Central Clearing and Collateral Demand [*]

Darrell Duffie [†], Martin Scheicher [‡], Guillaume Vuillemey [§].

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Abstract

We use an extensive data set of bilateral credit default swap (CDS) positions to estimate the impact on collateral demand of new clearing and margin regulations. The estimated collateral demands includes initial margin and the frictional demands associated with the movement of variation margin through the network of market participants. We estimate the impact on total collateral demand of more widespread initial margin requirements, increased novation of CDS to central clearing parties (CCPs), an increase in the number of clearing members, the proliferation of CCPs of both specialized and non-specialized types, collateral rehypothecation practices, and client clearing. System-wide collateral demand is increased significantly by the application of initial margin requirements for dealers, whether or not the CDS are cleared. Given these dealer-to-dealer initial margin requirements, mandatory central clearing is shown to *lower*, not raise, system-wide collateral demand, provided there is no significant proliferation of CCPs. Central clearing does, however, have significant distributional consequences for collateral requirements across market participants.

JEL codes: G20, G28, G15.

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†. Graduate School of Business, Stanford University, and National Bureau of Economic Research. E-mail: duffie@stanford.edu.

‡. European Systemic Risk Board. martin.scheicher@ecb.europa.eu

§. Sciences-Po Paris and Banque de France. E-mail: guillaume.vuillemey@sciences-po.fr

Introduction

We use an extensive data set of bilateral credit default swap (CDS) positions to estimate the impact of new central clearing and margin regulations on the aggregate market demand for collateral. In contrast to previous work based on hypothetical or roughly calibrated exposures, we use an actual network of long and short CDS exposures. We consider the implications for collateral demand of a variety of alternative market structures.

Central clearing for all standardized OTC derivatives is a key element of the ongoing reform of the financial system (FSB, 2013). A central clearing party (CCP) steps into bilateral trades by means of novation, becoming the buyer to every seller, and seller to every buyer. By taking on and subsequently mitigating counterparty credit risk, CCPs insulate their members from default losses. To this end, they collect collateral in the form of initial and variation margins, among other risk-management procedures.

Central clearing introduces a tradeoff in collateral demand between the benefits of multilateral netting within a class of contracts against lost bilateral netting benefits across contract types.[5] Duffie and Zhu (2011) and Cont and Kokholm (2014) demonstrate the key role in this tradeoff of the market network structure and of the covariance of price changes across asset classes, but do not provide a clear-cut answer as to which effect dominates. Furthermore, these prior studies did not rely on actual bilateral exposure and price data, and were limited to simplified market structures.

The impact of regulatory reform of the derivatives markets on collateral demand is a key concern for policy makers. On the one hand, because CCPs are set to become direct and large counterparties to the most important market participants, the increasing use of central clearing raises concerns about the concentration of risk within a few institutions.[6] High collateralization standards, central clearing, and capital requirements, among other new regulatory standards, have become the new norm. On the other hand, there have been concerns, for example those of Singh (2010b), over the extent to which CCPs tie up large amounts of cash or high-grade assets. In the empirical literature, a number of authors have assessed changes in collateral demand due to mandatory central clearing, arriving at a broad range of estimates, recently compiled by Sidanius and Zikes (2012).

We use a comprehensive dataset of CDS bilateral exposures covering about 31.5% of the global single-name CDS market to assess the impact of

5. Absent a CCP, bilateral netting opportunities exist across asset classes, or with contracts that are not eligible for central clearing. In contrast, multilateral netting through a CCP is typically possible for one asset class only and, within an asset class, for a subset of contracts being liquid or standardized enough. See Duffie and Zhu (2011) for a detailed theoretical investigation of this trade-off.

6. For example, the US Financial Stability Oversight Council has designated three CCPs as systemically important under Title VIII of the Dodd-Frank Act.

a variety of margining and clearing schemes on collateral demand and its decomposition. The case of CDS is of particular interest because credit risk is correlated with systemic risk (Duffie et al., 2009). Furthermore, CDS feature jump-to-default risk, thereby increasing the volatility of market values. Our sample, obtained from the Depository Trust & Clearing Corporation (DTCC), covers virtually all CDS bilateral exposures on 184 reference entities representing 31.5% of the global single-name CDS market as of the end of 2011. Uniquely among available data sets, this data set includes all counterparties at a *global* level for each referenced name, and is thus well suited to analyze the implications of margining and netting in the aftermath of the global derivatives market reform. Prior empirical work used aggregate data releases for dealers (Heller and Vause, 2012), or market-wide data (Sidanius and Zikes, 2012) at a product-level (CDS and interest rate swaps), thus missing some key effects of network structure and of the heterogeneity of counterparty portfolios. As a result, the multilateral netting benefits of clearing may have been mis-estimated in earlier work.

We study a variety of clearing schemes and market structures. Previous work had studied only simple market structures. Starting from a base case, either with or without new dealer-to-dealer margin requirements, we analyze four effects : an increase in novation to existing CCPs, an increase in the number of clearing members, an increase in the number of CCPs, and client clearing. (In a "client clearing" regime, dealers clear the derivatives portfolio of their client end-users.) The second and the fourth of these effects had not been examined in prior work on this subject. Although the effect on collateral demand of increasing the number of CCPs had been investigated by Duffie and Zhu (2011), that study was severely limited by lack of access to bilateral exposure data. We distinguish between the impact of adding "specialized" CCPs, as opposed to "non-specialized" CCPs, which are shown to be substantially less efficient in collateral use because of lost netting and diversification opportunities. This type of CCP specialization is indeed observed in the data. As opposed to prior research, our data enable us to model both dealer and customer positions.

We estimate a fully specified margin model that allows a decomposition of margin demand both by trader type (customer or dealer) as well as by type of margin demand. Our model captures portfolio-specific initial margins, a contract-specific short charge for net CDS sellers, a precautionary buffer stock of unencumbered liquid assets designed to meet uncertain near-term variation margin calls, and the "velocity drag" of collateral movement within the financial system. The last two of these components had not been examined in previous research. We show that these frictional demands for variation margin may have a significant impact on total collateral demand. Our model captures how these various components of margin demand incorporate the effects of cross-counterparty netting and diversification, which change with the clearing scheme and network structure.

Overall, we show that system-wide collateral demand is increased significantly by the application of initial margin requirements for dealers, whether or not CDS are cleared. Given the new requirement for dealer-to-dealer initial margins, mandatory central clearing is shown to substantially *lower* system-wide collateral demand, provided there is no significant proliferation of CCPs.

We show that client clearing reduces system-wide collateral demand provided that dealers are able to re-use a large enough share of the collateral that they receive from their clients. The drop in collateral demand is driven by cross-counterparty netting and by diversification benefits, both for customers and dealers, and depends on the size of each investor's portfolio. Netting and diversification benefits outweigh increased initial margin requirements for investors whose portfolios are large enough. Clearing thus has distributional consequences across investors, favoring traders with large and well-diversified portfolios. Collateral demand for investors with a low multilateral net-over-gross notional exposure can be significantly reduced when central clearing is implemented.

In sum, most of the increase in collateral demand associated with the new regulatory environment for CDS is caused by an increase in the set of market participants required to provide margin at standardized levels. Central clearing does not itself cause a major incremental increase in collateral usage, unless there is a further proliferation of central clearing parties. For a given level of protection against counterparty failure risk, the key determinant of collateral demand is netting. Combining offsetting and diversifying swaps in the same netting sets causes a significant lowering of collateral demand. Central clearing can either improve or reduce netting opportunities, depending on how much is cleared, how many CCPs are used, and the degree to which the same swaps are cleared in different CCPs. Although every unit of variation margin paid by some market participant is received by its counterparty, the need to retain buffer stocks of unencumbered funds suitable for variation margin payments and the frictional drag associated with the operational lags in the usability of margin funds are important components of the total demand for collateral.

The remainder of the paper is structured as follows. The relevant literature is briefly discussed in Section 1. The exposure data are then described in Section 2. The baseline model for collateral demand is presented in Section 3, and the basic results are then described in Section 4. Finally, the impact of four alternative clearing models is analyzed in Section 5.

1 Related literature

There is a growing literature on counterparty credit risk in OTC markets. Acharya and Bisin (2014) investigate theoretically the existence of a counterparty risk externality on opaque OTC markets, which is shown to be absent when a centralized clearing mechanism is implemented. Zawadowski (2013) models an OTC market in which unhedged counterparty risk may lead to a systemic run of lenders in case of idiosyncratic bank failure. Thompson (2010) studies the signaling incentives induced by counterparty risk. Empirical evidence on the pricing of counterparty risk on the CDS market has been provided by Arora et al. (2012).

Central clearing parties as institutions mitigating counterparty risk have recently been studied theoretically and empirically. Biais et al. (2012) and Koeppl et al. (2011) analyse theoretically the optimal design of incentive-compatible clearing arrangements. The working of clearing institutions during the October 1987 crash has been discussed by Bernanke (1990). More recently, clearing in derivative markets has been described by Pirrong (2009) and Singh (2010a). Hull (2010) discusses the issue whether all OTC derivative transactions can be centrally cleared. Loon and Zhong (2014) use data on voluntarily cleared CDS contracts to document a reduction of both counterparty risk and systemic risk. The exposure of a CCP to the default of its members has been quantified by Jones and Perignon (2013).

Our results are relevant to ongoing debates on the relative magnitude of the trade-offs involved in central clearing. On the one hand, Duffie and Zhu (2011) showed that central clearing need not reduce counterparty exposure if CCPs proliferate or if an insufficient fraction of positions are centrally cleared, leading to a loss in cross-asset bilateral netting. On the other hand, Cont and Kokholm (2014) qualify these results within the same framework by considering heterogenous risk characteristics for the cleared assets. As more highly volatile assets are centrally cleared, the gains from multilateral netting are larger. In related work, Anderson et al. (2013) analyse CCP interoperability and the efficiency of multilateral netting with linked and unlinked CCP configurations. Currently, there are no interoperating CCPs for credit default swaps.

Empirically, our paper is most closely related to Heller and Vause (2012) and Sidanius and Zikes (2012), who estimate the system-wide increase in collateral demand due to mandatory central clearing. We extend their work in several respects. Rather that using simulated exposure data, we use actual bilateral pre-reform exposure data. This enables us to distinguish between customers and dealers and to account for actual netting and diversification benefits at the level of bilateral portfolios. Because of the granularity of our data, we are able to considerably refine the impact of clearing schemes and market structures. For instance, emerging client clearing practices had not been modeled earlier, nor had the impact of the number of clearing members on collateral demand. Finally, from contract-level exposure data, our margining model enables us to document the netting and diversification benefits of increased clearing, as well as the size of each component of collateral demand. Among these, the demand for collateral in the system associated with variation margin precautionary buffers and velocity drag have not been analysed previously.

2 The CDS exposure data

This section describes our data and some descriptive statistics concerning the CDS network structure.

2.1 The bilateral exposure dataset

Our CDS bilateral exposure data are provided by DTCC, as extracted from the Trade Information Warehouse (TIW) [7]. The snapshot of the world CDS market is taken as of 30 December 2011, for a large number of major reference entities. The TIW is a global trade repository covering the vast majority of CDS trades worldwide, and virtually all recent CDS trades. This data set is a legal record of party-to-party transactions, as the Warehouse Trust Company (a subsidiary of DTCC which operates the TIW) is supervised by US regulatory authorities. In addition to capturing the positions of dealers and banks, our dataset encompasses non-bank market participants such as hedge funds, insurance companies, central counterparties and potentially some industrial corporations. The dataset is unique because of the global nature of its coverage. Most national regulators use DTCC exposure data that are related only to their *domestic* reference entities or institutions.

Our sample does not include all CDS names in the TIW. It covers 184 reference entities, including 9 G20 sovereign, 22 European sovereign and 153 global financial entities. The data do not include single-name non-financial corporate names nor multi-name and index CDS. The sovereign and financial names included in our data, however, represent a sizable and growing share of the global single-name CDS market. [8] Our dataset contains the names of the reference entities, but the identities of the counterparties are anonymized. A total gross notional of USD 4.91 trillion of CDS is covered by our sample. At the same date (30 December 2011) the total gross notional of the global CDS market was USD 25.9 trillion (ISDA, 2012). Our sample thus represents about 31.5% of the global single-name CDS market and 18.9% of the total CDS market (including multi-name instruments). We excluded

7. The bilateral CDS exposure data used in this paper are confidential and proprietary. These data were collected by DTCC under a regulatory mandate. Hence for legal reasons, they cannot be shared.

8. While the share of financial CDS within the global single name CDS market has been roughly constant over the past years—from 21.52% in end-December 2008 to 21.53% in December 2011 (sample date) and to 20.81% in February 2014—the share of sovereign CDS has been growing steadily—from 10.89% in end-December 2008 to 19.62% in December 2011 and to 23.80% in February 2014. This aggregated sector-wide data is retrieved from the public DTCC TIW data, “Open positions data,” Table 2.

Asian names in order to partition the set of reference entities into two subsets (European and American names), which is useful when analyzing the effect of specialized versus non-specialized central clearing. As our empirical analysis relies on the use of CDS price data, all CDS for which there is no available price time series on Bloomberg have been excluded.

For each reference entity, our dataset contains gross and net bilateral exposures between any two counterparties. The overall network consists of 44,155 bilateral exposures on individual reference entities. Any bilateral exposure may result from several separate transactions, so that the number of transactions covered is 503,119. We do not have access to additional information at a transaction level. For example, we know neither the date on which a particular deal was executed nor the maturity (initial or remaining) of each position. The market values of open positions are not available. We approximate changes in market values from CDS rate data, as explained in Appendix B, using daily mid-quotes for 5-year senior CDS from Bloomberg, from January 2008 to end-December 2011.

We have performed checks on data quality. We drop 328 bilateral exposures of a counterparty vis-à-vis itself. Such exposures involve 12 individual counterparties, are negligible for our purposes, and in any case reflect aggregation inconsistencies at a bank level (an internal trade between two accounts or two subsidiaries or other legal entities of the same firm).

2.2 Description of the CDS network

This subsection provides general descriptive statistics for the sampled CDS network[9] (Table 1) and for investor portfolios (Table 2).

In total, 855 counterparties have been active with a position referencing at least one of the 184 reference entities. While the market-wide gross notional amount is 4.91 trillion USD, the total net exposure is significantly lower, at about 375 billion USD. In settings such as this, with a low ratio of net-to-gross notional (here only 7.6%), central clearing has the potential to achieve substantially improved netting benefits. Our data show low net-to-gross ratios for both sovereign and financial reference names, at 8.6% and 6.9%, respectively.

A second stylized fact is the low share of net sellers of protection, only 18.1% in our sample, indicating that the vast majority of CDS end-users are net buyers. An implication is that ultimate credit risk exposure is potentially concentrated within a relatively small subset of CDS investors. This also highlights the benefits of capturing, as we do, cross-CDS diversification

9. A more detailed description of the CDS network, using the same dataset but a slightly larger sample (including both Asian names and names for which no CDS price data is available) can be found in Peltonen et al. (2014). They also provide a topological description of the CDS market using metrics developed in the literature on financial networks.

	All names	Sovereigns	Financials
Number of CDS	184	31	153
Number of traders	885	626	677
Gross notional (billion USD)	4,906	2,070	2,836
Net notional (billion USD)	375.3	178.2	197.1
Net over gross (%)	7.6	8.6	6.9
Number of Observations	44,155	10,653	33,502
Number of Positions	503,119	125,622	377,497
Avg. notional position (million USD)	9.75	15.58	7.51
Share of net sellers (%)	18.1	16.2	18.4

TABLE 1 – Descriptive statistics of the CDS sample. Underlying data source : DTCC.

effects when computing margins.

	Dealers	Customers
Number of traders	14	869
Avg. number of counterparties	288.4	5.0
Avg. number of names traded	182.8	11.3
Gross notional (billions USD)	8,285	1,528
Net notional (billions USD)	287.3	436.3
Net over gross (%)	3.5	28.6
Market share (%)	84.4	15.6

TABLE 2 – Descriptive statistics for CDS market participants. This table summarizes CDS portfolio characteristics for dealers and customers. Only sovereign and financial, non-Asian, referenced names are included. The calculation of gross and net notional exposures involves double counting, as any CDS position is counted for each of its two counterparties. Market shares are based on gross exposures. Underlying data source : DTCC.

2.3 Empirical Identification of CCPs and Dealers

We next turn to the empirical identification of CCPs and dealers within the set of anonymous market participants.

Some of the positions in our data were already centrally cleared at the date of our snapshot.[10] Given the anonymization of counterparties in the data and our focus on clearing schemes, we first separate the bilaterally

10. Loon and Zhong (2014) discuss why centrally cleared trades may coexist with un-

and centrally cleared exposures. CCPs are identified by their large gross exposures but consistently zero multilateral net exposures on *all* reference entities.[11] Among the 50 largest counterparties[12] as ranked by gross notional amounts bought and sold, we identify two CCPs with virtual certainty.

The identified CCP-cleared exposures represent 7.02% of the market gross notional amount. Consistent with this, at year-end 2011 ISDA estimated the percentage of CCP-cleared single-name CDS to be around 8%, based on a broader sample. The presence of 2 active CCPs for CDS in December 2011 is also consistent with market facts. Although 3 CCPs were active in the CDS market (ICE Clear Credit, ICE Clear Europe and LCH CDSClear), only the first two were active in single-name CDS according to the 2011 annual reports of these three firms. LCH CDSClear was active only in index CDS.

Descriptive statistics regarding the two CCPs are provided in Table 3. Of the 184 names referenced in our sample, we find that 39 of these have centrally cleared CDS. For reference names that have some CDS cleared by at least one CCP, on average 32% of the gross notional amounts are centrally cleared. No CDS is cleared by both CCPs. One CCP clears only European names, of which there are 14. The other CCP clears only North American and Latin American names, of which there are 25, and which we will henceforth call "American." The median gross notional amount of a cleared name is 13.5 billion USD, which is about 90% larger than the sample median, implying that clearable names are generally those with large gross notional outstanding amounts.

We next identify as dealers those market participants, other than CCPs, with very high concentrations of bilateral positions. We can easily identify 14 dealers, in line with anecdotal evidence according to which the CDS market is centered around 14 dealers (Brunnermeier et al., 2013; Peltonen et al., 2014). Dealers in the sample are the only CCP members. Comparative descriptive statistics for dealers and customers are presented in Table 4. The market structure is highly concentrated around these 14 dealers, who have positions in almost all CDS referenced names (182.8 on average for dealers,

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cleared trades, following the launch of ICE Clear Credit (ICECC), a leading clearinghouse. They document reductions in both counterparty and systemic risk that are induced by central clearing.

11. Formally, in terms of the notations introduced below (section 3.1), an institution i is identified as a CCP if $\sum_j \left[G^k(i,j) + G^k(j,i)\right] \geq 5.8$ billion USD and $\sum_j \left[X^k(i,j) - X^k(j,i)\right] = 0$ for all k. The threshold of 5.8 billion USD corresponds to the gross buy and sell notional amount traded by the 50th largest institution.

12. The criteria for identifying CCPs are valid for institutions with an large activity only. Indeed, we do observe a handful of much less active institutions trading one or two CDS and having a zero multilateral net exposure. These institutions, however, are not likely to be central clearing parties. Institutions below the top-50 trade gross long and short notional amounts below 3 billion USD. An active CCP is unlikely to trade such low notional amounts.

Descriptive statistics	Sample
Number of clearable CDS	39 of 184
Volume cleared through CCPs	7.02%
Notional cleared to notional clearable	
Minimum	0.4%
Average	32%
Maximum	47.9%
Market shares (notional)	
CCP 1	64.7%
CCP 2	35.3%
Market shares (names)	
CCP 1	American
CCP 2	European

TABLE 3 – Descriptive statistics on CCP-cleared exposures. This table describes the two CCPs identified in the dataset. No overlap in the names cleared by both of them is observed. Instead, an American/European breakdown is documented, with a larger market share for the CCP clearing American names. American names include Central and Latin America, Canada and the United States. European Names include Norway, Russia, Switzerland and the European Union. Underlying data source : DTCC.

out of 184 in total). Customers of dealers are exposed to only 11.3 names, on average. While customers have on average only 5.0 counterparties, each dealer has on average 288 counterparties. The hypothesis that exposures in the CDS market are distributed according to a power law cannot be rejected (Peltonen et al., 2014). This implies that interconnectedness in the CDS market does not arise from the large number of bilateral links between any two counterparties, but because all investors are close to one another due to the existence of a few highly-connected intermediary dealers.

Dealers are clearly the dominant intermediaries in the market. Only 3% of trades are customer-to-customer. Most customers trade with one of their prime brokers. In contrast, dealer-to-dealer trades represent 75.1% of the total number of trades. The ratio of net to gross notional exposures is 28.6% for customers ; for dealers, this ratio is only 3.5%. Thus, while dealers provide net (long or short) exposures to customers, a large part of these exposures is hedged either through dealer-to-dealer trades or through offsetting exposures to other customers. Hence, the highly skewed distribution of CDS market activity (as measured by gross notional exposures) does not match that of ultimate credit risk, as proxied by net notional exposures. While dealers account for 84.4% of gross market exposures, their positions represent only 39.7% of net exposures.

	Dealers	Customers
Number of institutions	14	871
Number of CDS traded		
Minimum	179	1
Median	184	5
Maximum	184	177
Gross notional (billion USD)		
Minimum	104.1	0.0002
Median	286.3	0.07
Maximum	503.7	120.5
Number of counterparties		
Minimum	102	1
Median	310	3
Maximum	460	50

TABLE 4 – Descriptive statistics for dealers and customers. This table presents comparative descriptive statistics for dealers and customers. The D dealers are identified by the fact that they belong to the existing central clearing parties. Dealers consistently trade a larger number of CDS than customers and with a larger number of counterparties. With one exception, this is also true for the gross notional amount traded. Group differences in median values are highly significant. Source : DTCC.

3 Baseline model

In the baseline model studied in this section, we focus on collateral demand for the actual network of exposures. In later sections we focus on the impact of increased novation to CCPs under a variety of alternative market structures.

3.1 Preliminaries

A set $\Omega = \{1, \ldots, n\}$ of market participants, called "investors" for simplicity, is partitioned into two subsets based on their membership in one or more CCPs. Of the n investors, D institutions, called *dealers* or *clearing members*, are members of at least one CCP. The remaining $n - D$ investors, called *customers* or *end users*, do not have a direct membership to central clearing parties. In addition, there is a set of n^{CCP} central counterparties that do not belong to Ω. Finally, there are K referenced entities. The $n \times n$ bilateral exposure matrix G^k for reference entity k has as its (i, j) element the gross CDS notional referencing k that is sold by investor i to investor j. This does not include exposures to or from CCPs. The associated $n \times n$ net bilateral exposure matrix X^k is defined by

$$X^k(i, j) = \max\left\{0; G^k(i, j) - G^k(j, i)\right\}.$$

Thus $X^k(i,j) = 0$ whenever $X^k(j,i) > 0$.

Collateral requirements are defined for four types of bilateral exposures : customer-to-dealer, dealer-to-dealer, dealer-to-CCP and customer-to-customer. Our model accounts for initial margin, a precautionary buffer stock to serve variation margin payments, and for variation margin "velocity drag" associated with limits on the speed with which payments sent by a market participant can be deployed by its receiver. In addition, we allow for differences in collateral posting and re-hypothecation between bilateral and centrally cleared positions.

Margin requirements for all types of institutions are summarized in Table 5. In the baseline model, these are designed to capture widespread market practices in place before mandatory central clearing was implemented. First, initial margins are posted by customers to all of their counterparties. By contrast, in the baseline model dealers do not post initial margins to customers. Dealer-to-dealer initial margins are treated parametrically so as to consider a range of cases. Ongoing regulatory reforms are set to require dealer-to-dealer initial margins (Basel Commission on Banking Supervision, 2013b). Dealers post initial margins to CCPs, whereas CCPs do not post initial margins to clearing members.

Party	**Counterparty**	**Initial Margins**	**Variation Margins**
Customer	Dealer	Yes	Yes
Dealer	Customer	No	Yes
Dealer	Dealer	Yes/No	Yes
Customer	Customer	Yes	Yes
Dealer	CCP	Yes	Yes
CCP	Dealer	No	Yes

Table 5 – Initial and variation margin requirements. This table describes the margin requirements for all possible pairs of trader types. In the baseline case and for alternative specifications, results are presented both with and without dealer initial margins, thus enabling a reproduction of both the pre-reform and the post-reform cases.

3.2 Initial margins

Initial margins between any two parties are computed at a bilateral portfolio level. These are calculated as the sum of a risk-based component and a short charge for net CDS sellers, in order to replicate current market practice, as explained in sources cited below. We define the bilateral portfolio $\mathcal{P}_{ij}$ between any i and j as the $K \times 1$ vector

$$\mathcal{P}_{ij} = \left(X^1(i,j) - X^1(j,i), \ldots, X^K(i,j) - X^K(j,i) \right).$$

Element k of $\mathcal{P}_{ij}$ is positive whenever i is a net seller to j on reference entity k, and negative otherwise. The absolute value of the change in the market value of $\mathcal{P}_{ij}$ over the period of T business days from $t-T+1$ and t is

$$\phi_T^t\left(\mathcal{P}_{ij}\right)=\left|\sum_k\left(X^k\left(i,j\right)-X^k\left(j,i\right)\right)\left(p_t^k-p_{t-T+1}^k\right)\right|, \tag{1}$$

where p_t^k is the price of CDS k at date t. The initial margin to be posted by i to j, denoted C_{ij}^{IM}, is the worst historical change in the value of $\mathcal{P}_{ij}$ over any T-day period, computed over the last $P \geq T$ days. Throughout our analysis, we take the look-back period P to be 1000 days. This general approach to setting initial margins is used by the largest market participants, including ICE Clear Credit and ICE Clear Europe (ICE, 2012).[13] Thus,

$$C_{ij}^{IM}=\phi_T^{t^*}\left(\mathcal{P}_{ij}\right), \text{ where } t^*\equiv \text{argmax}_{t\in\{T+1,P\}}\ \phi_T^t\left(\mathcal{P}_{ij}\right). \tag{2}$$

In addition to the portfolio-based initial margin (which is equal for both i and j), we follow market practice, described for example by LCH-Clearnet (2012), by adding a *short charge* for net CDS sellers in order to account for the asymmetric nature of CDS payoffs and mitigate jump-to-default risk.

As with market practice, beyond the elements already described, our initial margin calculations do not incorporate estimates of loss at reference entity defaults, of which there are none in our sample period.[14]

Appendix B explains how we approximate changes in market values of CDS from our CDS rate data. Because we do not have data on the maturity distribution of CDS positions, the total magnitudes of collateral demand that we estimate have a significant potential estimation error. Our main focus, however, is on the *relative* effects of various alternative market structures and practices. These relative effects are largely robust to the effects of variation in maturity, given that changes in market value are in practice roughly proportional to maturity, as discussed in Appendix B. This proportionality approximation does not apply to jump-to-default effects, but we apply a separate and maturity-independent short charge for initial margin to cover jump-to-default risk, as is common in practice.

Customers post initial collateral to any counterparty. By contrast, dealers post initial margin only to central clearing parties and, to an extent parameterized below, to other dealers.

13. Both ICE Clear Credit and ICE Clear Europe consider a 99% confidence level over a 5-day horizon. CME and Eurex Clearing use the same methodology. LCH-Clearnet (2012) use a closely related methodology. Minor differences exist in the look-back period P.

14. Another source of potential minor under-estimation of collateral demand stems from the fact that, due to data limitations, each exposure $X^k\left(j,i\right)$ may aggregate CDS traded at different dates and with different maturities. Thus CDS exposures which we consider as fully offsetting may nevertheless give rise to collateral posting on actual markets, once heterogeneity with respect to these contract specifications is considered.

The total initial margin to be posted by any customer i, denoted C_i^{IM}, is

$$C_i^{IM} = \sum_j \left[\upsilon^C \phi_T^{t^*}(\mathcal{P}_{ij}) + \alpha^C \sum_k X^k(i,j) \right]. \tag{3}$$

The first term in the sum across counterparties is the initial margin computed from the left tail of the portfolio historical value $\phi_T^{t^*}(\mathcal{P}_{ij})$. The second component is a short charge computed on the basis of all net bilateral short exposures at a reference entity level, parameterized by α^C. Here, $\upsilon^C \in [0,1]$ is a parameter capturing the fraction of collateralization of bilaterally cleared trades relative to centrally cleared trades. [15] For a fully collateralized position, $\upsilon^C = 1$.

In our base case, we assume no rehypothecation of collateral, and later examine the impact of rehypothecation by dealers. The total base-case initial margin of dealer i is thus

$$\begin{aligned} C_i^{IM} &= \sum_{d=1}^{D} \left[\upsilon^D \phi_T^{t^*}(\mathcal{P}_{i,d}) + \alpha^D \sum_d X^k(i,d) \right] \\ &\quad + \sum_{h=1}^{n^{CCP}} \left[\phi_T^{t^*}(\mathcal{P}_{i,CCP_h}) + \alpha^{CCP} \sum_h X^k(i,CCP_h) \right], \end{aligned} \tag{4}$$

where $\mathcal{P}_{i,CCP_h}$ denotes the bilateral portfolio of a clearing member i vis-a-vis CCP h. The first term in equation (4) corresponds to dealer-to-dealer initial margins. The second term corresponds to margins posted to CCPs. As reflected in (1) and (2), portfolio diversification reduces initial margin requirements.

In later sections, we allow the short charge for centrally cleared positions to vary from that for bilaterally held positions. That is, $\alpha^D < \alpha^{CCP}$. We also allow for different margin parameters for customers and dealers (υ^C and υ^D for partial-collateralization, α^C and α^D for the short charge). We also later consider a base case in which $\upsilon^D = 0$ and $\alpha^D = 0$, that is, an absence of dealer-to-dealer initial margins.

Throughout, we ignore the paid-in components of dealer contributions to CCP default guarantee funds, which are relatively fixed. To the extent that default guarantee fund contributions vary with market structure, they could be roughly approximated as a multiple of average initial dealer margins posted at CCPs.

15. Levels of collateralization below 1 are documented for bilaterally cleared trades by ISDA (2011, p.14).

3.3 Precautionary Buffer for Variation Margin

As explained in Appendix A, in order to be prepared to pay variation margins any market participant must have a precautionary stock of unencumbered assets ready to be transferred. In industry practice, this buffer is sometimes called "pre-funded" variation margin. For investor i, this collateral buffer is computed on the basis of its whole portfolio, regardless of the distribution of positions across counterparties, and is estimated by

$$C_i^{VM} = \kappa^{VM} \sigma \left(\sum_k \sum_j \left| X^k(i,j) - X^k(j,i) \right| \right), \tag{5}$$

where, for any portfolio p of positions, $\sigma(p)$ denotes the standard deviation of the one-day change in market value of the portfolio, and where $\kappa^{VM} > 0$ is a multiplier that we vary parametrically. We explain in Appendix A that κ^{VM} depends in part on the shadow price for holding idle collateral and on the cost of a need to obtain immediate liquidity in the event that the buffer stock is exhausted. The derivatives divisions of trading firms are often assigned by their group treasuries an explicit per-unit price for access to a pre-funded buffer of unencumbered assets for purposes of margin payments.

Equation (5) captures the benefits of portfolio diversification, including the impact on $\sigma(p)$ of covariances of changes in the market values of the CDS positions. These covariances are estimated from the trailing-1000-day sample of CDS pricing data.

3.4 Variation Margin Velocity Drag

As noted by Singh (2011), when considering system-wide demands for collateral related to clearing, the velocity of circulation of collateral matters. We use a simple reduced-form model of margin velocity "drag" that is further motivated in Appendix A. From the time that variation margin is committed to be transferred and until the time at which it becomes ready to deploy by the counterparty to whom it is transferred, variation margin payments are assumed to be unavailable, and thus augment the collateral demand by a "drag" amount

$$C_i^{D} = \sum_j \kappa^{D} \sigma \left(\sum_k \left| X^k(i,j) - X^k(j,i) \right| \right), \tag{6}$$

where κ^D is a fixed parameter. For example, in expectation, some fraction of the margin sent from investor i to investor j on a Tuesday may not be ready to deploy by investor j until Wednesday. Whereas variation margin precautionary buffers are computed on the basis of an investor's entire portfolio (regardless of the particular counterparties), the velocity drag component of variation margin depends on the structure of bilateral exposures. The magnitude of the variation margin drag therefore changes when a CCP is interposed between dealers, or with any other change in network structure.

In order to give a sense of the amount of variation margin "in flight" on a given day, we note the 2014 ISDA Collateral Survey indicates that each of the largest dealers receives, on average, over 7 billion USD in margin payments on a given day, the vast majority of which is variation margin. [16]

3.5 Total Collateral Demand

The total collateral demand C at a system level is the sum of the three components,

$$C = \sum_{i=1}^{n} \hat{C}_i^{IM} + C_i^{VM} + C_i^{D}. \quad (7)$$

4 Baseline Collateral Demand

This section focuses on collateral demand for the baseline case, taking the allocation of positions to CCPs as observed in the data. Here, we consider the impact on collateral demand of *(i)* adding dealer-to-dealer initial-margin requirements, *(ii)* varying the number T of days used to determine the "worst-case" historical loss for the purpose of initial margin requirement, from 3 days to 10 days, and *(iii)* the rehypothecation of collateral for uncleared positions. In the following section, we consider the impact on margin demand of increasing the set of positions allocated to CCPs, and various other alternative market designs.

4.1 Calibration

We describe here how our parameters are calibrated in order to approximate actual market practices.

Initial margins are designed to cover the potential future exposure of a party (including the CCP) over the period of days that may be needed to liquidate and replace exposures with a defaulted counterparty. In the base case, initial margins are based on the "worst-case" loss at a bilateral portfolio level over a period of $T = 5$ days, as estimated from historical simulation for the $P = 1000$ trading days prior to December 2011.

16. See Table 18 on page 22 of ISDA (2014). Of those reporting initial margin (IM) and variation margin (VM) separately, only 0.13 billion USD received is IM, whereas 2.4 billion USD is VM.

Relatively little public guidance exists to calibrate the precautionary buffer stocks of collateral used to "pre-fund" variation margin payments. Conversations with industry experts coupled with the modeling in Appendix B lead us to assume a buffer that is a multiple of $\kappa^{VM} = 2$ of the daily net-payment standard deviation. For illustration, in the absence of serially correlated returns, this means that an average investor sets aside a buffer that is roughly equal to the estimated standard deviation of net variation margin payments over a 4-day period. In practice, there is variation across types of investors. We understand that some participants in CDS markets, such as asset managers acting as agents for their clients or limited partners, typically hold an excess stock of unencumbered cash-like assets, so set aside no extra amount of collateral as a variation-margin buffer. Other investors such as broker-dealers treat access to unencumbered cash-like instruments as a binding constraint and arrange at a cost for the pre-funding of over a week's worth of adverse variation-margin payments. Under new Basel guidelines for liquidity coverage regulations, bank-affiliated dealers will be forced to set aside unencumbered cash-like assets sufficient to cover 30 days of net cash outflows, including those associated with variation-margin payment on derivatives.[17]

As for the "velocity drag" on margin funds associated with the lag between the time at which margin funds are sent and the time by which they are ready to be deployed by the receiver, we assume a drag coefficient of $\kappa^D = 0.5$, corresponding roughly to the assumption that half of the funds sent on a given business day can be re-deployed by the receiver on the same day.

The calculation of short charges in the CDS market relies on the estimation of wrong-way risk (credit event and counterparty default occurring simultaneously, see LCH-Clearnet (2012)). Given data anonymization, no such estimation is possible here. We adopt instead a simplified approach. Short charges α^C and α^D for both customers and dealers are assumed to equal 1% of their net bilateral notional exposure. CCPs are assumed to take a more conservative stance and require $\alpha^{CCP} = 0.02$.

The fractional collateralization parameter for customers, υ^C, is set to 0.75, in line with the figure provided by ISDA (2011) for the entire OTC derivatives market. We assume a lower fractional collateralization $\upsilon^D = 0.5$

17. The final "Liquidity Coverage Ratio" rule, Basel Commission on Banking Supervision (2013a), states at Paragraph 123 that "As market practice requires collateralisation of mark-to-market exposures on derivative and other transactions, banks face potentially substantial liquidity risk exposures to these valuation changes. Inflows and outflows of transactions executed under the same master netting agreement can be treated on a net basis. Any outflow generated by increased needs related to market valuation changes should be included in the LCR calculated by identifying the largest absolute net 30-day collateral flow realised during the preceding 24 months. The absolute net collateral flow is based on both realised outflows and inflows. Supervisors may adjust the treatment flexibly according to circumstances."

for dealers, based on the view that a sizable share of dealer activity, including market making and prime brokerage, does not generate significant medium-term bilateral exposure. Finally, we assume no rehypothecation ($\rho = 0$) in the base case. These baseline parameters, and alternative specifications, are summarized in table 6.

Parameter	Definition	Baseline
	Baseline case	
υ^C	Level of under-collateralization for customers	0.75
υ^D	Level of under-collateralization for dealers	0.5
T	Initial margin period (days)	5
P	Initial margin sample period (days)	1000
α^C	Bilateral short charge for customers	0.01
α^D	Bilateral short charge for dealers	0.01
α^{CCP}	Short charge to CCP	0.02
ρ	Rehypothecation ratio	0
κ^{VM}	Variation margin buffer	2
κ^D	Variation margin drag	0.5
d	Remaining duration of CDS contracts (in years)	3
	Alternative specifications	
$\bar{t}$	Exposure-level CCP eligibility threshold	0
λ	Re-usable collateral for client clearing dealers	0.5

TABLE 6 – Calibration for the baseline model and alternative specifications. This table presents the calibration used both for the baseline model and for alternative specifications.

4.2 Collateral demand decomposition, with and without dealer-to-dealer initial margins

We consider the magnitude and decomposition of collateral for two calibrations of the baseline case. In the first case, dealers do not post initial margin to each other. That is, $\upsilon^D = 0$ and $\alpha^D = 0$. In the second case, we allow variation in υ^D and α^D and focus on the impact on total collateral demand of dealer-to-dealer initial margins. The first scenario is akin to the pre-reform case, while the second captures post-reform initial margin requirements.

The decomposition of collateral demand for these cases is illustrated in the first two columns of Figure 1. In the absence of dealer-to-dealer initial margins, 75.5% of total margin is posted by customers in the form of initial margins. Margin posted by dealers to CCPs accounts for only 7.3% of the system-wide collateral demand. Variation margins, through both precautionary buffers and velocity drag, account for 17.1% of the system-wide demand for collateral.

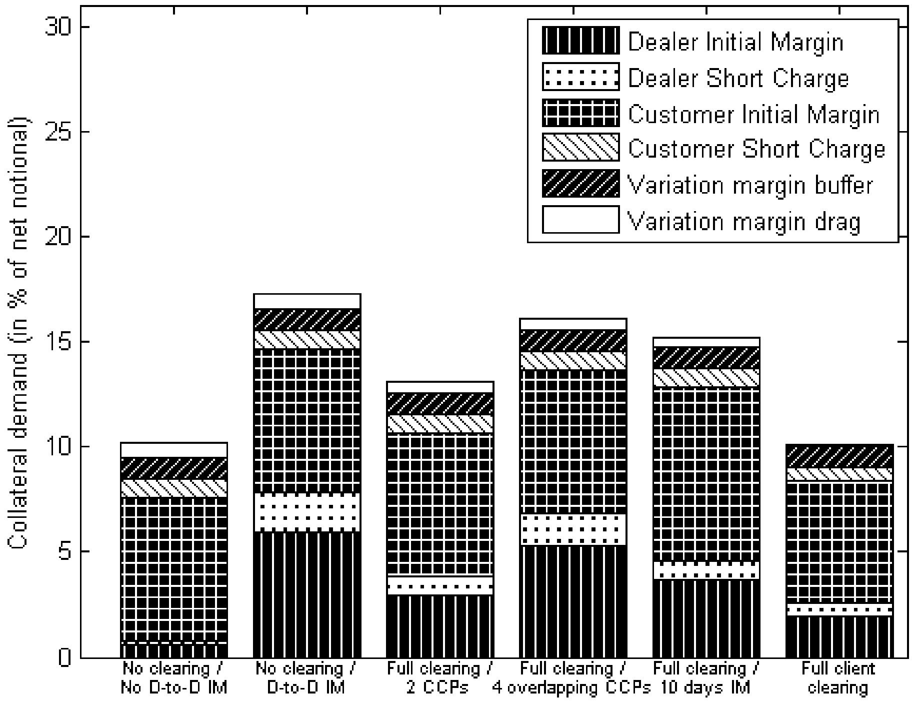


FIGURE 1 – Summary of the results. This chart summarizes the decomposition of system-wide collateral demand under six scenarios. The results are presented as a percent of the system-wide net notional exposure. "D-to-D IM" denotes dealer-to-dealer initial margins. All calibrations are those used in the models' respective sections and summarized in table 6.

The introduction of dealer-to-dealer initial margins increases total collateral demand by 69.7%. The increase is purely due to dealers' collateral demand, which increases by a factor of 10.5, then representing 45.4% of system-wide collateral demand. In this decomposition, the short charge component of initial margins is relatively more important for dealers (23.9%) than for customers (11.6%). This is due to the fact that dealers manage larger CDS portfolios than customers, therefore enjoying larger diversification benefits on the part of their initial margin requirement computed at a bilateral portfolio level (as suggested by equation (2)). The definition of the short charge excludes diversification effects, and thus represents a larger share of margin demands of dealers.

In terms of magnitude, without dealer-to-dealer initial margins, system-wide collateral demand is estimated to be about 10.2% of the market-wide net notional positions and 0.78% of the market-wide gross notional positions.

When including dealer-to-dealer initial margins, total collateral demand rises to 17.3% of net notional and 1.37% of gross notional. Even though our focus is less on the absolute level of collateral demand than on its decomposition and dynamics, our estimates are broadly consistent with market data. As of the end of 2011, the total reported worldwide collateral in use in OTC derivatives markets was 3.6 trillion USD (ISDA, 2012), while the gross notional amount of OTC derivatives worldwide was about 598 trillion USD, according to the BIS.[18] This yields a collateral-to-gross-notional ratio of 0.6%, slightly below our estimate of 0.78%. One potential reason for this difference is that we restrict attention to CDS which, due to their jump-to-default risk and higher mark-to-market volatility than interest-rate swaps, are relatively collateral intensive. Another explanation is that, due to our focus on a subset of the CDS market, we neglect some diversification benefits with reference entities which are not included in our sample. As mentioned in Appendix B, our estimates of absolute magnitudes of collateral demand are dependent on our assumptions and parameter values, in the absence of data bearing on the cross-sectional distribution of seasoned CDS maturities, regarding the average sensitivity of market values to changes in CDS rates. However, most of the collateral demand scales linearly in the calibrated CDS duration, so that relative effects—our main concern—are preserved. For reasons of tractability, our initial-margin model also neglects components that are sometimes assessed by CCPs for recovery risk margin, liquidity, and concentration risk. LCH-Clearnet (2012) offers a technical description of each of these components.

4.3 Sensitivity of initial margin to coverage period

In this subsection, we analyze the sensitivity of collateral demand to the initial margin model. The number of days T on which the worst historical change in portfolio value $\phi_T(\mathcal{P}_{ij})$ is computed (equation 2) is varied between 3 and 10 days. The appropriate choice of T for this purpose has been a matter of some disagreement between regulators and market participants in the United States.

Our results depend on the "clearing threshold," defined as the level of gross notional amount of CDS outstanding for a given reference name at or above which CDS for that reference name are assumed to be centrally cleared. Figure 2 plots total collateral demand, broken down between dealers and customers, for a given clearing threshold. From the baseline case ($T = 5$), an increase in the initial margin computation period to 10 days yields an increase in collateral demand by 25.5% for dealers and by 20.4% for customers. Moreover, the slope of the initial margin demand curve as

18. Semiannual OTC derivatives statistics at end-December 2011.

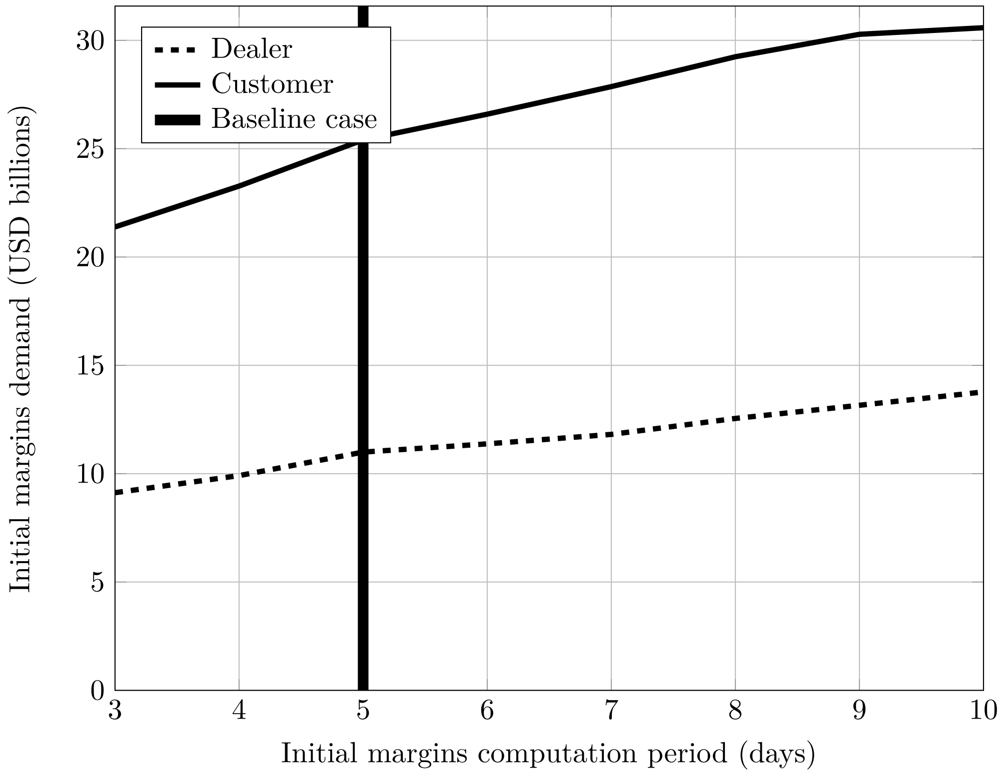


FIGURE 2 – Initial margins demand as a function of T. This chart plots the initial margins demand for dealers and customers when T is varied. The short charge is not included in the initial margin, as it does not change with T. This chart is for a given clearing threshold $\bar{T} = 1.4 \cdot 10^9$ (i.e. all CDS are centrally cleared).

T is varied is steeper for customers than for dealers. This higher sensitivity is explained by the fact that customers typically manage smaller CDS portfolios (as shown in Table 4), and therefore enjoy lower diversification benefits.

4.4 Impact of rehypothecation

In the market for bilaterally cleared derivatives, received collateral is commonly repledged, as indicated by ISDA (2014), economizing on the total amount of collateral held in the system. Because the objective of ISDA (2014) is to measure the degree to which counterparty exposures are covered by collateral, rather than the total amount of collateralizing assets "tied down" in the system, its results do not proportionately reduce collateral usage according to the extent of rehypothecation.

In this section we analyze the first-order effect of rehypothecation or other repledging practices in reducing total collateral demand. We denote by $\rho \in [0, 1]$ the "rehypothecation ratio," that is, the proportion of received collateral that a dealer may re-use. We assume that only dealers can re-use initial margin received from others. For dealer i, the total initial margin requirement, net of rehypothecated collateral, $\hat{C}_i^{IM}$, is

$$\hat{C}_i^{IM} = \max \left\{ 0; C_i^{IM} - \rho \sum_{d=1}^{D} C_{di}^{IM} \right\}. \tag{8}$$

Here, the collateral drag arising from rehypothecation is ignored.

The impact of rehypothecation on collateral demand in the baseline case is illustrated in Figure 3. In the presence of dealer-to-dealer initial margins for uncleared trades, the impact of rehypothecation on dealers' collateral demand is sizable. Initial margins decrease linearly with ρ, to the point at which, for a bank i, $\rho \sum_{d=1}^{D} C_{di}^{IM} > C_i^{IM}$. In the base case, with $\rho = 0$, dealers' collateral demand is 5.1 times higher than when $\rho = 1$. Because CCPs do not rehypothecate collateral, the increased use of central clearing lowers the collateral efficiency associated with rehypothecation, a point emphasized by Singh (2010b) and analyzed in the next section.

5 Impact of alternative clearing schemes

In this section we investigate alternative structural assumptions for the use of central clearing. We focus on the impact on collateral demand of *(i)* increasing novation to CCPs, *(ii)* increasing the subset of market participants that are clearing members of CCPs, *(iii)* increasing the number of CCPs, and *(iv)* introducing client clearing services.

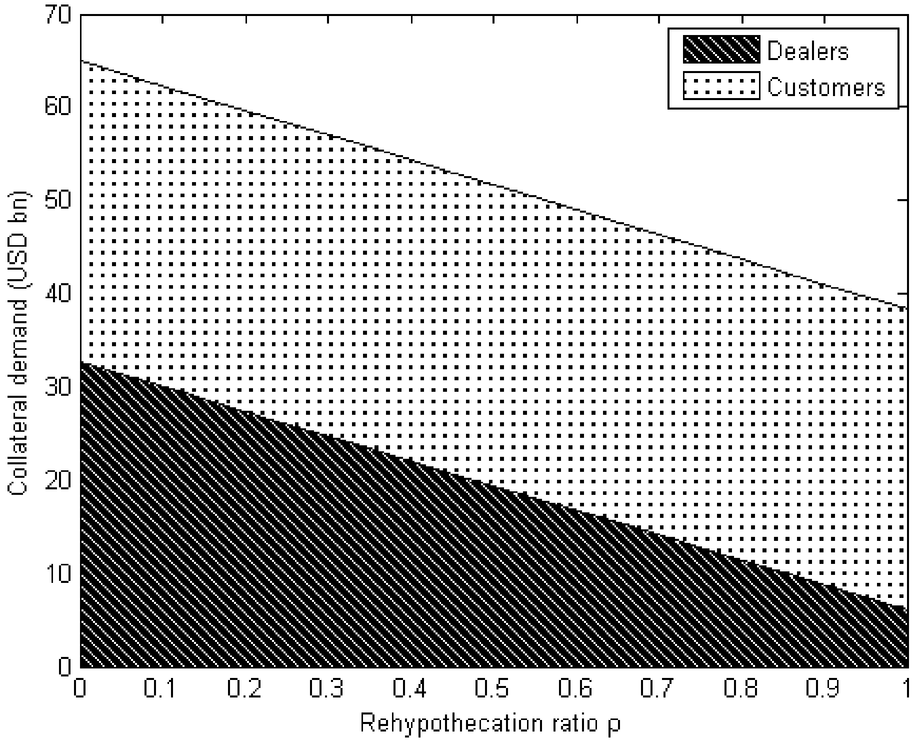


FIGURE 3 – Baseline collateral demand as a function of ρ. This chart shows a decomposition—between dealers and customers—of the system-wide collateral demand in the baseline case, as the rehypothecation ratio ρ is varied. The baseline case is with dealer-to-dealer initial margins, and with the network of exposures (including centrally cleared exposures) observed in the data. Only dealer-to-dealer collateral received is assumed be rehypothecated. Other calibrations are those of the baseline case.

5.1 Increased novation to CCPs

We first study the impact on collateral demand of increased novation to CCPs. We consider two base cases, with and without dealer-to-dealer initial margins.

The market-wide composition of customers, dealers, and CCPs, is kept at the baseline case. Regulatory reforms require central clearing for derivative contracts that are sufficiently standardized. We assume two requirements for a CDS exposure to be novated to a CCP. First, a CDS contract must be sufficiently actively traded. We assume that a reference entity is eligible for central clearing when its global gross notional amount is above a given threshold $\bar{T}$, a proxy for standardization. By dialing $\bar{T}$ down, we can analyze the gradual shift from the pre-reform to post-reform setting. Our dataset indeed suggests (as indicated in section 2.3) that CDS with the largest gross notional amounts (by referenced name) were the first to have been centrally cleared. This $\bar{T}$ is a reasonable proxy for "clearability." Second, whenever a reference entity is eligible for central clearing, only trades above a threshold $\bar{t}$ are assumed to be cleared. A justification for $\bar{t} > 0$ is that there may exist small-trader and other clearing exemptions, based on exposure-specific fixed costs associated with central clearing (data processing, information requirements). Formally, whenever

$$\sum_i \sum_j G^k(i,j) \geq \bar{T},$$

and $G^k(i,j) \geq \bar{t}$, an exposure $G^k(i,j)$ is assumed to be cleared at a CCP.

Only dealer-to-dealer exposures are eligible for central clearing in this subsection. Increased CCP membership and client clearing are explored in later subsections. The number of CDS cleared, at several alternative levels of $\bar{T}$, is presented in Table 8. The breakdown of trade types as a function of $\bar{T}$ is shown in Table 9.

We make additional assumptions on the assignment of particular exposures to CCPs. Consistent with the pattern observed in our dataset (see section 2.3), we assign each CDS positions to one of the two existing CCPs, based on European versus American reference names. All centrally cleared European (including European Union, Norway, Russia and Switzerland) CDS reference entities are assumed to be novated to the European CCP. All American (including Canada, Central and Latin America, and the United States) reference entities are assumed to be cleared by the existing American CCP. In the next section we investigate the case in which multiple CCPs may clear CDS transactions with the same referenced name.

Increased novation to CCPs has opposing effects on collateral demand. On the one hand, bilateral dealer-to-dealer exposures, which were not subject to initial margin requirements or which were under-collateralized to the extent captured by υ^D, are now subject to full margin requirements. On the other hand, increased novation implies increased cross-counterparty netting and diversification benefits.

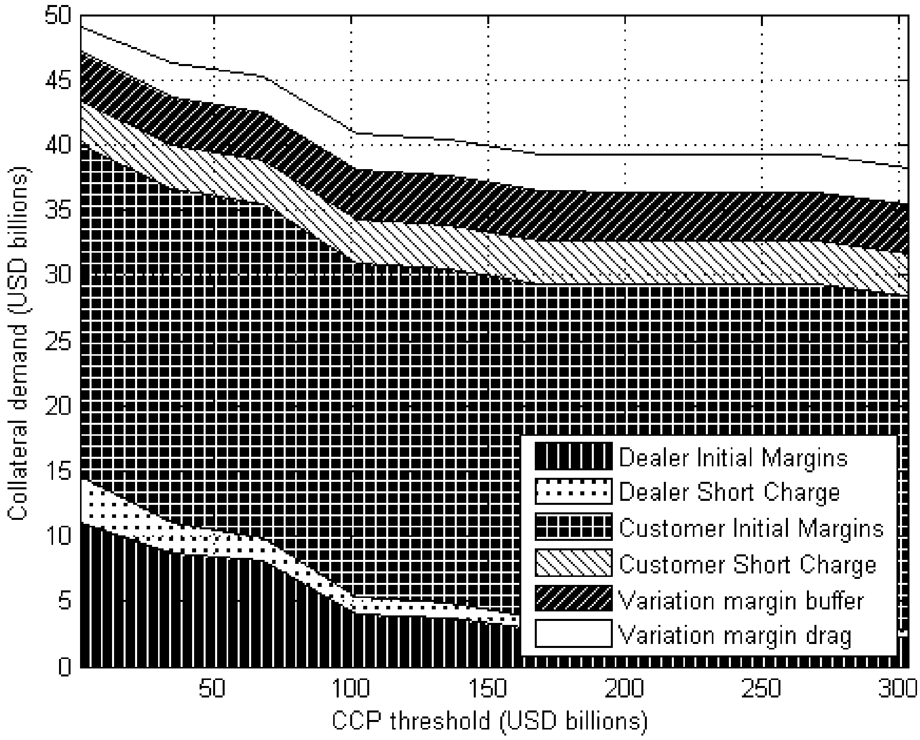
Figure 4 plots the decomposition of system-wide collateral demand when the central clearing threshold $\bar{T}$ is reduced from that of the base case (USD 305 billion) to 0 (that is, full clearing), both with and without dealer-do-dealer initial margins. In the absence of dealer-to-dealer initial margins, total collateral demand increases by about 28.2% when shifting from the baseline scenario to full CCP clearing. This increase is driven by dealer initial margins and short charges, as well as by the velocity drag of collateral. Customers' collateral demand is unchanged at this stage as they are not clearing members. (Client clearing is investigated below.)

Whereas dealer initial margins and short charges increase, the velocity drag decreases, due to the fact that increased central clearing amounts to pooling multiple bilateral exposures with one counterparty, therefore reducing the number of bilateral links and increasing netting opportunities. Accounting for changes in the velocity drag of collateral is potentially important, and has not been considered in previous research on collateral demand. A failure to account for velocity drag would result in an over-estimate of the increase in collateral demand implied by the shift to mandatory central clearing.

At a system level, the rise in collateral demand is of the same order of magnitude as that estimated by previous empirical studies. Our estimate of additional collateral demand amounts to 0.22% of the gross market notional, within the interval provided by Singh (2010b), who estimates this increase at between 0.16% and 0.33% of the gross market notional. Heller and Vause (2012), who study the whole CDS market for G-14 dealers only, provide estimates that depend on the prevailing level of market volatility. With the most conservative hypothesis, they estimate additional initial margin requirements to be above 100 billion USD. A linear extrapolation of our results (as we consider a subset of the CDS market only) yields an estimate comparable to the lowest estimates of Heller and Vause (2012). A potential explanation why we fall in the lower part of their estimated interval is that the iterative proportional fitting algorithm used by Heller and Vause (2012) tends to underestimate the extent of bilateral or multilateral netting opportunities. [19]

Our estimate of total collateral demand is above that of Sidanius and Zikes (2012), who assess the total initial margin requirement on both cleared and uncleared CDS to be between 78 and 156 billion USD (for the entire CDS market, including index and multi-name CDS). The total initial margin requirement (including the short charge) is about 43 billion USD in our sample, for a coverage of 18.9% of the global CDS market. Furthermore, we

19. The limitations of this iterative proportional fitting algorithm are well known in the estimation of interbank lending patterns. See Mistrulli (2011).



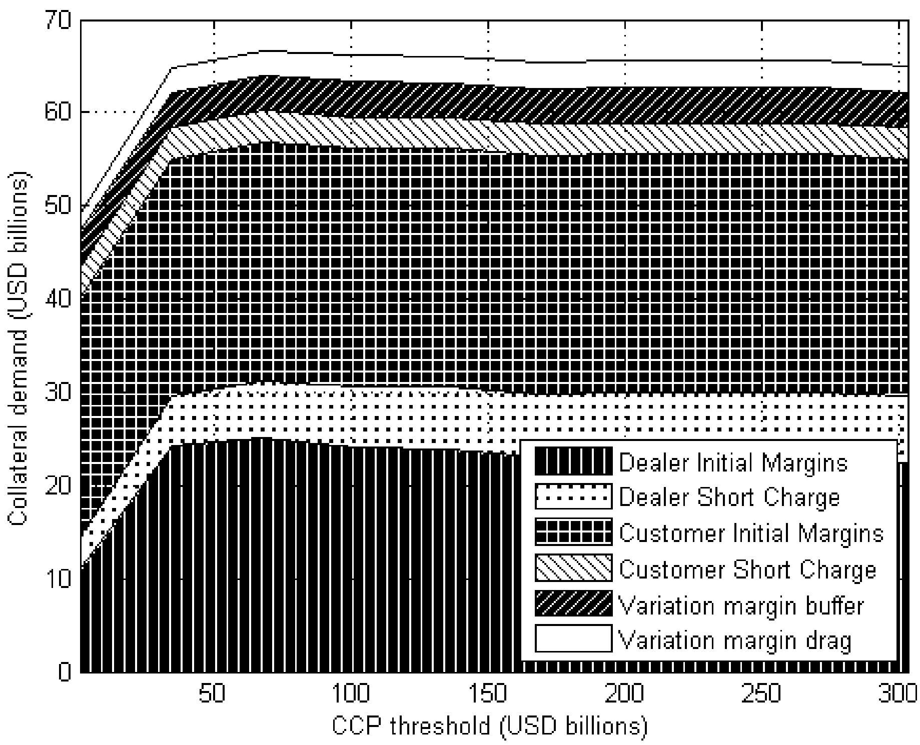


FIGURE 4 – Decomposition of the collateral demand as a function of $\bar{T}$. Total collateral demand is decomposed into six components, for each of two base cases. For the top chart, there are no dealer-to-dealer initial margins. For the bottom chart, dealer-to-dealer initial margins apply, with $\upsilon^D = 0.5$ and $\alpha^D = 0.01$. Other calibrations are those of the baseline case. Results for $\bar{T} = 305$ billion USD correspond to the baseline case.

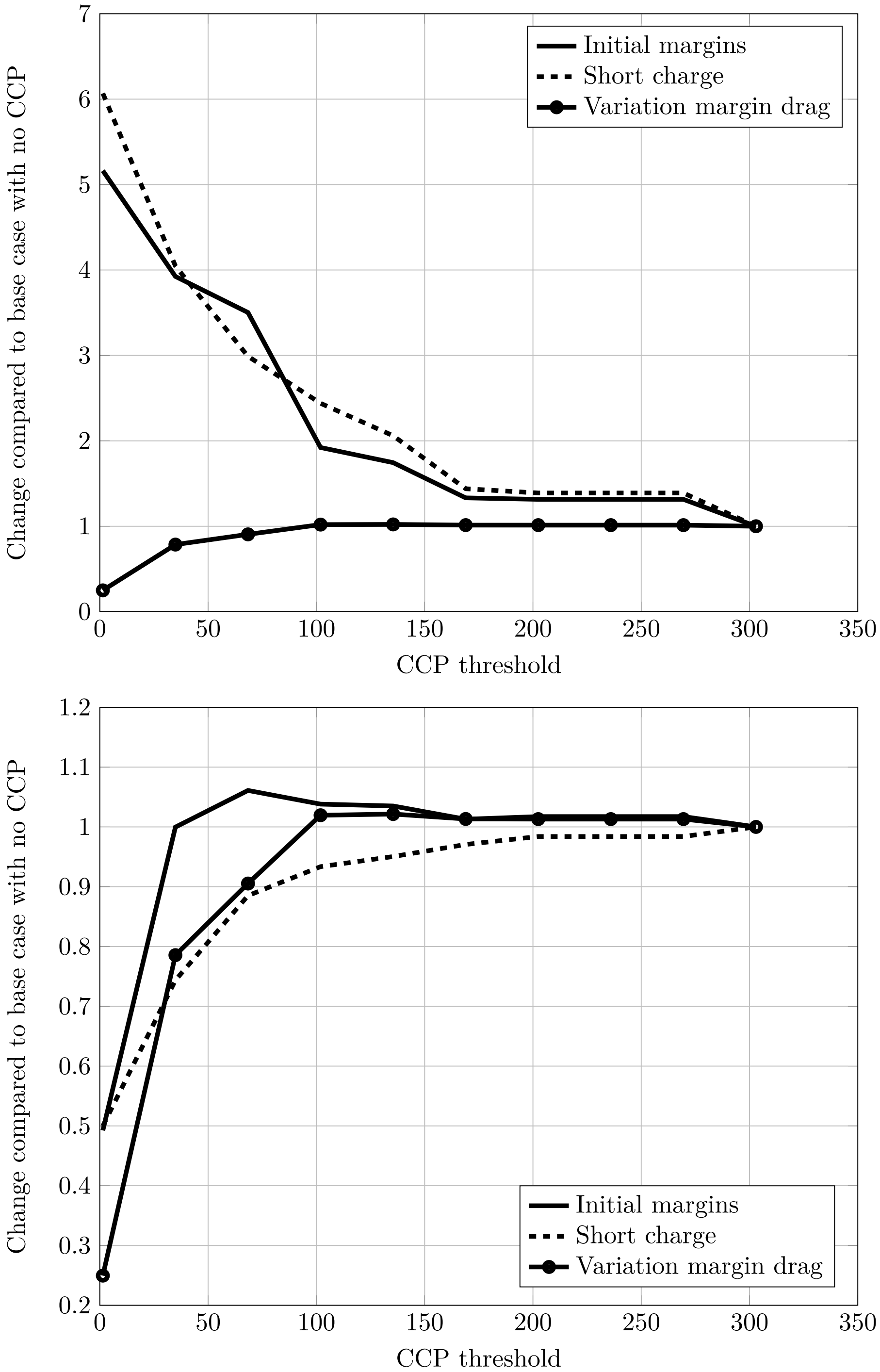


FIGURE 5 – Change in dealers' collateral demand as a function of $\bar{T}$. This figure depicts the change in collateral demand from a base case with $\bar{T} = 305$ billion USD, with increasing novation to CCPs. Each point represents the ratio of the collateral demand for each margin type to the corresponding demand in the base case with no central clearing. The top chart features a base case with no dealer-to-dealer initial margins. The bottom chart features a base case with dealer-to-dealer initial margins calibrated with $\upsilon^D = 0.5$ and $\alpha^D = 0.01$. Results for $\bar{T} = 305$ billion USD correspond to the baseline case with no CCP in both instances, so that the ratio is always equal to 1 at $\bar{T} = 305$.

rely on actual, as opposed to simulated, bilateral exposure data, and are thus able to provide a decomposition of aggregate collateral demand.

Although collateral demand by customers does not change with the implementation of full clearing, dealers experience an increase in collateral demand of 179%, as shown in Table 7, from its low pre-reform level. Second, among dealers, the increase in collateral demand ranges between 49.5% and 634.1%, depending on the size and composition of the dealers' CDS portfolios. Figure 5 decomposes the change in collateral demand for the 14 dealers. The velocity drag component decreases when central clearing increases, but this effect is more than offset by the increase in initial margin and short charge. When $\bar{T}$ decreases, the short charge increases faster than the primary initial-margin component, because the short-charge computation formula does not allow for the increasing potential effect of diversification as portfolio size increases.

5.2 Increased dealer-to-dealer initial margins

Turning to the case in which dealers post initial margins between themselves, increased central clearing *reduces* total collateral demand whenever the level of dealer-to-dealer initial margin (parameterized by υ^D) is high enough. At the level of individual positions, increased central clearing implies higher initial margin requirements. At a portfolio level, however, these higher collateral costs are more than offset by the cross-counterparty netting and diversification benefits of a CCP. With $\upsilon^D = 0.9$, the system-wide collateral demand, when shifting from the baseline case to full clearing, decreases by about 24.4%. In such a case, collateral demand by dealers falls by about 48.4%, with effects on individual dealer-level ranging from -25.9% and -66.1%. The above-mentioned trade-off at play in clearing is further seen through the fact that dealers' initial margin is not linear in $\bar{T}$, implying that novating few exposures to a CCP increases collateral demand, while novating the whole CDS portfolio lowers collateral demand.

Finally, we focus on the case in which dealer-to-dealer initial margins can be repledged (equation (8)). This amounts to analyzing the effect of repledging in the post-reform setting. Figure 6 plots dealers' collateral demand as a function of $\bar{T}$ for five values of ρ ranging between 0 and 1. The slope of total collateral demand is found to depend importantly on the rehypothecation ratio. When repledging is not allowed ($\rho = 0$) or allowed only to some limited extent, the collateral demand by dealers decreases as central clearing increases. In policy terms, dealers are given an incentive to novate a larger share of trades to CCPs under these conditions. When ρ is high enough, however, this effect is reversed and novation to CCPs does not provide high enough netting and diversification benefits to outweigh the loss of rehypothecation benefits. Interestingly, for a fairly broad range of values for ρ (including 0.5 and 0.75), collateral demand is not a monotonic function of

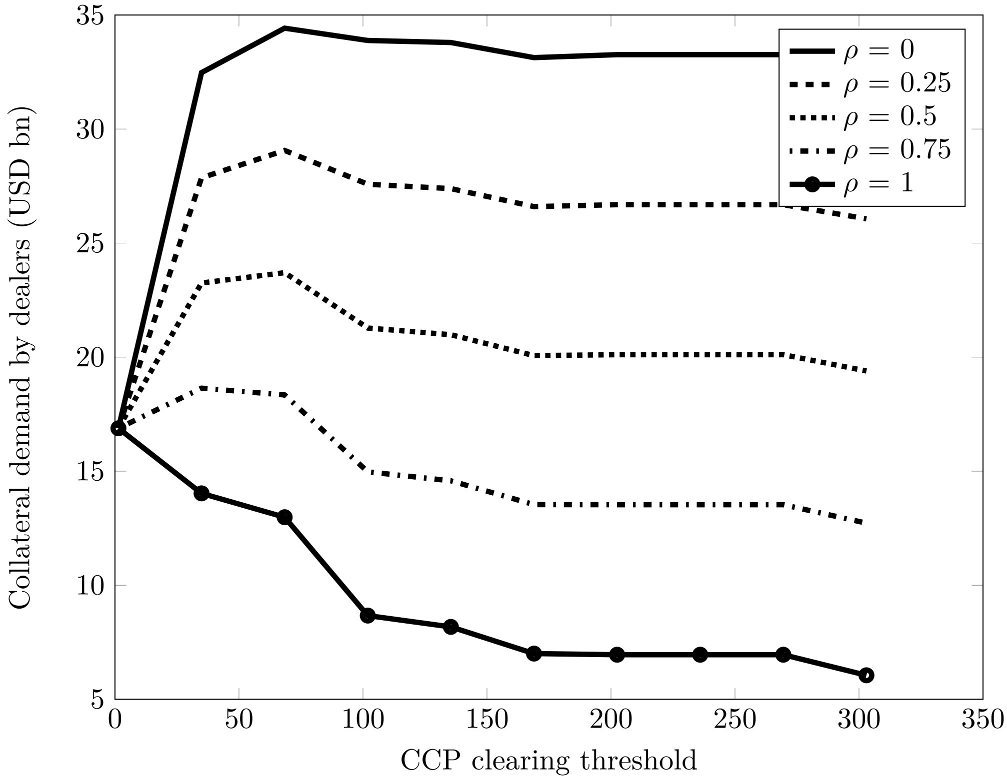


FIGURE 6 – Collateral demand as a function of ρ and $\bar{T}$. This chart shows collateral demand by dealers when the clearing threshold $\bar{T}$ is varied, for five values of the rehypothecation ratio ρ. The base case is with dealer-to-dealer initial margins. The sign of the change of total collateral demand depends on the extent to which rehypothecation is practiced. Collateral demand by dealers drives the system-wide effect on demand in this setting.

$\bar{T}$, as the benefits of central clearing outweigh the loss of rehypothecation benefits only when the share of centrally cleared trades is high enough.

5.3 Increasing the number of CCPs

We now focus on the loss of netting efficiency caused by increasing the number of CCPs. As opposed to Duffie and Zhu (2011), who do not investigate the role of CCP specialization by reference name, we study the effect of CCP specialization in referenced names along geographical lines, which we show in Section 2.3 to be a common market practice.

First, the set of reference entities, partitioned in the baseline case between European and American names, is further split. We create one new CCP for each geographic area. Each CDS reference entity is randomly made eligible by one of two area-wide CCPs, with equal probability of assignment. One characteristic of such a clearing scheme, similar to the baseline case, is that a CDS can be cleared at one CCP only. We call such CCPs "specialized," as there is no overlap in the set of reference entities cleared by each of them.

Second, we consider the case in which multiple CCPs clear the same CDS, within a given geographical area. Two new CCPs are added, with the same coverage and eligibility critera as those described for the baseline model. Whenever an exposure between any two dealers meets the eligibility criteria, it is randomly novated to one of the two CCPs, with equal probability. Such CCPs are called "non-specialized," given the overlap, at an area level, in the set of reference entities cleared by each of them.

Figure 7 shows total collateral demand with four CCPs, specialized and non-specialized, compared with collateral demand when there are only two CCPs. Whether one assumes dealer-to-dealer initial margins or not, an increase in the number of CCPs reduces the netting and diversification benefits, increasing collateral demand regardless of the clearing threshold $\bar{T}$. Whereas specialized CCPs imply only a loss of diversification benefits, non-specialized CCPs imply both netting and diversification losses. Thus, collateral demand increases to a much greater extent with non-specialized CCPs. With full clearing, an increase in the number of CCPs from 2 to 4 results in a 6.3% increase in collateral demand if CCPs are specialized, and otherwise an increase of 23.4%. This result is pertinent to the theoretical findings of Duffie and Zhu (2011), who focus on CCPs clearing different asset classes.

For the case of non-specialized CCPs, we consider the baseline case with dealer-to-dealer initial margins, shown in the bottom chart of Figure 7. Here, total collateral demand is not monotonic in the clearing threshold $\bar{T}$. An increasing degree of novation to CCPs first raises collateral demand, as additional margin requirements and the change in netting sets outweigh the potential cross-counterparty netting and diversification benefits a CCP may

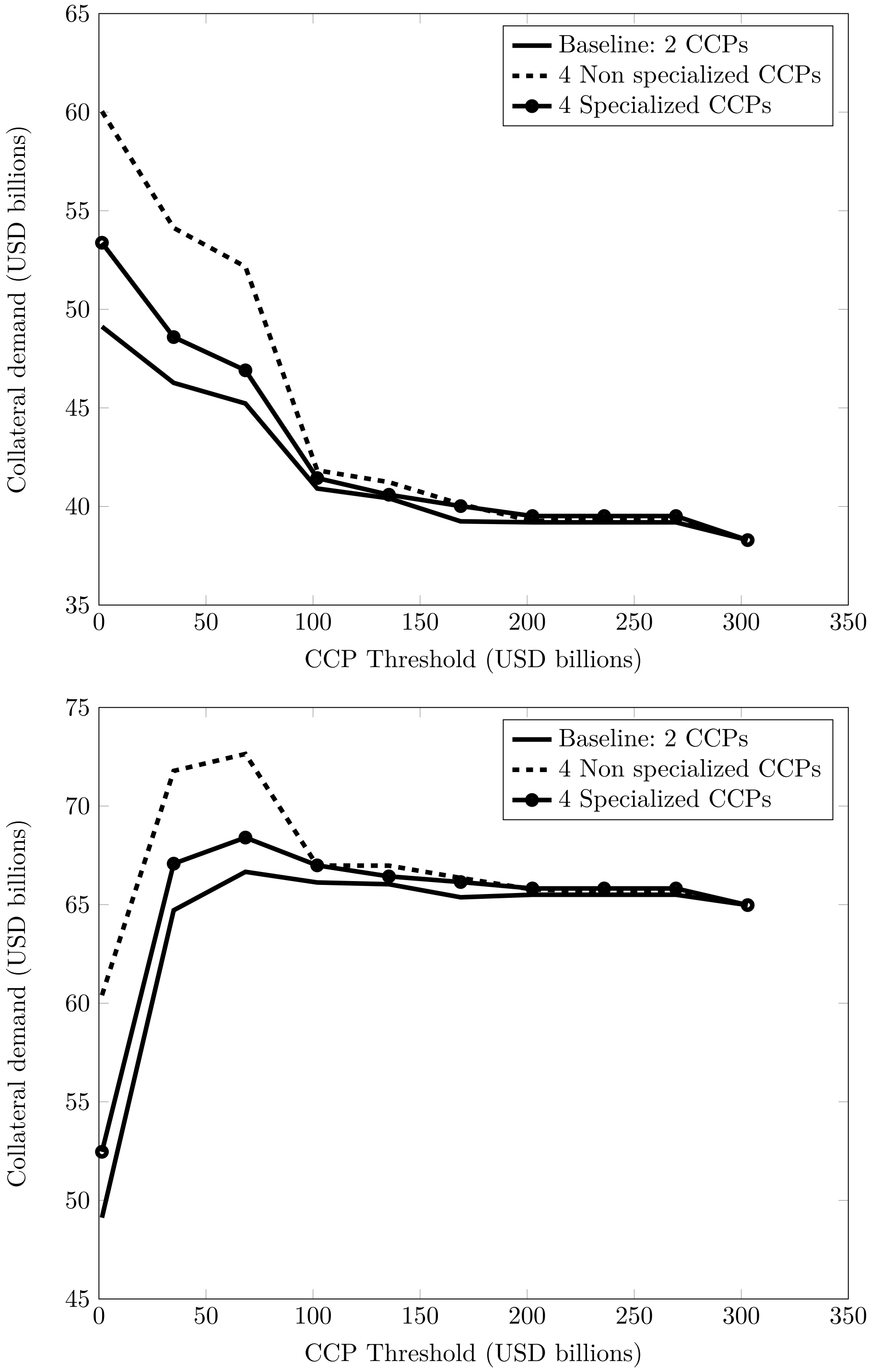


FIGURE 7 – Collateral demand as a function of the number of CCPs and of $\bar{T}$. $D = 14$. In the top chart, there are no dealer-to-dealer initial margins. In the bottom chart, dealer-to-dealer initial margins exist with $\upsilon^D = 0.5$ and $\alpha^D = 0.01$. For "specialized" and "non-specialized" CCPs, the collateral demand is the average over 10 simulations. Other calibrations are those of the baseline model. The results for $\bar{T} = 305$ billion USD correspond to the baseline case.

provide. Once a sufficiently large share of trades is cleared, however, these benefits prevail and collateral demand decreases relative to the base case.

5.4 The impact of client clearing

In the preceding analysis, only dealer-to-dealer trades were centrally cleared. In the post-reform environment, however, customer-to-dealer trades are required to be centrally cleared, putting aside special exemptions, such as those for commercial hedging and for the use of derivatives by sovereigns. When faced with this constraint, a large number of market participants with relatively lower levels of CDS market participation are likely to avoid becoming direct clearing members, given the implied costs (compliance to prudential standards, contribution to the default fund, and so). These firms are more likely to use client clearing services offered by dealers. A dealer collects CCP margins from these clients and posts the margins at the CCP on their behalf.

We refer to dealers offering client clearing services as "client clearing dealers." Each customer is assumed to have its entire CDS portfolio cleared by a unique client clearing dealer. In order for a customer-to-dealer trade to be centrally cleared, client clearing services may not be offered by a dealer that is also the counterparty to the CDS position. For each customer, we assume that a client clearing dealer is randomly assigned, with equal probabilities across the set of clearing members to which it has no direct exposure. In case a customer is linked to all D dealers, the one to which its exposure is the lowest (as measured by the number of CDS trades) is assigned as its client clearing dealer. Direct exposures to this client clearing dealers are assumed to remain uncleared. In the dataset, we find 32 such customers, whose uncleared exposures represent, in our dataset, 0.03% of the gross notional amount outstanding.

When posting collateral to their client clearing dealer, customers are assumed to post (on that part of their portfolio which is eligible for clearing) the amount of collateral they would have delivered to a CCP as a direct member. This amounts to setting $\upsilon^C = 1$ and $\alpha^C = \alpha^{CCP}$ in equation (3), thus requiring higher collateralization, *ceteris paribus*, for a given portfolio. However, customers also enjoy potential netting and diversification benefits, as trades with several counterparties are pooled with a single dealer. Whether one effect or the other dominates depends on the size of the portfolio of each customer, as we will emphasize later.

In this model, dealers clear the portfolios of their clients together with their own CDS positions. Thus, they enjoy potentially large netting and diversification benefits on their own initial margin requirements. However, as the size of their portfolio under management is larger, margin requirements in absolute terms are likely to be larger. We assume that dealers can immediately re-use a fraction λ of the collateral supplied to them by customers. In the absence of regulatory constraints, λ could be below one if client-clearing dealers offer collateral transformation services or if CCPs accept a narrower range of assets as collateral than that accepted by dealers (or if CCPs impose tougher concentration limits on the share of particular assets to be delivered as margins). We note the distinct roles of λ and ρ. The former parameter pertains only to collateral received through client clearing services, whereas ρ is related to collateral received from dealers on uncleared trades.

Total collateral demand in the presence of client clearing is compared with the baseline case in Figure 8, both with and without dealer-to-dealer initial margins. In both cases (with minor exceptions for high values of $\bar{T}$), implementing client clearing reduces collateral demand at a system level, provided that λ is high enough. The system-wide effect is driven by several mechanisms. First, customers face higher initial margin requirements at a position level, as exposures toward client-clearing dealers are assumed to be fully collateralized ($v^C = 1$). However, because all of their bilateral exposures are pooled towards their client-clearing dealers, they also enjoy cross-counterparty netting and diversification benefits. Which of these effects dominates depends on the size and composition of the CDS portfolio under management, as discussed below.

Turning to dealers, two potentially offsetting effects are at play. Larger portfolios must be centrally cleared by dealers at CCPs, implying higher collateral requirements in absolute terms. However, these larger portfolios offer increased netting and diversification benefits. This is likely to be even more the case when a sizable share of dealers' exposures arises from their market making or intermediary activity, thus allowing for large cross-client netting benefits. Whenever dealers re-use a high enough share of the collateral that they receive from their clients, the latter effect dominates. In the absence of dealer-to-dealer initial margins (and $\lambda = 0.5$), total collateral demand is kept roughly constant (within about 1%) when shifting from the baseline case to full clearing. This can be compared to the 28% increase in collateral in the absence of client clearing. Both with and without dealer-to-dealer initial margins, system-wide collateral with client clearing for $\bar{T} = 0$ is 21.5% lower than that with full clearing but no client clearing. However, in this setting of client clearing, and in the absence of dealer-to-dealer initial margins, total collateral demand is not monotonic in $\bar{T}$, as seen in Figure 8. From the base case, increasing central clearing increases collateral demand, with the effect being driven by dealers (as uncollateralized trades become subject to initial margin requirements). When the share of cleared trades is high enough, the netting and diversification benefits of client clearing (together with those of central clearing) outweigh these costs, so that collateral demand decreases. Thus market participants may favor large-scale novation to CCPs.

At the level of a given market participant, the sign of the change in collateral demand is ultimately driven by the size and composition of the portfolio under management, as well as by the parameter λ. Whereas our previous analysis has focused on aggregate collateral demand only, we go now to a more granular level here by investigating the distributional effects of client clearing across market participants. Given the anonymization of market participants in the dataset, we distinguish counterparties according to their total level of activity (or, eventually, other portfolio-related characteristics). Counterparties are ranked according to the sum of the gross CDS notional amounts (bought or sold) on all underlying reference entities. Quantiles are constructed on this basis.

The distributional effects of client clearing are depicted in Figure 9, where the ratio of collateral demand in the presence of client clearing over the demand in the base case is plotted for three values of the clearing threshold $\bar{T}$. We see first that the distributional effects of client clearing, and whether particular sets of market participants must post more or less collateral compared to the baseline case, depend importantly on the share of cleared trades, as captured by $\bar{T}$. Customers in the lowest quantile must always post more collateral with the implementation of client clearing, because their increased margin requirements outweigh cross-counterparty netting and diversification benefits. This arises from the fact that they trade relatively few CDS with a very small number of counterparties. At the other end of the size spectrum of market participants, dealers always benefit from client clearing (for $\lambda = 0.5$) even when $\bar{T}$ is high. In the range between these values, for large customers (those market participants ranked 15 to 200 by size), whether netting and diversification benefits are sufficient to offset increased initial margins or not depends importantly on $\bar{T}$.

6 Concluding Remarks

As explained by Anderson and Joeveer (2014), there are significant economic implications for the impact of new regulations on global collateral demand. We have analyzed the implications of specific types of regulations and changes in market design for collateral demands of different types in the OTC derivatives market, focusing on CDS.

Our quantitative analysis of extensive bilateral CDS exposure data allows a decomposition of collateral demand for both customers and dealers into four components, including the frictional demands for collateral associated with variation margin payments. We investigated the relative and absolute impacts on collateral demand of various market designs. The decomposition of collateral demands associated with some of the most salient specifications is summarized in Figure 1.

Among our main results is the fact that, based on year-end-2011 data, system-wide collateral demand is heavily increased by the introduction of dealer-to-dealer initial margins. Adding to that the requirement of central clearing leads to a substantial reduction in collateral demand. Our analysis provides a distinction, when considering the impact of CCP proliferation on collateral demand, between specialized and non-specialized CCPs. Our results indicate that client clearing will have significant distributional consequences for collateral demand across different types of market participants.

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Appendices

A Collateral Used for Variation Margin

This appendix provides a brief discussion of our assumption that the requirement to pay variation margin creates a net positive demand for collateral. This is so, we argue, despite the fact that any margin paid by one firm is received by another firm, which might superficially suggest zero total demand for collateral associated with variation margin.

We propose that there actually are two forms of net positive demand for collateral associated with variation margin payments : *(i)* a precautionary demand for collateral, of the same sort underlying traditional theories of the precautionary liquidity demand for money (e.g. Alvarez and Lippi, 2009), and *(ii)* a "drag" component associated with frictional delays between the time at which collateral is sent and the time by which it can be deployed by its receiver for other purposes.

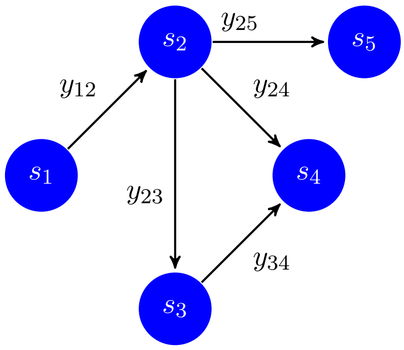

FIGURE 10 – The variation margin obligations of each firm i imply that collateral will be held away from other uses in the economy in two forms : a precautionary stock s_i held at firm i and an amount y_{ij} that has been sent from firm i to firm j but is not yet operationally available for use by firm j.

In practice, as illustrated in Figure 10, firm i must set up some stock s_i of collateralizing assets before these assets can actually be transferred to meet margin requirements. On a given day, firm i will therefore hold in advance a precautionary amount of collateral that is likely to cover some targeted fraction of the positive part of its total net variation margin payments to all counterparties. We assume that this precautionary demand is a fraction κ^{VM} of the standard deviation of the total variation margin payment, as captured by (5). That is, the precautionary demand for collateral is proportional to the degree of uncertainty of the total payment that must eventually be made, net of payments received. This includes the benefit of netting of positives against negatives (payments to be made, net of payments to be received) across counterparties.

As illustrated in Figure 10, in addition to the precautionary stock s_i of collateral held by firm i, there is some additional demand for collateral associated with the fact that the collateral y_{ij} that has been sent from i to j is not immediately available for deployment by firm j elsewhere in the economy. There could be lags in availability due to operational delays for execution, settlement, and planning. For example, if \$1 million is sent as a margin payment from i to j at 15:06 on a given Tuesday, firm j cannot use the same \$1 million to settle at the same time, 15:06, a tax payment to the government or a purchase of equities from an unrelated firm. Perhaps the cash value of this margin payment from i could be effectively deployed by j for other purposes by some time later that afternoon or on the next morning.

For example, consider the following structural cash-management model, based on Chapter 7 of Harrison (2013). This continuous-time model is too stylized to be reliable for direct estimation of magnitudes, especially because it ignores other sources of flows into the cash-management buffer of the investor. We use the model only to provide some support for the functional form of our reduced-form assumption that the precautionary buffer demand for collateral is linear with respect to the standard deviation of the net variation margin payments.

For this purpose, suppose that there is some opportunity cost $h > 0$ per unit of time for each unit of collateral held in an investor's cash-management buffer. Even if the collateral is held in interest-bearing instruments, h can be interpreted as the "convenience yield," meaning the opportunity cost associated with holding the collateral in place rather than using it for other purposes whenever convenient. We assume some incremental cost $\beta > 0$ for each unit of variation margin cash payment that must be made when the precautionary buffer is empty. This incremental cash could be obtained, for example, from a back-up liquidity source, whether internal or external. It matters only that there is some incremental cost to obtaining liquidity on short notice. We suppose that net variation margin payments are of mean zero, and that the cumulative flow of these net payments can be modeled as a Brownian motion with standard deviation parameter σ. As explained by Harrison (2013), the investor's optimal policy in this setting is to retain collateral in the buffer whenever the current buffer amount is below an optimal threshold b. Any incremental collateral above the threshold b is released for other use, given the assumed opportunity cost for holding the collateral in the buffer. By following Harrison's analysis, we have

$$b = \sigma \left(\frac{\beta}{h} \right)^{1/2}.$$

Further, the steady-state distribution of collateral held in the buffer is uniform on $[0, b]$, a property of driftless Brownian motion reflected on two barriers, 0 and b in this case. Because the mean of this uniform distribution is $b/2$, the steady-state average collateral demand in this simple model is $\alpha\sigma$, where

$$\alpha = \frac{1}{2}\left(\frac{\beta}{h}\right)^{1/2},$$

consistent with the form of our reduced-form assumption. The constant α is increasing in the ratio of the opportunity cost h of idle unencumbered liquid collateral to the cost β of obtaining cash on short notice.

We are also interested in estimating the mean collateral "velocity" drag, on average across scenarios. For this, we must first estimate the expected absolute value $E(|y_{ij}|)$ of the payment amount y_{ij} between investors i and j. For simplicity, we assume that this mean absolute payment amount is proportional to the standard deviation of y_{ij}. (For normally distributed y_{ij}, this involves no approximation error.) The frictional effect of the time lag on unavailable collateral at a point in time is approximated through a further proportional effect. For example, if the expected time lag between the send time and the time of availability for re-use is 0.5 days, then the mean proportional amount of sent collateral that is not available for immediate re-use is 0.5 times the mean daily amount sent (assuming independence of the delay time and the amount sent). The total drag coefficient κ^D in (6) is intended to reflect both of these proportional effects. This simple reduced-form model of collateral drag could be extended to a full-blown stochastic network inventory model of the sort described by Harrison (2013), although that is beyond the goals of this paper.

As an example of the practical perception of time drags on collateral, the U.S. Commodity Futures Trading Commission has recently proposed strong limits on the ability of derivatives central clearing parties to include in their regulatory measure of cash liquidity their stock of unencumbered U.S. treasury securities, under the premise that it takes time to convert even U.S. treasury securities to cash. [20] Even a payment of central bank deposits, once sent by i, cannot be immediately be resent by j, in light of typical "back-office" operational and planning frictions.

Velocity drag on collateral is distinct from the precautionary demand for collateral, in that the "drag" amount of collateral that is sent but unavailable for immediate use is not reduced by diversification across counterparties. Rather, the delayed accessibility of cash to the economy associated with the variation payment amount y_{ij} sent by i to j is not partially offset by the delayed accessibility associated with the amount y_{ki} sent by some other firm k to firm i. There is time "drag" along every active payment link. Thus, our

20. See 17 CFR Parts 39, 140, and 190, "Derivatives Clearing Organizations and International Standards" Federal Register, Volume 78, No. 159, Friday, August 16, 2013, Proposed Rules.

model (6) of variation-margin drag reflects an amount that is proportional to standard deviation of *each* variation margin payment, and is additive across payment links.

B Approximating Variation Margin Payments

This appendix describes our approach to estimating the changes in market values of CDS positions for purposes of our margin calculations. These changes in market values are used to estimate various forms of collateral demand, including initial margin, precautionary buffer demand for variation margin payments, and velocity drag for variation margin payments.

From our Bloomberg CDS rate data, we approximate the change in market value of a unit-notional CDS position referencing a given name from the usual duration-based "dv01" formula, by which a 100 basis point change in the CDS rate causes a change in market value of approximately $0.01d$, where d is the effective duration of the position. This follows from the fact (Duffie, 1999) that a protection-sold CDS position is essentially arbitrage-equivalent to a note issued by the referenced name that pays the default-risk-free floating rate plus a fixed spread equal to the CDS rate. As such, like any bond, the change in market value over a short time period such as one day is approximately equal to the change in spread (here, the change in CDS rate) multiplied by the effective duration. This effective bond duration is slightly less than the maturity of the CDS contract, except for referenced with extremely high CDS rates, of which there are very few in our sample. For example, as shown on Bloomberg's CDSW page, a typical investment-grade 5-year CDS has a dv01-implied effective duration of roughly 4.9 years. As an illustration, for such a CDS position, a one-day increase in the CDS rate of 10 basis points implies a loss in market value to the protection seller of approximately 0.49% of the notional size of the position.

In our case, unfortunately, the duration-based approximation is not nearly as important a source of approximation error as the fact that there is very limited information on the remaining maturities of the seasoned CDS positions represented in our data set. For the broad market population of U.S. CDS, the mode of the distribution of CDS maturities at origination is 5 years, with a mean of about 4 years, as indicated by Chen et al. (2011). Public DTCC Trade Information Warehouse data[21] also show that the majority of newly issued CDS have a 5-year maturity. The maturities of previously contracted CDS are reduced, however, as the positions become seasoned. Our bilateral CDS data set does not include the remaining maturities of the CDS positions. Charts A and B of Benos et al. (2013) show a half life of CDS contracts of under six months, due to various types actions that eliminate a

21. See "Market Risk Activity Analysis", Special report available from the TIW Reports webpage.

CDS position between two counterparties. Some of these actions, however, are assignments that need not stop the reduction in maturity. Other actions, such as compression trades and other forms of termination, eliminate the contracts entirely. Without the benefit of more detailed data, we simply adopt a crude assumption that the effective average duration of existing CDS contracts is 3 years.

We also ignore the imperfect correlation of returns on CDS positions on the same reference name across different maturities. In practice, these returns are highly correlated. For example, Palhares (2012) estimates that the first principal component of returns on CDS positions on the same reference name, at maturities of 3, 5, 7, and 10 years, captures 99% of the variance of the monthly returns of these various CDS positions.

Our resulting approximation of the magnitudes of changes in market values of CDS positions is extremely rough, but our qualitative conclusions are largely unaffected by this, given that the main source of approximation error is a re-scaling of the correct average duration, which re-scales all of the components of collateral demand that depend on changes in CDS market values (absent default) by the same factor. (In our dataset, there were no defaults, and only the short-position charge for initial margin associated with jump-to-default risk is not related to duration.) Our main conclusions are concerned with the *relative* impacts on collateral demand of various alternative market designs and regulations.

C Increasing the Set of Clearing Members

This appendix examines the implications for collateral demand of increasing the subset of market participants that participate in central clearing. Customers satisfying an exposure-size criterion are assumed to become clearing members. For this purpose, customers are ranked according to their total gross notional amount bought and sold on the CDS market [22], that is, $\sum_k \sum_j \left[G^k(i,j) + G^k(j,i)\right]$ for all i. Market participants for which this exposure is above some threshold are assumed to become members of both of the two central clearing parties, and are then effectively treated as dealers.

Increasing the subset of market participants that centrally clear has a material impact on the global demand for collateral. On the one hand, there are benefits from acquiring a dealer status, as dealers do not post initial margins to customers, and post no margins to other dealers in the base case (if $\upsilon^D = 0$) or reduced margins (whenever $\upsilon^D < \upsilon^C$). On the other hand, central clearing may be associated with higher collateral requirements

22. Given the anonymization of the data at a counterparty level, the set of counterparty-specific variables to be used to construct quantiles is limited. Other possible characteristics include the number of traded CDS or the number of counterparties. Spearman rank correlation with the total gross notional traded are respectively 0.77 and 0.84.

than bilateral clearing for a given set of exposures (whenever $\upsilon^D < 1$). Finally, central clearing offers cross-counterparty netting opportunities and diversification benefits, especially for institutions with a large number of bilateral counterparties. Which of these effects dominate depends on the CCP-clearing threshold $\bar{T}$, that is, on the share of cleared trades.

Figure 11 plots total collateral demand as the number D of clearing members and the clearing threshold $\bar{T}$ are varied. For a high CCP-clearing threshold (that is, a low share of centrally-cleared trades), an increase in the number of clearing members lowers total collateral demand. Once a major fraction of CDS are centrally cleared, total collateral demand is no longer monotonically dependent on the number of clearing members. This effect is further illustrated in Figure 12, where initial margins (including the short charge) delivered by customers to dealers and by dealers to CCPs are decomposed for three values of $\bar{T}$ as the number of clearing members is varied. The increase in dealer-to-CCP initial margins is offset to a large extent by a shrinkage in customer-to-dealer initial margins, but the overall effect on collateral demand depends on $\bar{T}$.

D Additional Tables and Figures

	D-to-D IM	No	Yes	No	Yes
	Client clearing	No	No	Yes	Yes
Δ demand by type of trader	Customers	0	0	-0.15	-0.15
	Dealers	1.79	-0.48	0.88	-0.65
Δ demand by type of exposure	C-to-C	0	0	-1	-1
	C-to-D	0	0	-0.15	-0.15
	D-to-D	-1	-1	-1	-1
	D-to-CCP	4.16	4.16	6.51	6.51
Δ total demand		0.28	-0.24	0.01	-0.41

TABLE 7 – Change in collateral demand from baseline cases. This table contains estimates of changes in total collateral demand when shifting from two base cases (with and without dealer-to-dealer initial margins) and no central clearing to full central clearing with and without client clearing. Only exposures which are already cleared in the dataset are centrally cleared in the base cases. "IM" stands for "initial margins", "C" for customer, "D" for dealer. The computation of the change in collateral demand by type of exposure excludes the variation margin buffer, as it is not allocated counterparty by counterparty, but at a portfolio level.

CCP Threshold $\bar{T}$ (USD billion)	Number of cleared CDS	Share gross notional cleared
1	184	1
34	41	0.64
68	15	0.37
101	8	0.26
135	5	0.19
168	2	0.10
202	1	0.06
235	1	0.06
269	1	0.06
305	0	0

TABLE 8 – Distribution of cleared CDS, by CCP clearing threshold ($\bar{T}$). This table displays the number of CDS cleared and the percentage of the market gross notional they represent as a function of $\bar{T}$. CDS exposures which are already cleared in the dataset are not accounted for here. The set of values of $\bar{T}$ is the one used in all other tables and figures where $\bar{T}$ appears. A threshold $\bar{T} = 305$ bn USD corresponds to the baseline case. A share of 1 represents full central clearing. Source : DTCC.

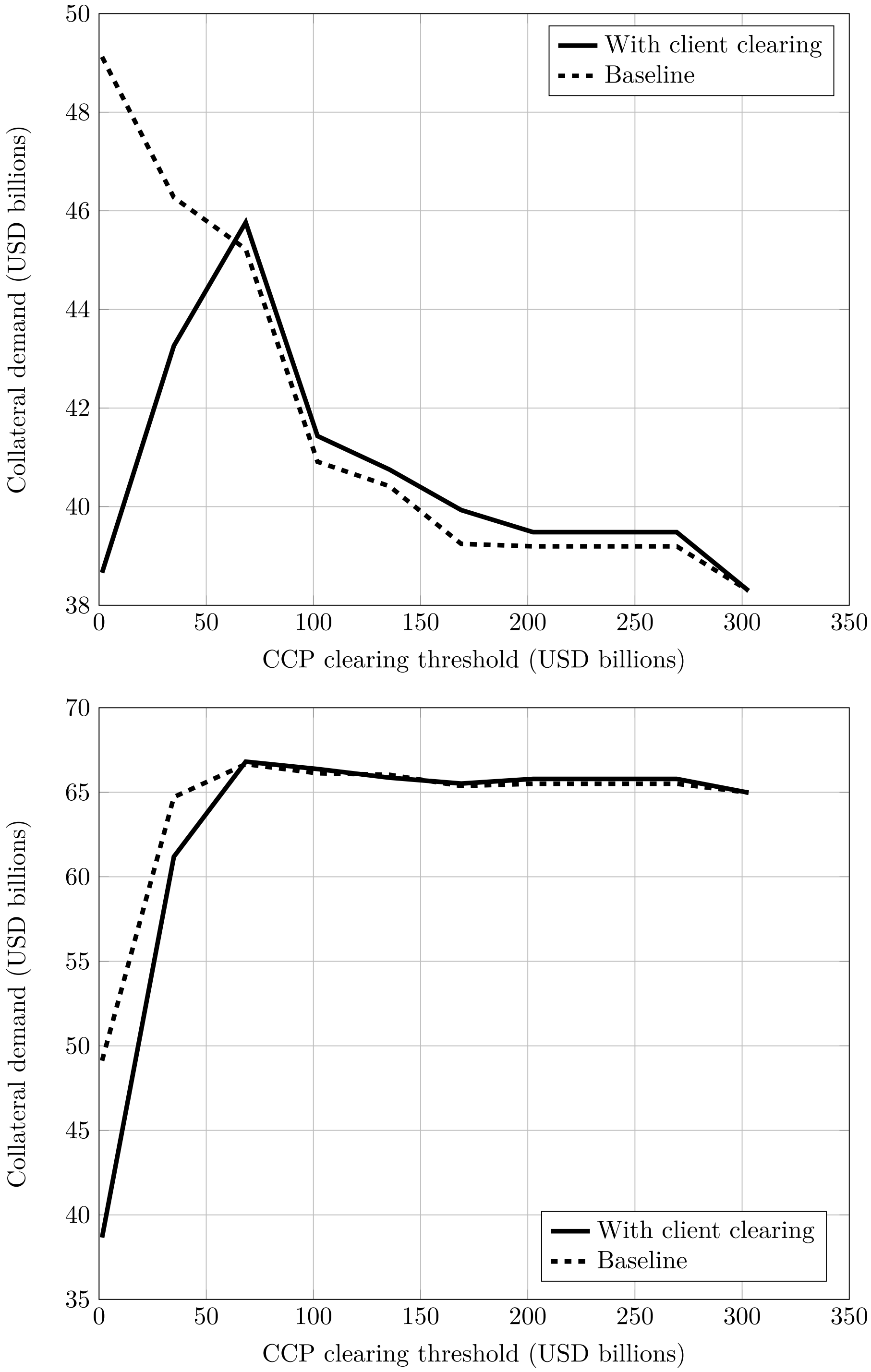

FIGURE 8 – Collateral demand with client clearing. Both charts compare the system-wide collateral demand with and without client clearing, for two base cases, with a varying CCP-clearing threshold $\bar{T}$. In the first chart, there are no dealer-to-dealer initial margins. In the second chart, dealer-to-dealer initial margins exist with $\upsilon^D = 0.5$ and $\alpha^D = 0.01$. Both are calibrated with $\lambda = 0.5$. Results for $\bar{T} = 305$ bn USD correspond to the baseline case.

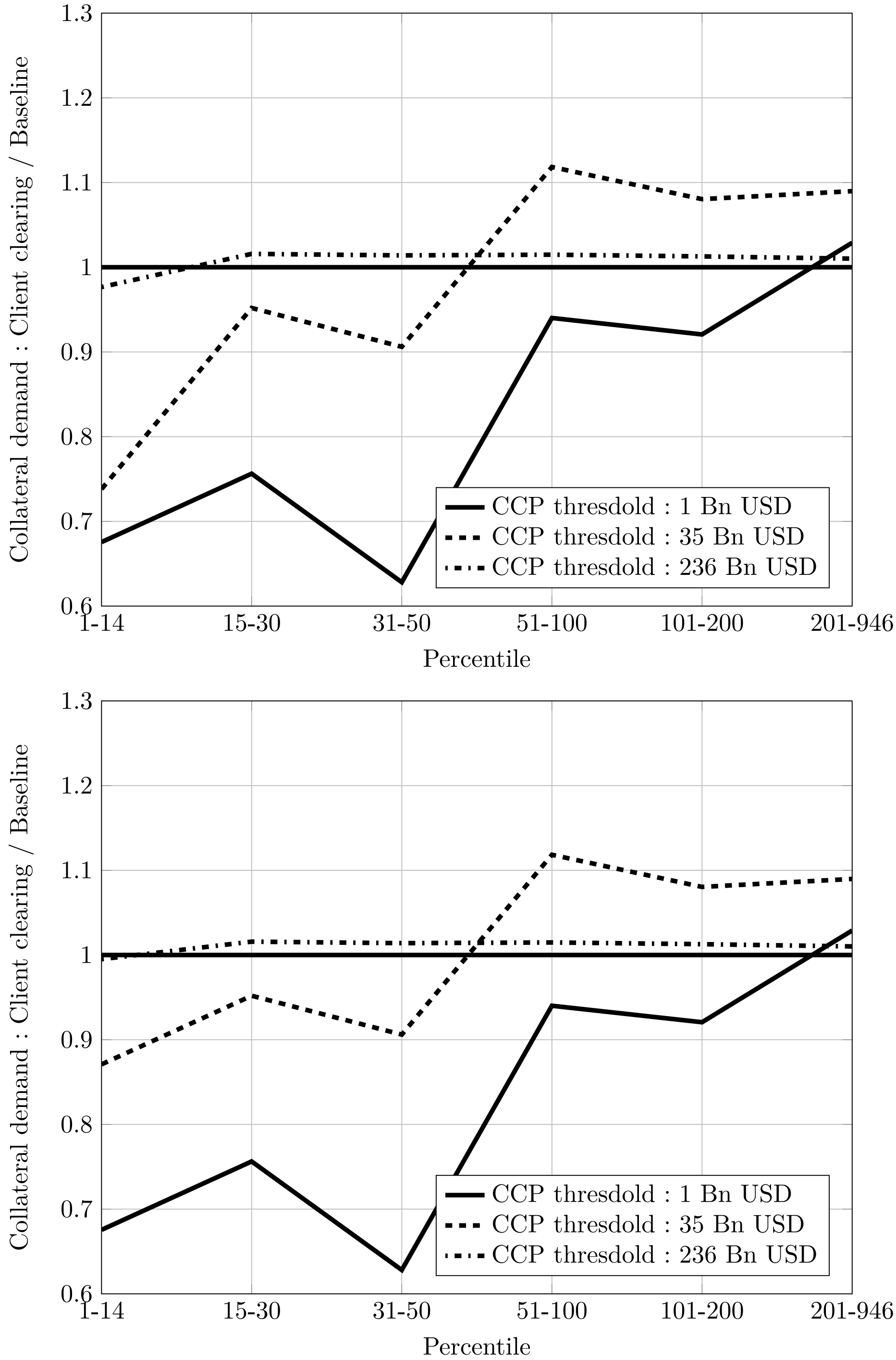

Figure 9 – Distributional effects of client clearing. The top chart illustrates the distributional effect of client clearing, as captures by the ratio of collateral demand with client clearing to collateral demand in the baseline case. In the top chart, the baseline case does not feature dealer-to-dealer initial margins for uncleared trades. In the bottom chart, dealer-to-dealer initial margins apply with $\upsilon^D = 0.5$ and $\alpha^D = 0.01$. Both charts are based on a collateral re-use coefficient of $\lambda = 0.5$. Percentiles are constructed based on each counterparty's total gross notional bought and sold on the CDS market.

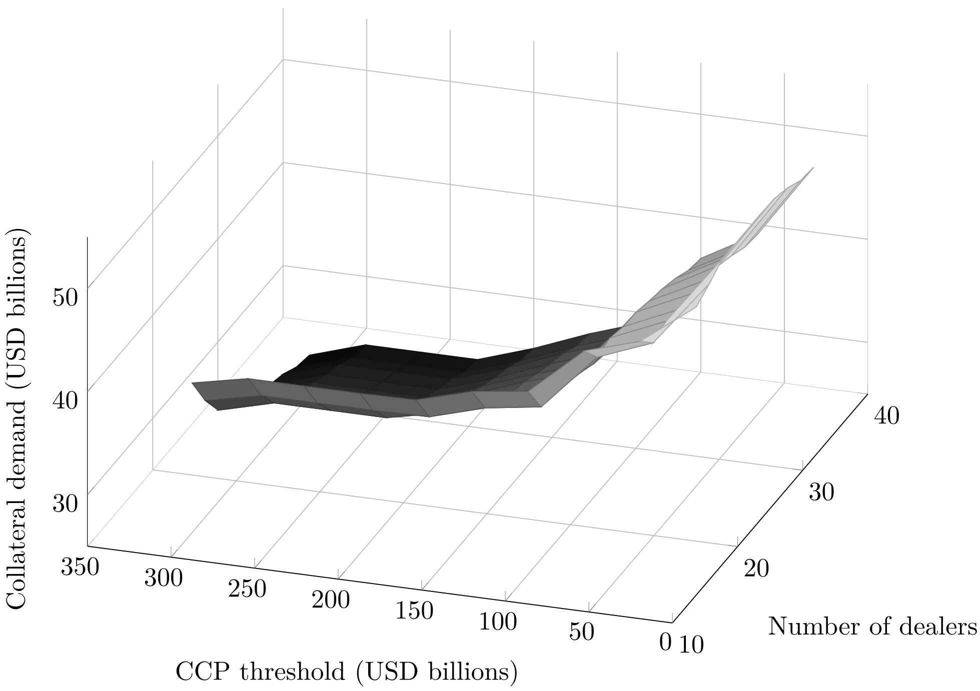

Figure 11 – Collateral demand as a function of the number of clearing members and of $\bar{T}$. This surface chart plots total collateral demand as a function of both the number of clearing members (or dealers) and the CCP clearing threshold $\bar{T}$. The base case is with no dealer-to-dealer initial margins. Other calibrations are those of the baseline model. Results for $\bar{T} = 305$ bn USD correspond to the baseline case.

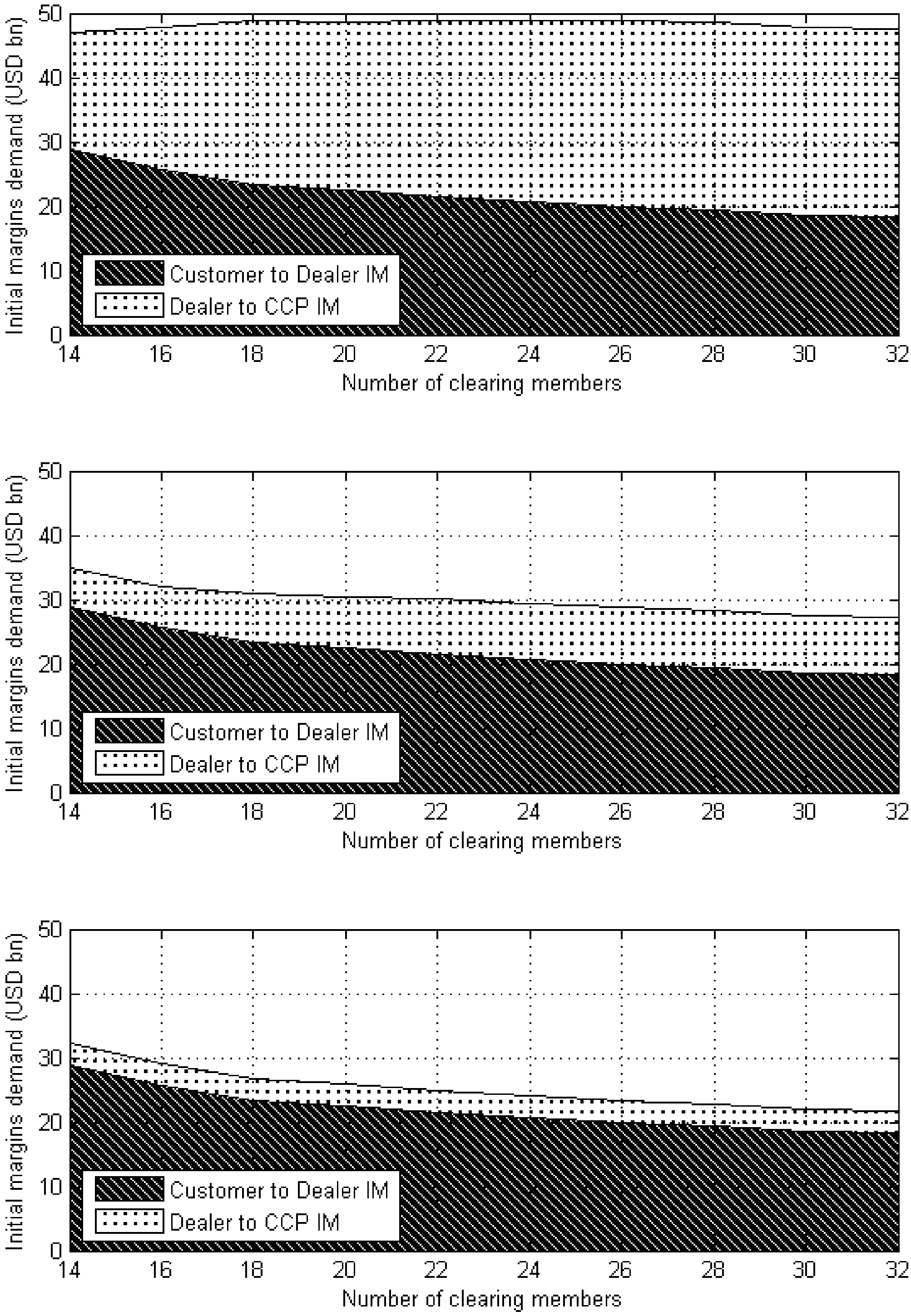

FIGURE 12 – Decomposition of initial margins demand as a function of the number of clearing members. These chart decompose system-wide initial margins between customers and dealers initial margins. In the first chart, $\bar{T} = 1$ Bn USD ; in the second $\bar{T} = 135$ Bn USD ; in the third $\bar{T} = 305$ Bn USD. The base case is here with no dealer-to-dealer initial margins. Other calibrations are those of the baseline model.

	CCP Threshold (USD bn)	1	34	68	101	135	168	202	235	269	305
Customer-to-customer	Number of trades (share)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Net notional (share)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Customer-to-dealer	Number of trades (share)	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
	Net notional (share)	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Dealer-to-dealer	Number of trades (share)	0	0.27	0.32	0.33	0.34	0.35	0.35	0.35	0.35	0.35
	Net notional (share)	0	0.22	0.34	0.39	0.42	0.46	0.47	0.47	0.47	0.49
Dealer-to-CCP	Number of trades (share)	0.36	0.10	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01
	Net notional (share)	0.49	0.27	0.15	0.10	0.07	0.04	0.03	0.03	0.03	0.00

TABLE 9 – Trade types and net notional as a function of $\bar{T}$. This table presents the share of trade types, and the share of net notional exposure they represent, for all pairs of party-to-counterparty exposures. Changes in the CCP clearing threshold $\bar{T}$ does not affect customer-to-customer or customer-to-dealer exposures. A decrease in $\bar{T}$ lowers the share of dealer-to-dealer trades and increases the share of dealer-to-CCP trades. Each column, by indicator type (share of number of trades and share of net notional), sums up to 1.