); this multilayer network

[13] This figure was not produced for the 2016 data collection.

chart shows the four most important layers for CCP risk management, with the top layer being clearing members. The red nodes represent CCPs and the green nodes represent other entities. In each layer of the multiplex network, only the entities that provide that particular service (e.g. clearing, credit and liquidity provisions, custodian and intraday liquidity) are visible. If an entity is connected to a CCP in more than one of these networks, its node will appear in the same position in each relevant layer. This is highlighted by the green dashed line.

The size of each node on each layer is proportional to the number of connections the entity has with other entities in the same layer (i.e. its degree). For example, the red dashed line helps to visualise the same CCP in the four multiplex layers. The larger size of the node in the top layer of the network indicates that the CCP has a higher number of clearing members than providers of other services. At the same time, the CCP receives financial services from entities in the bottom three layers that are also its clearing members in the top layer.

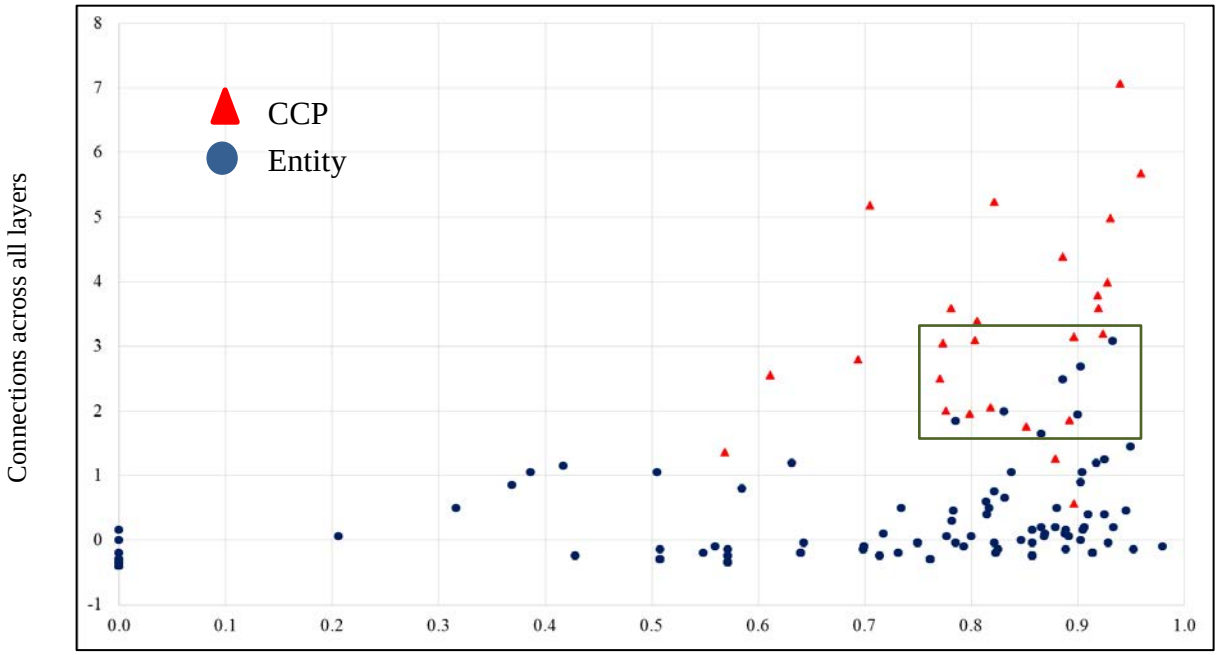
Figure 5: Clearing members providing multiple roles as custodians, credit and liquidity providers



Note: This figure illustrates how entities are connected through four financial services provided to CCPs. In each layer of the multiplex network, only the entities that provide that particular service (e.g. clearing, credit and liquidity provisions, custodian and intraday liquidity) are visible. If an entity (green node) is connected to a CCP (red node) in more than one of these networks, its node will appear in the same position in each relevant layer. This is highlighted by the green dashed line. Meanwhile, the size of each node on each layer is proportional to the number of connections the entity has with other entities in the same layer (i.e. its degree of interconnectedness). For example, the red dashed line helps to visualise the same CCP in the four multiplex layers. The larger size of the node in the first layer of the network indicates that the CCP has a higher number of clearing members than providers of other services. At the same time, the CCP receives financial services from entities in the bottom three layers that are also its clearing members in the top layer.

Figure 6 is another way of depicting a multiplex network, which quantifies the participation of single nodes to the structure of each layer and the importance of each node to the multiplex network.[14] As expected, CCPs (red nodes in the upper right hand corner) are the most active and connected nodes in the different layers of the network. The figure also shows that there are many entities that are as active and connected as some CCPs as highlighted by the green box. Hence, should these nodes default, it would have implications for multiple CCPs and for different services provided to CCPs.

Figure 6: Node importance in a multi-layered network



Note: This chart analyses the seven ways an entity can be connected to a CCP as described within Figure 3. The vertical axis represents the total number of connections across the different layers (i.e. the Z-score of its overlapping degree). The horizontal axis represents a measure of activity for each entity for each layer of the network. This measure is called the multiplex participation coefficient. The multiplex participation coefficient measures the homogeneity of the number of connections for a node across the different layers of the network and it ranges from 0 to 1. If this coefficient is equal to 1, a node has the same number of connections in each layer, that is, the node is equally active in all the layers of the network (i.e. the node is 'multiplex'). If the coefficient is equal to 0, the node is active only in one of the layers, that is, the node is specialised in just one service to CCPs (i.e. the node is 'focused').[15] See Annex E for details on the calculation of overlapping degree and the multiplex participation coefficient. Entities (blue nodes) located at the bottom left corner of the chart are not highly active and are focused., while entities (red nodes) located at the top right corner of the figure are highly active and multiplex on the x-axis and y-axis, respectively.

3.3 Common clearing members across CCPs

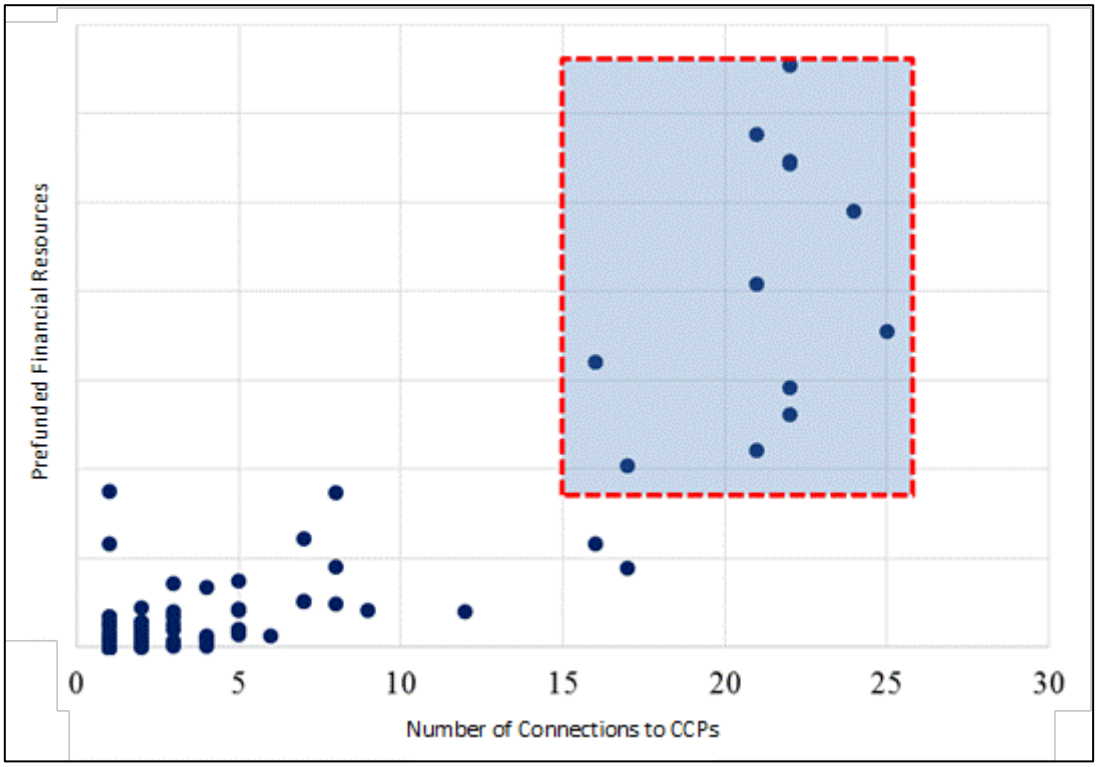
The study of interconnectedness can be enriched by looking at the number of CCPs that may be impacted by the default of a clearing member. Figure 7 shows the amount of prefunded financial resources provided by each financial institution in relation to the number of CCPs to

[14] F Battiston, V Nicosia and V Latora. *Structural measures for multiplex networks*, March 2014.

[15] CCPs (red triangles) are expected to have a high multiplex participation coefficient, as they are connected to multiple service providers on most layers of the network.

which it is connected. The chart shows that at least 16 of the 26 CCPs could be impacted by the default of any of the 11 largest clearing members (highlighted in the red rectangle). This suggests a high degree of interconnectedness among the central clearing system's largest and most significant clearing members.[16] Also, in those instances in which fewer than 16 CCPs are connected to a clearing member, the clearing members are characterised by a relatively low level of prefunded financial resources.[17]

Figure 7: Clearing members' size and number of connections to CCPs



4. Interdependencies between CCPs and custodian and settlement banks

Custody and settlement service provisions are a critical service that CCPs require in order to ensure successful operation at all times. These services are often provided to multiple CCPs by a number of entities, which results in a complex network of relationships between CCPs and custody and settlement service providers. The analysis of custodian and settlement banks is grouped because the services provided by custodian and settlement banks are of a similar nature. It is important to note, however, that the information on custodians (total amount of assets under custody) is a stock variable while the data on settlement banks (total amount of settlement flows) is a single-day flow variable. Hence, the impact of disruptions to these

[16] It should be noted that aggregation of clearing members across distinct clearing services and within corporate groups for the purposes of this analysis may obscure barriers between clearing services or between affiliated entities that serve to limit contagion and so may bias results in favour of observing a greater degree of interconnectedness. Similarly, diversity of exposures (e.g. unrelated product classes) and the possibility of offsetting exposures across CCPs clearing related products means the interconnectedness in this context does not imply a measure of risk.

[17] This analysis was not performed on the 2016 data.

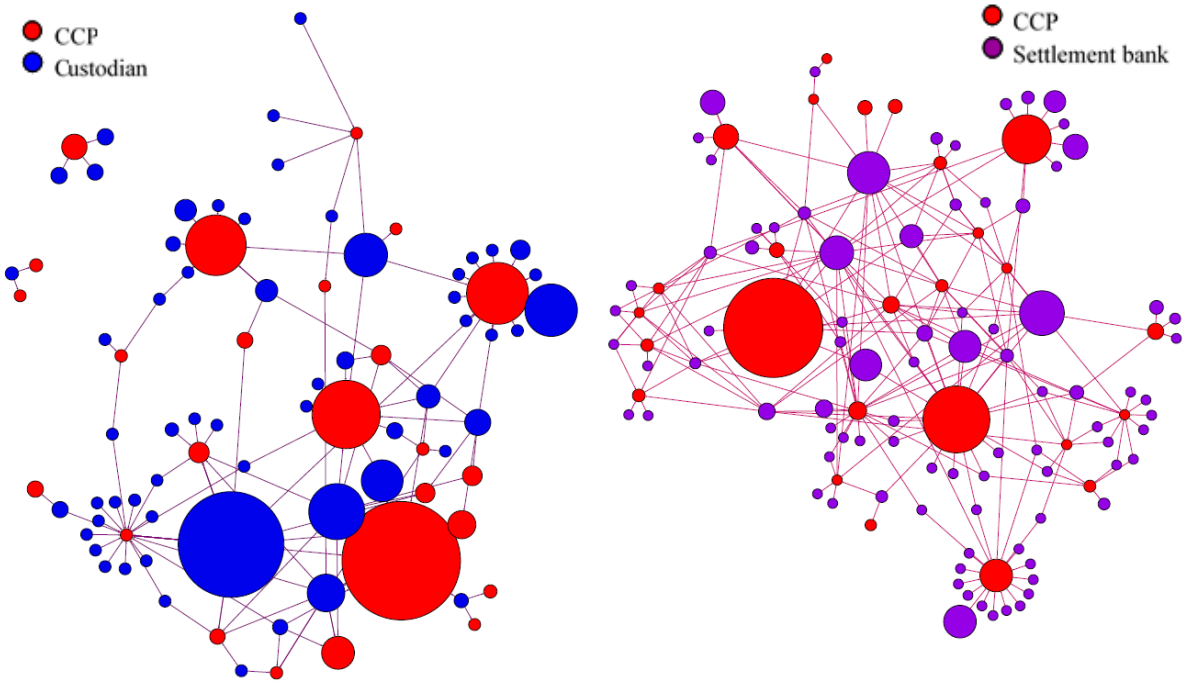
services is fundamentally different. Custodians safeguard prefunded financial resources that have been provided to the CCP on behalf of the CCP's members and their clients. Such resources include initial margin and default fund contributions made by members. Settlement banks process collateral flows between CCPs and their members and their clients. As an example, variation margin payments that are made between CCPs and their members are processed through settlement banks. Settlement banks also assist in processing movements of funds and securities for cash market transactions. Central banks that provide settlement services for CCPs were included in this analysis.

Figure 8 presents the CCP-custodian (left-hand chart) and CCP-settlement bank (right-hand chart) networks. The size of each CCP (red node) represents the total amount of assets that were held in custody with all the custodians that service the CCP. The size of each custodian (blue node) represents the total amount of assets under custody across all CCPs that it serves, and the size of each settlement bank (purple node) represents the total amount of settlement flows from all settlement banks servicing a given CCP.

CCPs vary substantially in the number of custodians used. For example, the CCP in the lower-left of the network chart utilises 16 different custodians (15 in 2016) while the largest CCP in the network, depicted in the lower-right of the graph uses a few relatively large custodians. Meanwhile another large CCP, depicted in the upper-right of the graph, uses 11 smaller (eight in 2016) and two larger custodians. In general, the CCP-custodian network is characterised by a small number of relatively large custodians (in terms of total assets under custody) that maintain a large number of connections to various CCPs and a number of smaller custodians that maintain relationships with one or only a handful of CCPs. This is similar to the findings from the 2016 exercise.

Meanwhile, consistent with the 2016 exercise, there are some CCPs that maintain relationships with a small number of settlement banks, while other CCPs maintain relationships with a large number of settlement banks. The CCP-settlement bank network shows some similarity to the CCP-custodian network. The network is characterised by a small number of relatively large settlement banks (in terms of flows) and a large number of smaller settlement banks.

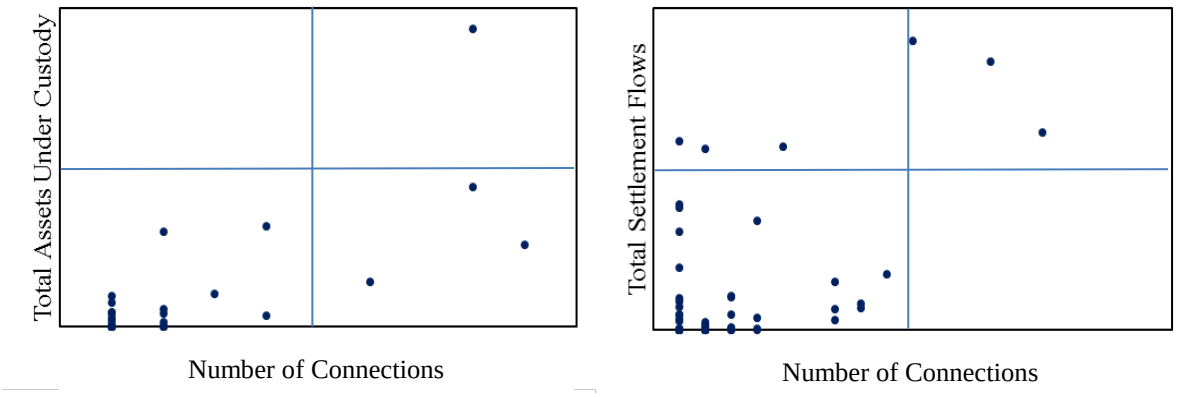
Figure 8: CCP-custodian (left) and CCP-settlement bank (right) networks



Another way of analysing the interconnections between CCPs and custodians and settlement banks is to measure the link between size and connectedness of entities providing those services to CCPs, which is depicted in Figure 9. Once again, size is measured by total assets held in custody in the left panel and by total settlement flows in the right panel. Connectedness is measured by degree of centrality in both panels. Each blue node represents an entity. The nodes in the upper-right of each scatterplot correspond to entities that are both large and well-connected, while those closer to the origin are small and peripheral. Thus, one can imagine the graph divided into four quadrants with “small” and “large” running along the vertical axis and “peripheral” and “connected” running along the horizontal axis.

These charts support what is depicted in the above network charts. In the left-hand panel, the figure reveals that there is one large (upper right quadrant) and three smaller (lower right quadrant) custodians that are well connected, with the vast majority being relatively small and peripheral (bottom left quadrant). For settlement provisions (right-hand panel), there are three relatively large settlement providers (upper right quadrant) that are well connected and three large settlement providers (upper left quadrant) that are peripheral; the vast majority of settlement service providers are small and peripheral (bottom left quadrant).

Figure 9: Size and degree centrality of custodian (left) and settlement providers (right)



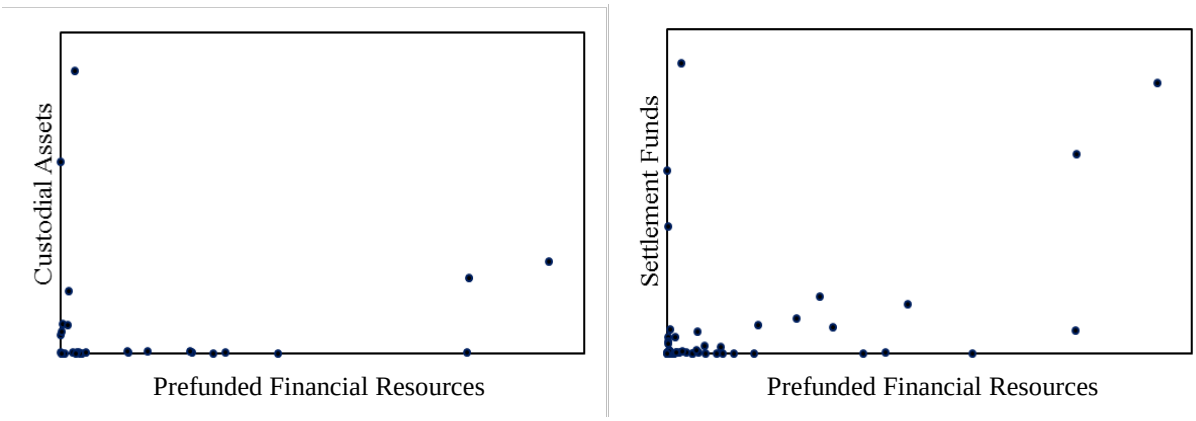
4.1 Interconnections between clearing members and providers of custodian and settlement services

A number of entities that provide custodian and settlement services to CCPs are also clearing members. As shown in Figure 1, there are 29 custodians and 59 settlement banks that are also clearing members. Accordingly, the distress of a clearing member could also impact the provision of critical custodial and settlement services to the central clearing system. Figure 10, however, suggests that there is no strong relationship between clearing member size (as measured by prefunded financial resources) with assets held in custody or with settlement flows. These scatterplots analyse the 29 clearing members that also provide custodial services (left hand chart) and the 59 clearing members that also provide settlement services (right hand chart).

The scatterplot of custodian services (left hand chart), shows on the horizontal axis the total prefunded financial resources provided by each clearing member to all CCPs, and on the vertical axis, the total amount of assets held in custody by that member (or an affiliate) for all CCPs. While a few large members are relatively large providers of custodian services (such as the clearing member pictured at the far right of the horizontal axis), there appears to be no strong and systematic link between being a large clearing member and a large provider of custody services.

The graph on the right shows a similar scatterplot except the vertical axis reflects the total settlement flows handled by settlement banks across all CCPs covered in the data collection. There are a few relatively large clearing members that are also significant providers of settlement services, as reflected at the far right of the horizontal axis. Although there seems to be a relationship between clearing member size and the provision of settlement services at the extreme, the relationship is relatively weak and driven by one or two observations.

Figure 10: Interconnections between clearing members and custodians (left) and settlement services providers (right)



5. Interdependencies between CCPs and liquidity and credit providers

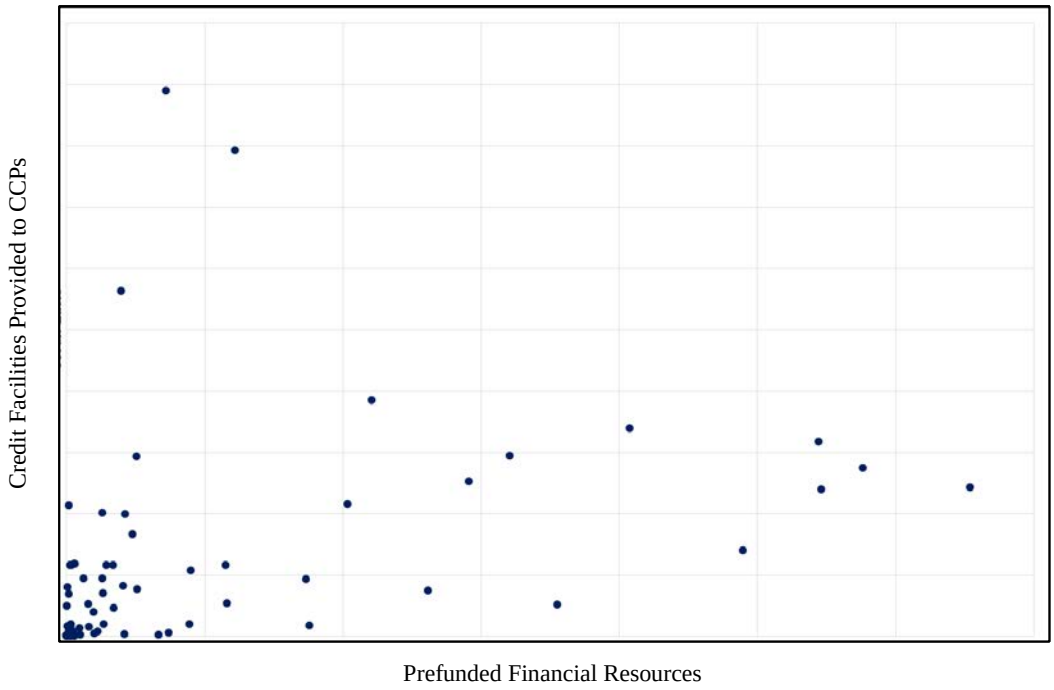
The relationships between CCPs and their credit and liquidity providers are an important source of interdependencies in the central clearing system. CCPs make use of longer term credit/liquidity lines and may make use of intraday liquidity/ settlement lines. These services facilitate the operation of a CCP, and in certain situations a CCP might need to draw on liquidity or credit facilities to deal with the default or financial distress of a clearing member. Credit and liquidity service providers often provide these services to more than one CCP. In this section, the relationships between CCPs, intraday liquidity and settlement line providers ('intraday liquidity providers') and providers of longer term credit and liquidity facilities ('credit providers') are mapped and analysed.

5.1 Interconnectedness between credit providers and clearing members

Figure 11 shows a scatterplot of total prefunded financial resources provided by each clearing member to all CCPs on the horizontal axis and the total amount of credit facilities provided to all CCPs on the vertical axis. Figure 11 includes the 82 clearing members that are also credit providers (or affiliates of credit providers), and excludes all other clearing members that are not credit providers and all other credit providers that are not clearing members. Accordingly, the figure reports credit lines provided by only a subset of credit line providers in the SGCCI study.

The scatterplot suggests that there is a general tendency for clearing members that are large through the entire clearing system, in terms of prefunded financial resources contributed to CCPs, to provide more credit to CCPs through credit facilities. As with the 2016 data collection, it is worth noting that there are a few entities that provide large amounts to CCPs through credit facilities that are or are affiliated with relatively small clearing members in the central clearing system. This can be seen by observing points clustered the northwest quadrant of the figure.

Figure 11: Clearing membership and credit facilities



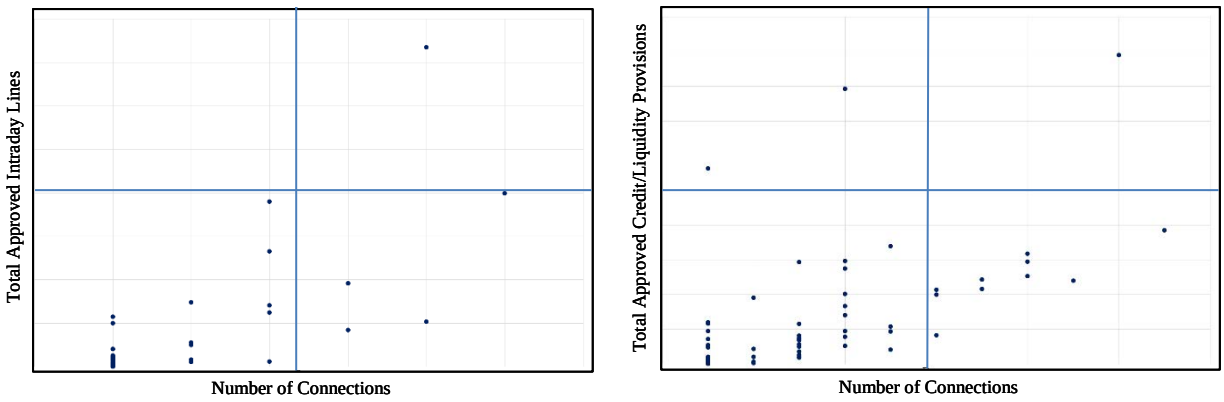
5.2 Interconnections between CCPs and intraday liquidity and term credit providers

Another means of assessing the degree of interdependence between credit and liquidity providers and CCPs is to consider the propensity of large credit and liquidity providers to be connected to many CCPs.

Figure 12 plots the aggregate level of intraday liquidity/settlement lines (left-hand chart) and approved term credit facilities by each entity providing credit facility resources (right-hand chart) against the number of CCPs to which it provides term credit (i.e. the degree of centrality of that institution within the credit facility network). Nodes in the upper-right of the scatterplot correspond to liquidity and credit providers that are both large and well-connected, while those closer to the origin are small and peripheral. Thus, similar to Figure 9, one can imagine the graph divided into four quadrants with “small” and “large” running along the vertical axis and “peripheral” and “connected” running along the horizontal axis.

Comparing the charts in Figure 12 suggests that there are a smaller number of intraday liquidity/settlement providers than term credit and liquidity providers, as depicted by the overall number of nodes in each chart. In addition, the scatterplots show that intraday liquidity/settlement line providers are generally less connected with CCPs than term credit and liquidity providers (comparing the right side quadrants). That is, while term credit and liquidity providers serve more CCPs than intraday liquidity providers, they also are generally smaller and more peripheral (i.e. are in the lower-left part of the figure).

Figure 12: Size and number of connections of approved intraday liquidity and settlement lines (left) and approved credit and liquidity providers (right)



6. Interdependencies between CCPs and investment service providers

CCPs rely on investment management services to safeguard and invest collateral assets held on behalf of their members. The provision of investment services is critical to the operation of CCPs and so understanding the interdependencies between investment service providers and CCPs is important. Data was also collected for third-party investment managers that facilitate CCPs' investments.

6.1 The CCP-investment service provider network

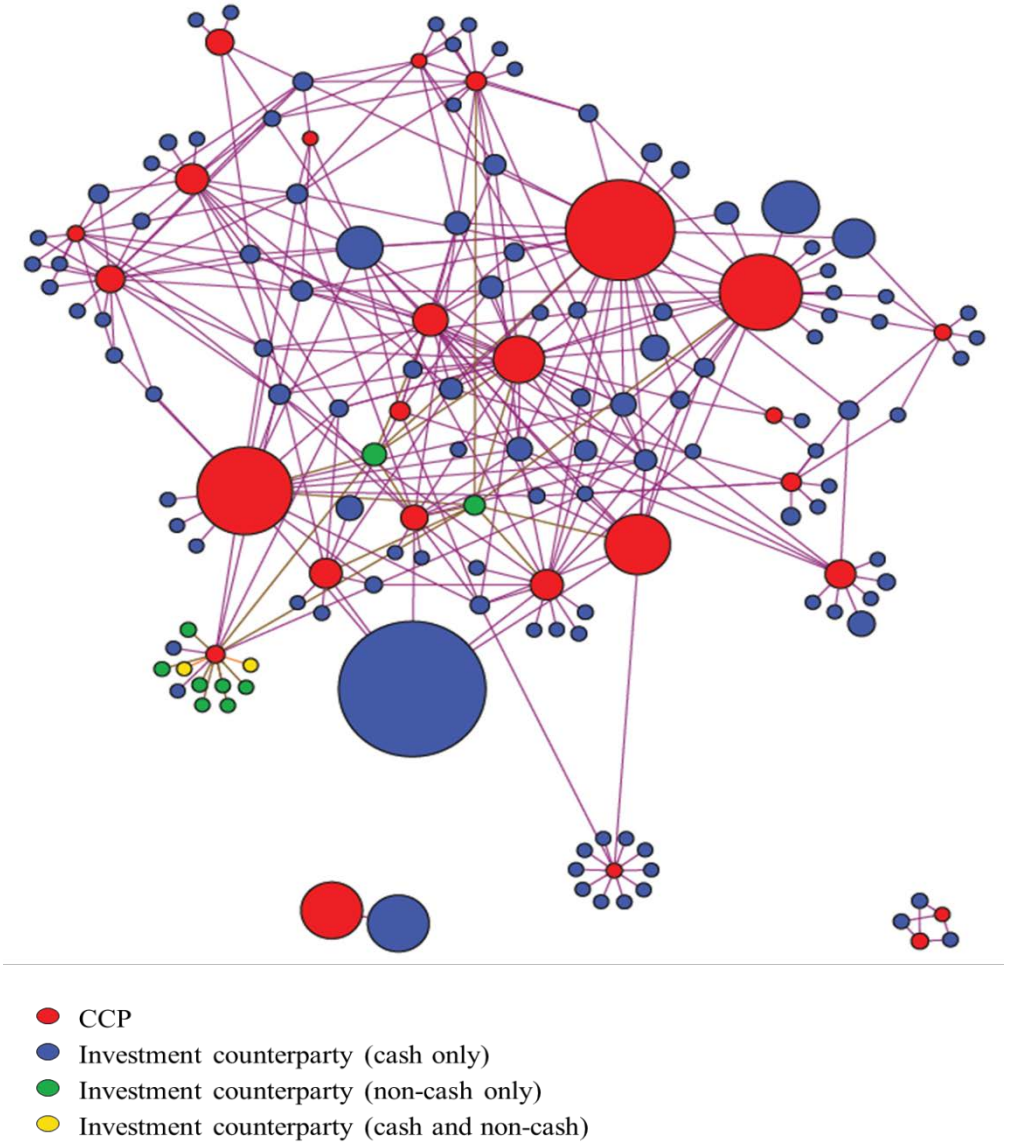
Figure 13 maps the network of CCPs and investment counterparties, and excludes third-party investment management relationships with CCPs. CCPs are depicted in red and investment counterparties are depicted in blue, yellow and green. The size of each CCP (red node) represents the total amount of assets that have been placed with all its investment counterparties. The size of each investment counterparty (blue, green and yellow nodes) represents the total amount of assets it has received from all CCPs in the network.

As observed in the 2016 exercise, the network graph shows that there is a core of CCPs and investment counterparties (including central banks) that are highly interconnected, and a periphery of smaller CCPs and investment counterparties that are less connected to other entities in the network. Moreover, among the CCPs in the centre of the network, a few are considerably larger than the other CCPs, measured in terms of assets placed with investment counterparties. The distribution of size among investment counterparties, when measured in terms of CCP assets invested, is relatively more uniform with the exception of one very large investment counterparty. Note that central banks could be included as investment counterparties in Figures 13 and 14.

In addition, as noted in the 2016 exercise, cash investment services (blue nodes) are used much more frequently by CCPs than non-cash investment services (green nodes). In fact, in 2017 only eight CCPs (seven in 2016) of the 26 CCPs surveyed reported a relationship with a non-cash investment counterparty. Interestingly, the chart also shows that in a number of cases large CCPs rely on a modest number of investment counterparties, while a few of the smaller CCPs use a large number of investment service providers. For example, one small CCP on the

south-west end of the network chart has relationships with 17 different investment counterparties (20 in 2016), while a relatively large CCP at the bottom of the network only uses one provider.

Figure 13: CCP-investment counterparty network

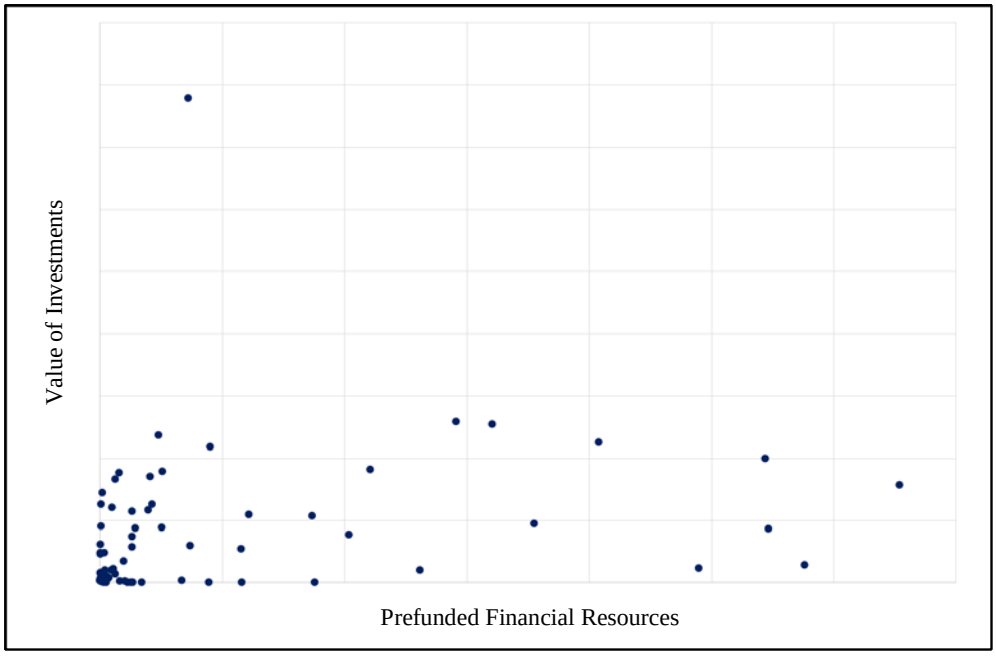


6.2 Interdependencies between investment counterparties and CCPs

It is important to recognise that many investment counterparties are also parts of groups that are also clearing members. Accordingly, the default or distress of a clearing member could create financial distress for one or more CCP's investment counterparties. Figure 14 is a scatterplot of total prefunded financial resources provided by each clearing member to all CCPs on the horizontal axis and the total amount of assets under management from all CCPs for investment counterparties. The figure includes the 79 clearing members that are also investment counterparties, or affiliated with investment counterparties, and excludes all other clearing members that are not investment counterparties and all other investment counterparties that are not clearing members.

The figure supports the observations from the 2016 exercise, and shows that there is a tendency for clearing members that provide more prefunded financial resources to CCPs in aggregate to also provide investment services for a larger share of aggregate CCP assets. Moreover, as measured here, some relatively large investment counterparties are relatively small clearing members in the CCP network.

Figure 14: Interdependences between clearing members and investment counterparties



6.3 Impact of investment counterparty default on other CCPs

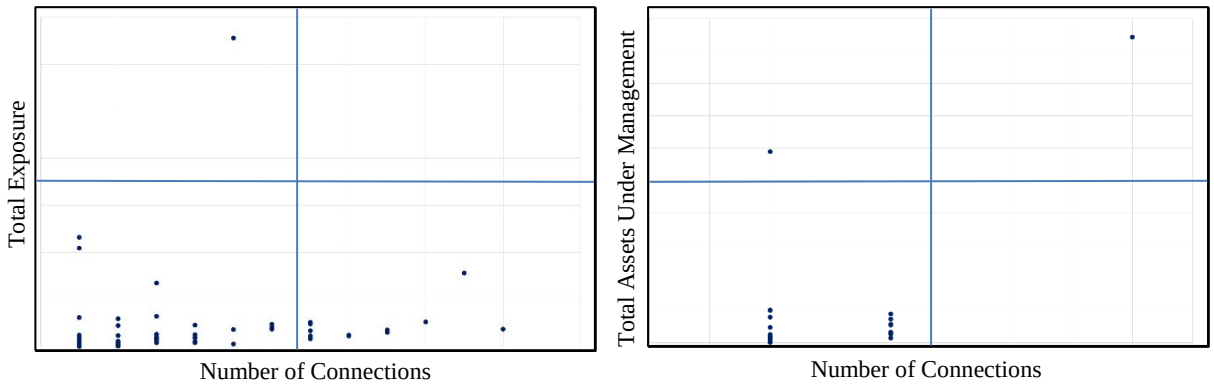
Given the degree of interconnectedness among investment service providers, the extent to which large investment service providers are shared across CCPs is analysed. One way to look at this is to compare the size of an investment provider to its level of connectedness with all 26 CCPs of the network. Figure 15 plots the aggregate level of AUM (vertical axis) by an investment counterparty and each third-party investment manager, against the number of CCPs to which it provides investment management services (i.e. its degree of centrality in the network). Nodes in the upper-right of the scatterplot correspond to third-party investment managers (right) or investment counterparties (left) that are both large and well-connected, while those closer to the origin are small and peripheral. Thus, similar to Figures 9 and 12, one can imagine the graph divided into four quadrants with “small” and “large” running along the vertical axis and “peripheral” and “connected” running along the horizontal axis.

Comparing the charts in Figure 15, CCPs seem to use a larger number of investment counterparties than third-party investment managers as depicted by the overall number of nodes in each chart.

The left-hand scatterplot shows that there are a relatively large number of small investment counterparties that are well connected to CCPs (bottom right quadrant), and one large investment counterparty that is somewhat connected to CCPs. The vast majority of investment counterparties, however, are small and on the periphery (bottom left quadrant).

Meanwhile, there is only one large third-party investment manager that is highly interconnected (upper right quadrant of the right-hand chart) and one relatively larger investment counterparty that is less connected to CCPs (upper left quadrant or the left hand chart), with the vast majority small and on the periphery (bottom left quadrant).

Figure 15: Size and number of connections of investment counterparties (left) and third-party investment managers (right) with CCPs



7. Conclusion

CCPs are an important part of the financial system. Their importance has grown significantly since the financial crisis and their importance is likely to grow over the coming years as central clearing continues to expand. Central clearing is intended to reduce the risk of contagion in financial markets, but it does not eliminate it. As part of the broader financial system, CCPs maintain a number of relationships with other financial institutions that either make use of services offered by the CCP or provide important services to the CCP that are necessary for its operation in both normal times and times of stress. It is also the case that several CCPs often maintain relationships with the same financial institutions which creates a complex network between multiple CCPs and the financial institutions with which they maintain relationships. Understanding this network on a broad and comprehensive scale is important for assessing the state of the central clearing system.

This report utilises a novel data set that contains comprehensive information about a global set of CCPs, their members and other critical service providers such as custodians and investment service providers to empirically map the resulting CCP network. The report attempts to shed light on the interdependencies between CCPs and different aspects of the financial system. The results indicate that there is a wide range of patterns in interconnectedness across the several networks that CCPs maintain with different types of financial entities (e.g. members, settlement banks, investment counterparties, and so on), and indirectly across different CCPs.

The results presented in this report are largely descriptive and do not account for feedback effects. Accordingly, it is not appropriate to draw any strong conclusions regarding the overall risk profile, adequacy of prefunded financial resources, or systemic risks posed based on these results. At the same time, the results in the report are useful for making comparative analyses

of different aspects of the central clearing system such as differences between the interdependencies in the CCP-clearing member network versus the CCP-custodian network.[18]

The data that has been collected and analysed in this report do provide valuable insight into the central clearing system at another point in time. When compared to the 2016 exercise, this report's findings appear qualitatively similar. Financial institutions and CCPs appear no more or no less interconnected in the different network layers than they were in 2016. The distribution of assets and flows across CCPs and other entities also generally do not appear to show substantial change. Taken together, this suggests network structures and interdependencies that have been relatively steady over the course of thirteen months.

In summary, the SGCCI has provided a global view of CCP interdependencies that provides the Committees with key baseline facts about the current state of the clearing network. In addition, it has developed analytical tools that may help future work streams that engage in similar analyses of central clearing, or attempt to describe other types of financial networks. Going forward, it could therefore be useful to explore the value of collecting such data through time to help track the evolution of the central clearing system.

[18] It is also useful to distil the main features of the network into a small number of quantitative metrics that can be easily compared across different networks and across time for a given network. A set of standard, quantitative network metrics are presented in Annex E for the various networks considered in this report. These metrics complement the graphical evidence presented in the network graphs and could be used to systematically measure different network features across different networks and over time.

Annex A: Participating CCPs in the bespoke data collection

The SGCCI, in collaboration with national authorities, identified 26 CCPs to approach for its bespoke data collection effort. This list was drawn from a larger list of 46 CCPs that were included in other work streams on resiliency, recovery planning and resolvability.

CCP name	Jurisdiction
Americas	
B3 S.A. – Brasil, Bolsa, Balcão	Brazil
Asigna, Compensación y Liquidación	Mexico
Contraparte Central de Valores	Mexico
CME Group Inc.	US
DTCC – Fixed Income Clearing Corporation	US
DTCC – National Securities Clearing Corporation	US
ICE Clear Credit LLC	US
ICE Clear US	US
The Options Clearing Corporation	US
Europe	
LCH SA	France
Eurex Clearing AG	Germany
Cassa di Compensazione e Garanzia s.p.a.	Italy
European Central Counterparty NV	Netherlands
Nasdaq Clearing AB	Sweden
SIX x-clear AG	Switzerland
ICE Clear Europe Ltd	UK
LCH Ltd	UK
LME Clear Ltd	UK
Asia-Pacific	
ASX Clear (Futures) Pty Limited	Australia
ASX Clear Pty Limited	Australia
HKFE Clearing Corporation Limited	Hong Kong
Hong Kong Securities Clearing Company Limited	Hong Kong
Clearing Corporation of India Limited	India
Japan Securities Clearing Corporation	Japan
The Central Depository (Pte) Limited	Singapore
The Singapore Exchange Derivatives Clearing Limited	Singapore

Annex B: Clearing services across the 26 CCPs

1. Base Metals
2. Cash Bonds and Repos
3. Cash Equities
4. Cash Equities and Listed Derivatives
5. Cash Equities, Derivatives, Securities Lending
6. Cash Equities, Equity Derivatives, ETFs
7. Cash Equity
8. Cash Securities
9. CCP Clearing of Trades in Collateralised Borrowing and Lending
10. CCP Clearing of Trades in Forex Spot
11. CCP Clearing of Trades in Rupee Derivatives
12. CDS
13. CDS
14. Commodities
15. Commodities
16. Commodities
17. Credit Default Swaps
18. Derivative products, on equity indexes, equities, currencies, interest rates, fixed income and commodities
31. FX Forward
32. General Collateral Repo
33. Government bonds
34. GSD-Eligible Securities
35. Interest Rates, Equity Index, Agricultural Products, Energy Products, OTC IR Swaps, Index Swaps, Basis Swaps
36. IRS
37. JGB
38. Listed Cash Products
39. Listed Derivatives
40. MBSD-Eligible Securities
41. Non-Deliverable EM Currency Forwards
19. Derivatives (Futures, Options, Swaps)
20. Electricity Derivatives
21. Equities
22. Equities, Equity-ETFs, Bonds
23. Equity derivatives, fixed income derivatives, interest rate derivatives, commodity derivatives, precious metal derivatives, FX derivatives, property futures, dividend futures, volatility futures, cash equities, bonds, OTC interest rate swaps
24. Exchange Traded Derivatives, OTC Commodities, OTC Financial Derivatives
25. Exchange Traded Single Stock and Index Options
26. Financial and Commodity Derivatives, Equities and Equities Derivatives, and Gold
27. Fixed Income/Stocks
28. Futures and Options on Energy, Financials and Softs
29. Futures and Options on Futures
30. FX derivatives
42. NSCC-Eligible Securities
43. Options, Futures, Securities Lending
44. OTC - IRS, OIS, VNS, Basis Swaps, FRAs, Inflation Swaps
45. OTC CDS
46. OTC IRS
47. Precious Metals
48. Primarily Futures and Options on Futures
49. Repurchase agreements
50. Retails and Wholesale Bond
51. Shares, Warrant, Convertible Bonds, ETF, ETC, Stock and Index Futures and Option

*Product descriptions are as provided by each CCP unless the description uses specific product names that would identify the identity of the CCP in which case a more general description is used.

Annex C: CCP clearing members by type of financial institutions and region[19]

	Type of Institution									Region		
CCP	G-SIFI	Non-G-SIFI	Bank	Broker-Dealer	Fund Manager	Central Bank	Govt	Non-Financial	Other	Americas	APAC	EMEA
1	11	45	44	3	7	0	1	0	0	6	44	6
2	29	17	35	6	0	0	0	1	0	6	24	16
3	22	21	37	3	0	0	0	0	1	11	4	28
4	18	20	33	3	0	0	0	1	0	7	1	30
5	13	26	36	2	0	0	0	0	1	5	0	34
6	17	13	23	5	0	0	0	1	0	15	3	12
7	14	52	26	0	1	0	2	31	2	5	2	59
8	12	15	24	3	0	0	0	0	0	16	0	11
9	16	10	23	1	0	0	0	2	0	7	3	16
10	19	18	27	6	1	0	2	1	0	21	7	9
11	12	10	16	3	0	0	0	3	0	8	5	9
12	10	28	26	4	0	0	0	1	0	0	1	37
13	10	13	14	7	0	0	0	0	0	8	9	6
14	11	8	17	2	0	0	0	0	0	6	6	7
15	10	14	18	6	0	0	0	0	0	5	13	6
16	13	11	17	6	0	0	0	0	0	13	0	11
17	13	10	20	3	0	0	0	0	0	14	1	8
18	14	9	21	2	0	0	0	0	0	5	9	9
19	13	2	15	0	0	0	0	0	0	7	1	7
20	2	5	5	2	0	0	0	0	0	5	0	2
21	7	17	10	14	0	0	0	0	0	18	1	5
22	12	13	21	2	0	0	0	0	0	7	0	18
23	16	10	26	0	0	0	0	0	0	5	1	20
24	13	11	17	4	1	0	0	0	0	17	1	6
25	5	4	7	2	0	0	0	0	0	2	2	5
26	4	4	7	1	0	0	0	0	0	3	2	3

[19] Calculations performed at legal entity level rather than parent level.

Annex D: Quantitative network statistics

	Density		Degree Centralisation		Normalised Degree Centralisation		Single-Mode CCP Centralisation		Single-Mode Participant Centralisation	
	2017	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**
Clearing members	0.093	0.091	0.206	0.196	0.910	0.911	0.158	0.155	0.897	0.896
Custodians	0.080	0.074	0.012	0.011	0.074	0.076	0.261	0.169	0.052	0.053
Settlement banks	0.093	0.089	0.022	0.012	0.174	0.164	0.199	0.116	0.142	0.131
System access	0.082	0.097	0.016	0.009	0.081	0.088	0.227	0.137	0.062	0.052
Intraday liquidity and settlement line providers	0.084	0.086	0.013	0.013	0.073	0.070	0.185	0.222	0.042	0.039
Credit and liquidity facilities	0.108	0.108	0.026	0.024	0.145	0.142	0.159	0.180	0.111	0.096
Third-party investment managers	0.138	0.144	0.004	0.003	0.039	0.039	0.416	0.311	0.010	0.013
Investment counterparties	0.098	0.094	0.031	0.030	0.171	0.207	0.127	0.119	0.150	0.175

Density Measure of the proportion of the potential connections in a graph that are actual connections.

Degree centralisation Network-wide measure for bipartite networks that shows the extent to which a network resembles the most centralised network that is theoretically possible for the same distribution of nodes, i.e. CCPs and participants, based on node degree. For this index, the centrality of a CCP is measured by the total number of participants the CCP is connected to, and the centrality of a participant is measured by the total number of CCPs the participant is connected to.

Normalised degree centralisation Network-wide measure for bipartite networks that shows the extent to which a network resembles the most centralised network that is theoretically possible for the same distribution of nodes, i.e. CCPs and participants, based on normalised node degree. For this index, the centrality of a CCP is measured by the total number of participants the CCP is connected to normalised by the maximum possible number of CCP's connections, and the centrality of a participant is measured by the total number of CCPs the participant is connected to normalised by the maximum possible number of participant's connections.

Single-mode CCP centralisation A measure for the set of all CCPs that shows the extent to which the distribution of CCP connections resembles the network with a distribution of CCP connections that result in the most centralised distribution that is theoretically possible for a given set of nodes. This measures shows how CCPs are central relative only to other CCPs.

Single-mode participant centralisation A measure for the set of all participants that shows the extent to which the distribution of participant connections resembles the network with a distribution of participant connections that result in the most centralised distribution that is theoretically possible for a given set of nodes. This measures shows how participants are central relative only to other participants.

Annex E: Node importance in a multi-layered network[20]

The overlapping degree o_i of a node i is the total number of i 's connections across all layers:

$$o_i = \sum_{l=1}^{8} d_i^l$$

where l is the index for network layers and d_i^l is the number of $i's$ connections in layer l.

A Z-score is used to rank nodes by their overlapping degree:

$$z(o_i) = \frac{o_i - \overline{o}}{\sigma_o}$$

where $\overline{o}$ is the mean overlapping degree in a multiplex network and σ_o is the corresponding standard deviation. The Z-score is what is plotted on the vertical axis of Figure 6.

Multiplex participation coefficient measures the heterogeneity of the number of neighbours of node i across the layers and is calculated according to:

$$p_i = \frac{7}{7-1}[1 - \frac{1}{o_i^2}\sum_{l=1}^{7}(d_i^l)^2]$$

This coefficient is plotted on the horizontal axis of Figure 6.

[20] F. Battiston, V. Nicosia and V. Latora. Structural measures for multiplex networks (17 March 2014). Available at https://arxiv.org/pdf/1308.3182.pdf.