Comparing the pre-settlement risk implications of alternative clearing arrangements

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Abstract
In recent years, there has been a marked expansion in the range of products cleared through central counterparty clearing houses (CCPs), accompanied by a trend towards consolidation in the clearing infrastructure. The financial stability implications of these developments are of considerable policy interest. In this paper, we use a simulation approach to analyse, in a systematic way, the potential replacement cost risk implications of these developments. Our results point towards substantial risk-reduction benefits from multilateral clearing arrangements. First, the multilateral netting of trading exposures delivers significant reductions in both replacement cost risk and total pre-settlement costs, with these benefits increasing in the number of trading counterparties. Furthermore, losses are more dispersed when exposures are netted via novation to a CCP, further reducing the risk of second-round contagious effects. We also find that diversification across a broad array of imperfectly correlated assets in a consolidated multi-product CCP can deliver additional risk-reduction benefits relative to a single-product CCP. Finally, the paper examines individual incentives to join multilateral clearing arrangements, illustrating how arrangements with restricted direct participation and tiered membership may be a natural response to the uneven distribution of total pre-settlement costs when agents are of heterogeneous credit-quality and it is costly to individually tailor margin.

Key words: clearing, netting

JEL classification:

1. Introduction

This paper analyses the risk implications of different arrangements for clearing financial market trades involving securities and derivatives.[(1)] In recent years there have been two distinct trends in the clearing arena. First, there has been a marked expansion in the range of products cleared through central counterparty clearing houses (CCPs). For example, since 1999 the London Clearing House (LCH) has introduced CCP services for swaps, repos and, most recently, securities traded on the London Stock Exchange. Second, there has been a trend towards consolidation in the clearing infrastructure, notably the London Clearing House and Clearnet merging in 2003, and the Chicago Mercantile Exchange (CME) Clearing House taking over the clearing of trades for the Chicago Board of Trade (CBOT) in the same year.

These developments are of considerable policy interest. For instance, there is a live and active debate underway in both policy and financial market circles regarding the potential risk-reduction benefits of centralised clearing arrangements for OTC derivative products (Counterparty Risk Management Policy Group (2005); Geithner (2004)). With the exception of certain vanilla interest rate products, these are currently typically cleared under purely bilateral arrangements. There is also the important question of whether a CCP arrangement is feasible, or desirable, for such products, and whether other centralised approaches might be appropriate.

There is a sizeable literature describing the key features of alternative clearing arrangements, their historical evolution and their current roles (Moser (1998); Hills et al (1999); Kroszner (1999); and Ripatti (2004)). These papers also identify the risks that can arise in clearing arrangements, and describe the infrastructural innovations that have emerged to deal with them. Bank for International Settlements (2004), in the context of CCPs, also gives a comprehensive overview of risks and risk management issues. However, to our knowledge, there is no established analytical framework for evaluating, *quantitatively*, the relative cost and risk implications of a range of clearing methods, covering different constellations of products, trader profiles and market structures. This paper seeks to provide such a framework and offer some insight in this regard, while also examining agents' individual incentives to participate in particular arrangements.

And while the potential efficiency gains from consolidating the activity of several market-specific CCPs into a single cross-market entity have been the subject of much recent debate (for example, European Securities Forum (2000)), with competition issues also addressed in Tapking and Yang (2004), the implications for financial stability have not been addressed in any systematic study to date.

[(1)] The Bank for International Settlements (2003) defines 'clearance' as the 'process of calculating the mutual obligations of market participants, usually on a net basis, for the exchange of securities and money.' It is recognised that the term is sometimes also used with reference to the process of transferring securities on settlement date, but our focus here is on arrangements for the management of risks arising during the *pre-settlement* period.

The approach we take here is to construct an analytical framework for the simulation and quantification of agents' pre-settlement costs and risks under alternative bilateral and multilateral clearing arrangements. Simulation facilitates the examination of a richer array of scenarios than would be possible with a purely analytical approach. Importantly, this approach yields some quantitative comparisons and allows us to both introduce several sources of ex-post heterogeneity and examine some complex interactions, such as that between ex-post heterogeneity in trading positions and the concentration of replacement cost losses.

We restrict attention to two metrics for pre-settlement risk: the magnitude of replacement cost losses; and how such losses are shared among trading agents. To capture the relevant factor in the decisions of risk-neutral agents, we also compare total pre-settlement costs borne by agents, which include both replacement cost losses and the opportunity cost of posting margin/collateral.(2)

Replacement cost risk arises during the period between trade and settlement and reflects the cost to a trader of replacing a trade on which a counterparty has defaulted. Consider a bilateral trade between agents *i* and *j*: should agent *i* default prior to settlement, agent *j* does not incur a loss on the principal, because the asset has not yet been delivered and no money has changed hands; but, should the market price of the asset have moved adversely since the deal was struck (or since the trade was last marked-to-market and variation margin collected), agent *j* may face a loss from replacing the trade. Agents will generally mitigate replacement cost risk by collecting margin from their trading counterparties during the pre-settlement period; hence a trader (or CCP) will only incur a replacement cost loss if there is a coincidence of events: an adverse change in the underlying contract price in excess of the per-unit value of margin collected from a counterparty, combined with a default by that counterparty. However, the requirement to post collateral may impose a significant cost on agents, which in our analysis is quantified and compared across arrangements.

We identify two basic sources of replacement cost risk differentials across the arrangements under consideration: netting ratios and margin-pooling. These have been foreshadowed elsewhere in the literature. For example, Baer, France and Moser (2004) present an analytical framework in which the potential benefits of moving from bilateral to multilateral netting are usefully explored; and Gemmill (1994) illustrates the diversification benefits from clearing several imperfectly correlated assets through a single CCP.

In this paper, we do not explicitly model spillover effects from an agent's default; i.e. the extent to which losses incurred by an agent due to the default of a counterparty lead to knock-on default or liquidity dislocation. This would require potentially arbitrary assumptions, related, for example, to the size of individual banks'/traders' exposures relative to their total capital or liquid resources. We would contend,

(2) This paper has nothing to say about the implications of different clearing arrangements for operational risks or other 'single point of failure' issues often raised in the context of consolidation of infrastructure. We leave analysis of these risks for future research.

however, that the potential for spillovers is likely to be correlated with the size of replacement cost losses imposed by a defaulting trader. Hence, the concentration of these losses, as well as their absolute magnitude, may be an important indicator of financial stability risk in this context.

Moser (1998) identifies three distinct clearing and settlement arrangements for futures markets: (i) clearing by direct settlement (bilateral clearing); (ii) clearing through 'rings' (multilateral clearing, without novation to a CCP); and (iii) complete clearing (CCP clearing). These alternative arrangements form the basis for our comparative exercise in this paper. Although one can trace a natural evolution from direct settlement, through ringing, to complete clearing, the emergence of new products and other financial innovations means that multiple clearing arrangements can co-exist. An overarching assumption in this paper, therefore, is that the asset(s) considered in our model *could* be traded through any one of these arrangements.(3)

In the first of these, clearing by direct settlement, trading agents calculate and perform on their original bilateral obligations. We therefore use the terminology 'bilateral clearing' to describe this class of arrangement. This has historically been the most common clearing arrangement, and, though largely superseded by CCP clearing for exchange-traded products in recent years, it remains the most common arrangement for off-exchange and OTC trading, particularly in less standardised products. Margin will generally be posted on the basis of the bilateral net position.

The second approach, clearing through rings, is the next step in the historical evolution of clearing arrangements. 'Ringing' is a vehicle for achieving multilateral netting of exposures, but without novation to a common central counterparty. Rather, the original bilateral exposures are extinguished and multilateral net exposures reallocated, according to some algorithm, among members of the ring.(4) In a traditional 'ringing' arrangement, described in detail in Moser (1998), members of the ring agree to offset trades within the group, thereby treating each others' contracts as perfect substitutes. Importantly then, a ringing arrangement reduces collateral costs and optimises the liquidity cost of effecting settlement, but agents retain some counterparty credit exposure to one another.

In his historical overview, Kroszner (1999) remarks that "credit risk [in ringing arrangements] continued to vary with the individual counterparties or members of the trading rings"; in short, members' contracts were *not* perfect substitutes for one another. A 'complete clearing' arrangement thus ultimately emerged, taking ringing a step further by introducing novation of all trades to a central counterparty; the CCP

(3) For example, while LCH.Clearnet Limited provides clearing services for vanilla interest rate swaps, market coverage is incomplete due to restricted participation. And, as noted, many other OTC derivatives products are currently cleared only through bilateral arrangements. While at present there are, to our knowledge, no formal ringing arrangements in operation at present, we are aware that some market participants would favour such an arrangement for certain OTC derivative products.
(4) The replacement of exposures would be effected either via direct close-out of the original trades, and generation of the new net trades at the ring price; or via novation. This would typically be facilitated by a clearing house, which would also collect and hold margin.

interposes itself as legal counterparty to both the buy- and sell-side of a trade. In the absence of counterparty default, the CCP has a balanced book and does not, therefore, face any market risk. By providing centralised risk-management and facilitating anonymous trade, CCP-clearing is particularly beneficial in the case of exchange-traded assets, particularly those with long settlement periods, such as derivatives.

The starting point for our comparative simulation analysis is a matrix of normally distributed bilateral net trading exposures between agents, initially in a single asset. In this sense, our approach has much in common with simulation-based analyses of trading systems or interbank loan markets (e.g. Devriese and Mitchell (2005); Wells (2004); Elsinger et al (2002)). The asset price distribution is assumed known and agents' *ex ante* default probabilities are observed (we assume costlessly) by bilateral counterparties. In order to isolate the key factors affecting replacement cost risk in these arrangements, we build up from the case in which homogeneous agents trade a single generic asset, to cases with homogeneous agents trading two assets, and finally to heterogeneous agents trading a single asset.

We first present some results on netting ratios under each arrangement, showing that if trading positions are drawn from a symmetric distribution with mean zero, the expected value of outstanding exposures under multilateral netting declines in proportion to the square root of the number of bilateral trading counterparties. For instance, if trade takes place between 10 agents, each of whom trades with all other agents, then the expected value of the multilateral net exposures generated is a factor of three ($\sqrt{9}$) lower than the expected value of bilateral net exposures generated. We demonstrate that this also implies a similar pattern of decline for expected replacement cost losses and opportunity costs from posting collateral. This basic 'square-root law' has a long history in academic thought, dating back to Edgeworth (1888), and has been applied in a variety of contexts. An important corollary of this result is that, although the netting ratio is the same for both ringing and CCP-clearing, expected replacement cost losses will tend to be more concentrated in the ringing case, due to the absence of mutualised loss-sharing.

In the context of multi-asset clearing, we find that 'margin-pooling' is also an important effect. This is the risk-mitigation benefit derived when an agent's margin payments in respect of multiple positions can be pooled, such that, in the event that the agent defaults, the margin-taker can draw upon any residual margin in the pool (either from profitable, or only modestly loss-making, positions) to cover losses arising on any individual position(s).

Beginning with the assumption that margin is set on an asset-by-asset basis, our simulations show how this margin pooling benefit varies with different degrees of price and position correlation across assets. The effect on replacement cost losses of margin-pooling in CCPs is modelled by comparison of the case in which assets are cleared through 'single-product' CCPs, and that in which they are cleared through multi-product' CCPs. This comparison also allows us to establish the implications of consolidation of CCPs previously clearing only for largely homogeneous assets.

The assumption that margin is set on an asset-by-asset basis is perhaps not unreasonable in the case of CCP-clearing, where portfolio-based margining does not tend to be applied outside of distinct families of assets.(5) In bilateral clearing arrangements, however, portfolio-based margining is becoming increasingly common, and hence we also consider cases in which a portfolio approach is adopted. We show that, in this case, agents face lower collateral costs, and indeed, lower total pre-settlement costs overall, but the replacement cost element increases. This may raise concerns from a financial stability perspective.

We introduce heterogeneity in trader credit quality in order to analyse agents' individual incentives to adopt particular clearing arrangements. We show that with sufficient heterogeneity, restricted access or tiered clearing arrangements will emerge, even though from a financial stability perspective full-membership of a CCP arrangement with mutualised risk may be preferred. For instance, high credit quality agents bear a disproportionate cost burden under the mutualised structure of a CCP, unless the CCP is able to tailor margin requirements to individual default probabilities.

Tailored margining, however, is rarely observed in practice, perhaps due to CCPs' facing higher monitoring costs, or lower monitoring incentives, than individual members clearing bilaterally. Thus, high-quality agents may only wish to access a CCP directly if strict access criteria are applied, leaving lower quality agents to clear either indirectly or bilaterally. Similarly, unless margin can be tailored at low cost, ringing arrangements might also be expected to include the highest quality members only. Our findings here are consistent with the arguments in Kroszner (1999) that financially strong members may be unwilling to implicitly subsidise weaker members by entering into mutualised clearing arrangements, and that concerns about difficulties in evaluating creditworthiness may be important in this regard. Moser (2002), on the other hand, considers circumstances in which high-quality participants would be willing to bear a disproportionate margin cost. He argues that subsidies to lower quality traders can encourage wider market participation, thereby improving the depth and liquidity of the underlying market, and hence trading 'immediacy.'

The remainder of the paper is organised, as follows: Section 2 sets out the analytical framework used in our analysis, highlighting the key assumptions and describing the modelling approach adopted to capture agents' margining policies. Section 3 then uses simulation to compare the risk and cost implications of alternative clearing arrangements when agents are homogeneous, drawing out, in particular, the effects of multilateral netting and margin pooling. Section 4 goes on to examine the effects of heterogeneity among agents on the structure of the clearing landscape, focussing, in particular, on the likely implications for tiering in participation. Section 5 concludes.

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(5) The Standard Portfolio Analysis of Risk (SPAN) margining technology, developed by the Chicago Mercantile Exchange, is widely used by CCPs around the world. SPAN effects portfolio-based margining for distinct families of assets, for which established correlations, justified by clear economic relationships, exist. The SPAN approach is described in detail in Millard and Polenghi (2005).

2. The analytical framework

In our comparative simulation analysis, we examine the properties of the alternative clearing arrangements introduced above: (i) bilateral clearing; (ii) multilateral clearing via ringing; (iii) single-product CCP clearing; and ultimately, (iv) multi-product CCP clearing. With the key features of each arrangement having already been described above, this section introduces the modelling set-up, which will then be subjected to simulation analysis using plausible parameter values.

2.1 The system

We start by modelling a system of n risk-neutral agents(6), all trading a single generic asset k with one another. To generalise the results, one might interpret each generic asset as a set of homogeneous or highly correlated assets. The bilateral exposures generated in this system, denoted by the superscript, b, can be described in an n x n matrix, $T^{b,k}$. Our starting point is a system of n homogeneous agents, in which each agent trades with every other agent, and each bilateral trade is drawn from the same distribution. These assumptions are relaxed later.

$T_{ij}^{b,k}$ represents the bilateral net position(7) (which may be interpreted as the net number of outstanding contracts) in asset k awaiting settlement that exists between agent i and agent j, where $T_{ij}^{b,k} > 0$ denotes that agent i has a long position with agent j. As these are net bilateral positions, this matrix is exactly negatively symmetric about the diagonal. This is illustrated in **(1)**:

$$T^{b,k} = \begin{bmatrix} 0 & T_{12} & \cdots & T_{1n} \\ T_{21} & 0 & & T_{2n} \\ \vdots & & \ddots & \vdots \\ T_{n1} & T_{n2} & \cdots & 0 \end{bmatrix}, \text{ where } T_{ij} = -T_{ji} \qquad \textbf{(1)}$$

In our simulation exercise, we populate this matrix by drawing from a normal distribution with mean 0 and standard deviation σ_T^k.

To model the multilateral ringing case, we first calculate each agent's net exposure to all other members of the ring.(8) Multilateral positions are denoted by the superscript,

(6) In thinking about the application of this approach and the interpretation of the results, it is convenient to assume that the agents are large, professional financial firms.

(7) We assume that agents would have legally robust i.e. enforceable, bilateral netting agreements in place. For example, in the context of OTC derivatives, the International Swaps and Derivatives Association (ISDA) Master Agreement is typically employed by broker-dealers to establish the terms and conditions of the trade, including provisions for close-out netting in case of default.

(8) We begin with the case in which all traders are in the ring, going on later, once heterogeneity has been introduced among agents, to allow for restricted ring membership. We also assume that ring members submit all of their trades to the ring.

m. Agent i's multilateral net position, $T_i^{m,k}$, is simply the sum of its bilateral positions with each agent, j:

$$T_i^{m,k} = \sum_{j=1}^{n} T_{ij}^{b,k} \quad \textbf{(2)}$$

We model the multilateral netting that takes place in a ringing arrangement by application of a simple netting algorithm which extinguishes the original bilateral trades and then, based on the agents' net positions, generates a new bilateral matrix with the smallest possible number of new trades. More precisely, the algorithm first creates a new bilateral exposure between the agent with the largest net long position and that with the largest net short position, and adjusts the net positions accordingly; this process is then repeated iteratively until all positions have been reallocated. It can be shown that the maximum number of new bilateral positions generated by this algorithm is *n-1*. For example, if agents A, B , C and D have net exposures of +10, -15, -20 and +25, respectively, three new bilateral exposures would be generated under the ringing agreement: D long 20 contracts against C, and 5 against B; and A long 10 contracts against B.

In the case of CCP clearing, all bilateral obligations between traders are novated to the CCP. Hence, positions represented by the bilateral matrix in **(1)** are extinguished and replaced by a vector of net settlement exposures between the CCP and each trader. The CCP's positions with each trader are given by **(2)** above, where $T_i^{m,k} > 0$ denotes that agent i has a long position with the CCP.

Replacement cost losses will only arise to the extent that a counterparty default coincides with an adverse price move in excess of the per-unit margin collected from that counterparty; therefore to quantify replacement costs we need to model *price changes*, *margin policy* and *counterparty default*.

2.1.1 Price changes

We capture the change in the price of asset k, Δp^k, by once again drawing from a normal distribution: this time with mean 0 and standard deviation $\sigma_{\Delta p}^k$ [9]. The potential for replacement cost losses thus arises if and only if the draw from this distribution exceeds the per-unit level of margin posted, m_i^k, *and* both the position held in the asset and the sign of the price change are the same: i.e. in the bilateral clearing case, $T_{i,j}^{b,k} \Delta p^k > \left|T_{i,j}^{b,k}\right| m_i^k$. We impose the condition that agents can never profit from a counterparty default. Therefore any profit or excess margin remaining after the defaulted position has been closed out is returned to the defaulting agent[10]. The

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[9] For simplicity, we do not explicitly model the market for asset k. We also assume that agents can correctly observe asset return distributions and hence their precise form is not critical to the analysis.
[10] We understand this to be accepted practice at least for CCPs; for example the case of Drexel Burnham Lambert Ltd (DBL) who defaulted on margin calls from the London Clearing House in February 1990. Settlement of DBL's positions left a net surplus of approximately $18 mn which was repaid to DBL's administrator. See London Clearing House (2002) for further details.

margin level itself is set according to the optimisation approach described in Section 2.1.2.

2.1.2 Margin policy

Trading agents (and CCPs) typically seek margin from their counterparties (or, in the case of CCPs, their members) to mitigate replacement cost risk during the pre-settlement period. We assume in our simulation exercise that margin is set according to an optimisation approach, and apply a variant of the model developed in Baer et al (2004).(11)

The benefits of adopting the optimisation approach are threefold. First, the optimal level of margin can be interpreted as the threshold value in a value-at-risk (VAR) analysis (i.e. a margin level of m would, under certain distributional assumptions, be expected to be exceeded with probability α) and hence can provide some justification for particular coverage levels that might be employed in a pure statistical approach to margining. Second, this approach formalises the problem for both individual traders and a group of traders, allowing us to understand the impact of alternative margin levels on total pre-settlement costs at both the individual and collective levels. This is important when we introduce heterogeneity into the analysis. Finally, the model as presented can readily be submitted to simulation analysis and applied consistently for both bilateral and multilateral clearing arrangements.

Taking first the bilateral case, the optimisation approach assumes that the two parties to a transaction set margin levels so as to jointly minimise total expected pre-settlement costs. We abstract from bargaining problems here, appealing to competitive market conditions that drive the market to an efficient solution.(12)

For each agent i, there are two distinct components to expected pre-settlement cost, $E[TC_i]$: (i) the (opportunity) cost of posting collateral; and (ii) the expected replacement cost loss, $E[R_i]$, should the counterparty to the trade default.

In the application by Baer et al (2004), default occurs endogenously, with agents choosing to strategically default on positions that have moved sufficiently far out of

(11) This is one of several possible approaches. In their review of the literature on CCP clearing arrangements, Knott and Mills (2002) summarise the various models that may be applied to establish appropriate margin levels; including pure statistically-based VaR approaches; option-pricing methodologies and optimisation. The fundamental structure of the optimisation model presented here has been applied in a variety of contexts, including analysis of the precautionary demand for reserves (Baltensperger (1974)) and recent work on banks' optimal collateral choices when cross-border use of collateral is permitted (Manning and Willison (2005)).

(12) In the context of the OTC derivatives market, where bilateral clearing predominates, Bliss and Kaufmann (2005) suggest that agreements on close-out netting can give broker-dealers market power vis-à-vis buy-side firms. This reflects the fact that a buy-side firm will generally have an incentive to close out a position with its original broker-dealer counterparty, so as to be able to take advantage of bilateral netting. This argues against the assumption of competitive market conditions. However, the increasing incidence of contract assignments and the emergence of cross-margining agreements between the major broker-dealers, both serve to dilute this effective market power. We leave for future research a model of clearing with oligopolistic elements.

the money, such that the gain from exercising the default option exceeds any loss from foregoing up-front collateral posted. By contrast, we assume that agent *i* defaults exogenously, with *ex ante* probability δ_i, where δ_i is observed by both parties. The role of the ratings agencies in the objective determination of default probabilities may be important here, as suggested by Kroszner (1999). Continued acquisition of credit-relevant information by each party through a range of business activities might also serve to erode private information. We justify our approach on the assumption that in both the bilateral and multilateral cases, a strategic default would lead to exclusion from future trading and hence there are high non-pecuniary costs to default.[13]

Our assumption of exogenous default also implies that an agent's market risk and credit risk are independent; that is, δ_i is independent of Δp^k. This simplification is consistent with the assumption that the risk in an agent's trading positions is small relative to its capital, although we acknowledge that there could be cases in which the two were correlated; e.g. during periods of stress.

More formally, for a single asset, *k*, the optimal margin levels per contract for each agent *i*, m_i^k*, are the values of m_i^k that minimise the expected joint pre-settlement costs of the two counterparties to the transaction (here, agents 1 and 2). The objective function is given by expression **(3)**, in which $|T_{i,j}^{b,k}|$ represents the absolute net number of contracts transacted, bilaterally between agents *i* and *j*, in asset *k*; r is the recovery rate on replacement cost losses (assumed invariant with respect to both the identity of the agent and the underlying asset); c_i is the per-unit opportunity cost of margin; and Δp^k is the change in the contract price for asset *k*.[14]

$$E[\sum_{i=1}^{2} TC_i] = |T^{b,k}|(c_1 m_1^k + c_2 m_2^k) + (1-r)|T^{b,k}|\left(\delta_2 \int_{m_2^j}^{\infty} (\Delta p^k - m_2^k) f(\Delta p^k) d\Delta p^k + \delta_1 \int_{m_1^j}^{\infty} (\Delta p^k - m_1^k) f(\Delta p^k) d\Delta p^k\right) \quad \textbf{(3)}$$

We minimise **(3)** with respect to m_i^k, subject to $m_i^k \geq 0$. And hence, assuming *F(.)* is invertible, the optimal level of margin is given by **(4)**, below:

$$m_i^k* = \max\left[F^{-1}\left(1 - \frac{c_i}{(1-r)\delta_i}\right), 0\right] \quad \textbf{(4)}$$

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[13] This assumption derives support in a later extension to the central model in Baer et al (2004), and also in Moser (1998), where it is argued that the incentives for strategic default will in practice be small because agents would risk forfeiting their valuable membership of an exchange and/or CCP.

[14] Under the assumption that prices are drawn from a symmetric distribution, $\int_{m}^{\infty}(p-m)f(p)dp = \int_{-\infty}^{-m}(p+m)f(p)dp$. Hence, both integrals can be expressed in terms of the positive side of the distribution.

In the context of a multilateral ringing arrangement, this approach can be applied to the new bilateral matrix generated from the multilateral net positions. When margin is applied on an asset-by-asset basis, the approach detailed above can be applied repeatedly in the multi-asset case to obtain margin choices for a series of bilateral relationships covering several assets. Under portfolio-based margining, margin would reflect the covariance of asset prices and actual trading positions in these assets.

In the case of CCP clearing, an analogous approach can be applied. Under the assumption that the CCP is owned by its participants, margin will be set so as to minimise the joint expected pre-settlement costs of all participants. (15) The expression for the optimal level of margin is analogous to that in **(4)**. As before, this can readily be scaled up to the multi-asset case.

2.1.3 Counterparty default

As noted above, default occurs exogenously in our set-up. We apply an exogenous default vector, *D*, which is generated on the basis of δ_i; that is, default shocks arise ex post in accordance with ex-ante probabilities. In the first instance, we assume that agents have the same ex-ante default probabilities, $\delta_1 = \delta_2 = \delta_i$, and in Section 4 examine the case in which agents are of heterogeneous credit quality, with ex-ante default probabilities: δ_h = high risk; and δ_l = low risk, where $\delta_h > \delta_l$. For each agent *i*, D_i is a binary indicator variable, taking the value $D_i = 1$ if agent *i* has suffered a default; and taking the value $D_i = 0$ if the agent has not defaulted. That is:

$$D_i = \begin{cases} 1 \ \ with \ \ prob \ \ \delta_i \\ 0 \ \ with \ \ prob \ \ (1-\delta_i) \end{cases} \qquad \textbf{(5)}$$

While there is some variation in CCPs' post-default procedures, replacement cost risk exposures are typically managed through the collection of both margin and default fund contributions. In the event of default, initial recourse is typically to the margin posted by the defaulting party; then to the default fund contribution of the defaulting party; and then to default fund contributions of survivors. Should these resources be insufficient to cover replacement cost losses, a CCP would typically first draw upon its own capital and then seek additional contributions from surviving participants. (16) Margin posted by survivors cannot be drawn upon to cover replacement cost losses

(15) Under a demutualised ownership structure, it is conceivable that alternative preferences would be reflected in the CCP's objective function. For instance, Koeppl and Monnet (2005) consider the extent to which margin levels influence the scale of trading activity, and how this might influence a demutualised CCP's risk-management approach.

(16) In some cases, CCP participants are *obliged* to make additional contributions in such an event; in other cases, there is no such explicit provision. For example the rules of LCH.Clearnet Ltd do allow for calls for additional contributions to replenish the default fund, but these cannot be used to deal with the original default that caused the fund to be depleted. LCH.Clearnet SA, on the other hand, has the right to call for additional contributions from its members to replenish the default fund and these contributions can then be used to cover the original default. Some CCPs also have insurance funds to cover to guard against any losses due to default. We do not allow for this possibility in our analysis.

faced by a CCP. As our metric for replacement cost risk is expected losses borne by surviving participants, we are able to simplify matters in our analysis: we make no distinction between collateral contributed by survivors *ex-ante* (as default fund contributions) and any additional contributions made *ex-post*. Therefore, once the margin posted by defaulting agents has been exhausted, all residual losses are shared among survivors and classified as replacement cost losses. Hence, we assume that there is no possibility of a default by a CCP, which is consistent with the focus on first-round effects only. For simplicity, we assume that the losses are shared in proportion to the size of each agent's positions with the CCP, which becomes important when we compare the concentration of losses across different clearing arrangements. Alternative loss-sharing rules could of course be considered.

In the bilateral and ringing cases, residual losses once the defaulting party's margin has been exhausted are borne entirely by the bilateral counterparty: the original counterparty in the bilateral case; and the new ring counterparty (once positions have been multilaterally netted and reallocated) in the multilateral ringing case.

2.2. Metrics for comparison

In this sub-section, we introduce the relevant metrics for comparing cost and risk outcomes under the four alternative clearing arrangements considered. These are: (i) the magnitude of replacement cost losses; (ii) the concentration of replacement cost losses; and (iii) the total pre-settlement costs borne by agents, which comprises the sum of the opportunity cost of posting collateral and the replacement cost loss.

2.2.1 The magnitude of replacement cost losses

Under all clearing scenarios the metric of interest is replacement cost losses borne by surviving members.

In the case of bilateral clearing, the mean *ex-post* replacement cost loss faced by agent *i*, $R_i^{b,k}$, is calculated by summing the product of the mark-to-market losses on open positions with each of the other *n-1* agents in the system (allowing for the margin held against default), and the default realisation of those agents. Given our assumption that *ex ante* default probabilities are realised, and that we make repeated draws from the distribution of price changes and trading positions, this can be interpreted as the *expected* replacement cost loss. The minimum replacement cost loss is zero, given that we apply a rule that any profit made on closing out positions is returned to the defaulter. Therefore, replacement cost losses for agent *i* are given by:

$$R_i^{b,k} = \sum_{j=1}^{n} D_j \max[0, T_{ij}^{b,k}(\Delta p^k - m_j^k)] \qquad \textbf{(6)}$$

Extension to the multi-asset case is straightforward, with the max. expression in **(6)** simply becoming $\max[\,0, T_{ij}^{b,k}(\Delta p^k - m_j^k) + T_{ij}^{b,l}(\Delta p^l - m_j^l)]$. And, to obtain replacement cost losses for the system as a whole, $R^{b,k}$, we sum across agents.

Calculation of agent *i*'s replacement cost loss in the multilateral ringing and CCP clearing cases is analogous. In the ringing case, the relevant positions are those in the new bilateral matrix generated from agents' multilateral net positions. Under CCP clearing, the mean ex-post replacement cost loss faced by the CCP (and hence it's surviving members) is calculated in an analogous fashion, but this time using the multilateral net position vector. In this arrangement, consistent with our loss-sharing rule, each surviving agent, *i*, bears a loss in proportion to the size of its outstanding positions with the CCP.

2.2.2 The concentration of replacement cost losses

The degree of concentration of replacement cost losses across agents may have implications for social welfare. While we do not explicitly model spillover effects, it seems reasonable to assume that, for a given level of replacement cost loss, the likelihood of knock-on default or liquidity strains arising outside of the model will be increasing in the extent to which this loss falls disproportionately on a single counterparty. We measure concentration of losses, *S*, by calculating the ratio of the maximum replacement cost loss incurred by a single agent, *i*, over total replacement cost loss incurred by all agents. We calculate this measure in all scenarios where losses occur, and take the mean.

In the bilateral and ringing cases we use observed replacement cost losses to calculate concentration; in the CCP case, on the other hand, agents' relative multilateral net positions can be used to calculate concentration, as this is the basis on which we assume losses are shared. The relevant expressions for the bilateral, ringing and CCP cases, respectively, are then as in **(7)**, below:

$$S^{b,k} = \frac{\max(R_i^{b,k})}{R^{b,k}}\,;\quad S^{r,k} = \frac{\max(R_i^{r,k})}{R^{r,k}}\,;\quad S_{CCP}^{m,k} = \frac{\max\left|T_i^{m,k}\right|}{\sum_{i=1}^{n}\left|T_i^{m,k}\right|} \qquad \textbf{(7)}$$

2.2.3 Total costs

Recall that, throughout our analysis, we assume that agents are risk-neutral and therefore care only about expected costs. From an agent's perspective, total pre-settlement costs, TC_i, are simply given by the sum of collateral costs and replacement cost losses. Again, given that we can interpret replacement cost losses generated in our simulation as expected replacement cost losses, total costs can also be interpreted as expected total pre-settlement costs.

At the level of the system, we sum all agents' collateral costs and all replacement cost losses arising in the system. In the bilateral case, total costs borne are as given in **(8)**:

$$TC^{b,k} = c\sum_{j=1}^{n}\sum_{i=1}^{n} T_{ij}^{b,k} m_i^{b,k} + R^{b,k} \tag{8}$$

Again, total costs for the ringing and CCP cases are calculated in an analogous fashion.

3. The risk implications of alternative clearing arrangements: comparative simulations

Taking the set-up described above, this section uses simulation analysis to investigate the cost and risk implications of the alternative clearing arrangements considered.

In our work we identify two basic determinants of replacement cost risk differentials among the various clearing arrangements considered: multilateral netting; and margin pooling. We introduce two core propositions that between them capture the important implications of these effects and illustrate these propositions using simulation methods. For each proposition, we also introduce some corollaries. These capture differences in concentration of losses; differences arising from alternative assumptions on trading position and price correlations; and the effects of portfolio-based margining. Our analysis begins with the simplest possible trading arrangement: that is, homogenous agents (i.e. traders have identical ex ante default probabilities and draw from the same distribution of trading positions) trading a single asset. This allows us to tease out the importance of each risk mitigating effect in turn, by relaxing the relevant constraints on the trading arrangement.

For each of the simulations carried out in this section, we evaluate 2500 trading position matrices, drawing from a normal distribution of positions in each asset, *k*, with N(0, σ_{T^k})=N(0, $\sqrt{20}$). We also generate 2500 different scenarios for price changes in asset *k*, drawing from a price-change distribution with N(0, $\sigma_{\Delta p^k}$)=N(0, $\sqrt{2}$); and 2500 default realisations for each agent, applying default vector, *D*. We assume that the latter is based on ex-ante default probability, $\delta_i = 1\%$. Margin coverage is based upon this default probability; the price distribution; an assumed collateral cost of 15bp; and a recovery rate, *r*, of zero(17). We pair the price and default scenarios and apply each of the 2500 pairs to every distinct trading position matrix; therefore, a total of 6.25 million distinct position, price and default scenarios are evaluated. It is necessary to undertake a large number of simulations to

(17) Our parameters for the standard deviation of positions and price changes are essentially arbitrary. However, their precise values have little effect on our results. Default probability is chosen to capture the fact that defaults are rare events, without making default events so rare as to require an inefficiently high number of simulations to obtain accurate results. Collateral cost is assumed to reflect the difference between secured and unsecured borrowing rates. This interacts with the volatility of price changes to determine the relative importance of collateral holding costs and replacement costs. Our parameters imply that agents will require margin up to an 85% coverage level when default probability is 1%. This is significantly lower than the 99% coverage that would typically be regarded as a minimum requirement for CCPs . However it may be more accurate in a bilateral setting, to the extent that agents are willing to take some unsecured exposure to high-quality counterparties. The important consideration in this analysis is to use the same coverage level across all clearing scenarios.

get accurate results, because the price change and default scenarios chosen make significant default events rare occurrences.

3.1. Single asset clearing with homogeneous agents

We begin with the case in which a single asset is traded bilaterally by a group of *n* homogeneous agents, and cleared either bilaterally or multilaterally via a ringing arrangement or a CCP. This set-up allows us to isolate the effect a shift from bilateral to multilateral netting will have on expected replacement cost losses and total expected pre-settlement costs. Clearly, with a single asset, we cannot consider consolidation of product-specific CCPs in this initial example.

Proposition 1: Multilateral netting, via either novation or direct offset of positions, will reduce the level of outstanding trading exposures in the market, and hence will also reduce replacement cost losses and total expected pre settlement costs. The ratio of replacement cost losses between bilateral and multilateral clearing arrangements, will depend only on the netting ratio, which, with trading positions drawn from a symmetric distribution, will be increasing in the number of each agent's trading counterparties, but at a decreasing rate.[18]

Proof: With trading positions in a single asset drawn from a normal distribution, and each agent trading with every other member of the system, the netting ratio can be expressed formally as in **(9)**, below. This expression shows that the netting ratio is equal to the square-root of the number of trading counterparties with whom each agent transacts.

$$NR = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} | T_{ij}^{b,k} |}{\sum_{i=1}^{n} \left| T_i^{m,k} \right|} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} | T_{ij}^{b,k} |}{\sum_{i=1}^{n} \left| \sum_{j=1}^{n} T_{ij}^{b,k} \right|} = \frac{n(n-1)C_0}{n\sqrt{(n-1)}C_0} = \sqrt{(n-1)} \qquad \textbf{(9)}$$

---

[18] Proposition 1 may be illustrated with a simple example. Consider a sequence of trades in which A buys 100 contracts from B and later sells 50 of these contracts to C and 50 to D. With multilateral netting effected via ringing, the existing contract between A and B would be directly offset or extinguished, and two new bilateral trades generated between B and each of C and D, each for 50 contracts. Similarly, with the clearing house interposing itself as common counterparty under CCP clearing, the CCP would have a long position of 100 contracts against B; short positions of 50 contracts with each of C and D; and a net position of zero with A. In the bilateral case, however, there remain three outstanding (though offsetting) trades in the system. Hence, were A to suffer a solvency shock and the asset price to simultaneously fall sharply, there would be no replacement cost risk in either of the multilateral clearing cases, while, under bilateral clearing, B would suffer a replacement cost loss on the outstanding 100 contracts (were the price to fall by more than the amount of margin posted). Although A would have an offsetting gain on its outstanding short positions with C and D, these gains (on close-out) would go into the creditors' pool; they might ultimately offset some of B's loss, but perhaps only a small fraction thereof. In this particular example, the total absolute value of outstanding positions in the bilateral case is 400 contracts (A's position is 200 (100 with B; and 50 with each of C and D); B's position is 100; and C and D each have positions of 50 contracts). In the multilateral case, the absolute value of outstanding positions is just 200 contracts (a position of 100 for B; and 50 for each of C and D), yielding a netting ratio of 2.

where: $T_{ij}^{b,k} \sim \mathrm{N}(0,\sigma_T^k) \rightarrow E(T_{ij}^{b,k}) = \sqrt{\frac{2}{\pi}} = C_0$

It can readily be shown that the first and second derivatives of **(9)** are positive and negative, respectively. Hence, the netting ratio is increasing in the number of trading counterparties, but at a decreasing rate.

It is immediately clear from the expressions for replacement cost losses presented in Section 2.2.1 that replacement cost losses under bilateral and multilateral clearing will be dependent only on the netting ratio applied to trading exposures. This reflects the fact that the unit price change in asset *k* is independent of the clearing arrangement, as is margin per-unit when agents are homogeneous.■

The analytical result in proposition 1 is borne out by our simulation exercise for the single asset/homogeneous agent case (applying the parameter values introduced above), in which we compare replacement cost losses across the alternative arrangements, for alternative values of *n*. The results are shown in Table 1, below. We also confirm that total cost differentials are dependent solely on the netting ratio.

Table 1. Ratio of replacement cost losses, total pre-settlement costs, and concentration under alternative clearing arrangements (with differing numbers of traders)

Benchmark: CCP
Position matrices evaluated: 2500
Default scenarios: 2500
Default probability: 1%
Cost of collateral: 15 bps
Margin coverage: 85%
$\sigma_{\Delta p}^k = \sqrt{2}$; $\sigma_T^k = \sqrt{20}$

Number of traders	**5**	**10**	**20**
Expected replacement cost loss			
Bilateral	2.0	3.0	4.3
Multilateral Ring	1.0	1.0	1.0
Total expected pre-settlement cost			
Bilateral	2.0	3.0	4.4
Multilateral Ring	1.0	1.0	1.0
Concentration (% of total losses)			
Bilateral	74	46	25
Multilateral Ring	89	88	89
CCP	39	24	14

The outcome for concentration of losses is particularly interesting, however, and reveals the crucial difference between the two multilateral clearing arrangements. This leads us to corollary 1:

Corollary 1: While the magnitude of replacement cost losses will be equivalent under ringing and CCP-clearing, losses will typically be more concentrated when multilateral netting has been achieved via ringing.

This corollary reflects the fact that agents' multilateral net positions are reallocated among the members of the ring according to an algorithm which ensures the fewest new bilateral positions. Hence, in the new bilateral matrix, traders will typically have exposures to just a small subset of counterparties. In the event of a default, losses will be borne only by those counterparties with a direct exposure to the defaulting agent. In the CCP case, by contrast, we apply a rule such that losses are shared across *all* members, in proportion to the size of their exposures to the CCP, rather than their exposures to the defaulting trader. The differences in the concentration ratios between the ringing and CCP cases will be increasing in n, due to the fact that, with a larger number of traders in the system, it is more likely that losses will be shared across a larger number of agents in the CCP case.[19]

The results in Table 1, above, are calculated for a complete bilateral trading matrix, in which each agent has trading positions with every other agent. In practice, even for exchange-traded assets, a complete bilateral trading matrix would not be observed. Corollary 2 below shows how the result in Proposition 1 can be generalised to encompass this.

Corollary 2: Where the trading position matrix is not complete, the netting ratio equals the square root of the weighted-average number of counterparties with whom each agent transacts.

By way of illustration, consider a case with n=10, in which 50% of agents are 'complete agents', who have trading exposures with all other agents, while the remaining 50% of agents only have trading exposures with these complete agents. The relevant netting ratio in this case will thus be $\sqrt{7}$, rather than $\sqrt{9}$ in the complete matrix case. Hence, the ratio of replacement cost losses (total expected pre-settlement costs), will be 2.65, rather than the 3.0 reported in Table 1. More generally, for a given number of traders, the ratio of risks and costs between the bilateral and multilateral arrangements will decline as the matrix becomes less complete.

3.2. Multi-asset clearing with homogeneous agents

Introducing a second asset, we are able to analyse the effect of portfolio diversification and margin pooling. By margin pooling, we refer to the fact that, even though a bilateral counterparty or a multi-product CCP may calculate an agent's margin obligations on an asset-by-asset (or position-by-position) basis, the margin is pooled once collected. Should that agent then default, any margin in the pool may be drawn upon to meet replacement cost losses arising on that agent's positions. With

(19) This concentration effect can be readily illustrated using the stylised example in footnote (18), above. Consider a default by C, combined with a large price decline. Under CCP-clearing, any replacement cost loss associated with this position would be shared in the ratio 2:1:0 across B, D and A, respectively. Under a ringing arrangement, by contrast, losses would be borne entirely by B, the only agent with an exposure to the defaulting party in the new bilateral matrix.

imperfectly correlated price changes, a replacement cost loss arising on one asset may then be mitigated by drawing upon residual margin posted in respect of the other.

This allows us, in particular, to offer some initial insight into the risk implications of consolidation of product-specific CCPs: when each asset is cleared through a separate, product-specific, CCP, only the effects analysed in Section 3.1, above, will be observed. However, when an agent's positions in both assets are cleared together through a multi-asset CCP, then margin-pooling effects can be important. We can assume that both assets will always be cleared together in the bilateral and multilateral ringing cases, so the cost and risk implications of these arrangements relative to the multi-product CCP will be as before. Therefore, we only compare these arrangements with the single-asset CCP case, and indeed cast most of our results in terms of the comparison of single-asset and multi-asset CCP clearing. The analysis in this sub-section is based initially on the case in which margin is calculated on an asset-by-asset basis under all arrangements. We then go on to consider the case of portfolio-based margining; i.e. the practice of granting margin offsets to reflect the diversification in a trader's asset portfolio.

3.2.1 Asset-by-asset margining - equal price-change variances and equal position variances

In the context of CCP consolidation, the effect of risk benefits of margin-pooling for the case with asset-by-asset margining are summarised in proposition 2, below.

Proposition 2: When margin is set on an asset-by-asset basis and both asset prices and trading positions are imperfectly correlated, expected replacement cost losses will be lower when all assets are cleared through a single CCP than when they are each cleared through separate CCPs.

Proof: Proposition 2 may be expressed as a comparison of expected replacement cost losses when clearing two assets through either a single or two CCPs. Under the assumption that margin is calculated on an asset-by-asset basis, the total value of margin posted by agent *i* is the same in the two cases: $|T_i^{m,k}| m^k + |T_i^{m,l}| m^l$. Importantly, however, clearing through a single CCP allows margin posted by agent *i* to be pooled across assets and applied to meet replacement cost losses in either.

Equally, trading positions are pooled when assets are cleared through a single CCP, and although, in setting margin levels, the CCP ignores any portfolio effects, the expected replacement cost loss associated with agent *i*'s position will take into account the true covariance of both asset price changes and trading positions. Hence, it must be true that: $E[|T_i^{m,k}\Delta p^k| + |T_i^{m,l}\Delta p^l|] \geq E[|T_i^{m,k}\Delta p^k + T_i^{m,l}\Delta p^l|]$. This expression will only hold with equality if *both* trading positions and price changes in the two assets are perfectly correlated (either both positively or both negatively correlated). For imperfectly correlated assets and/or trading positions, expected replacement cost losses will be lower when assets are cleared through a single CCP. ■

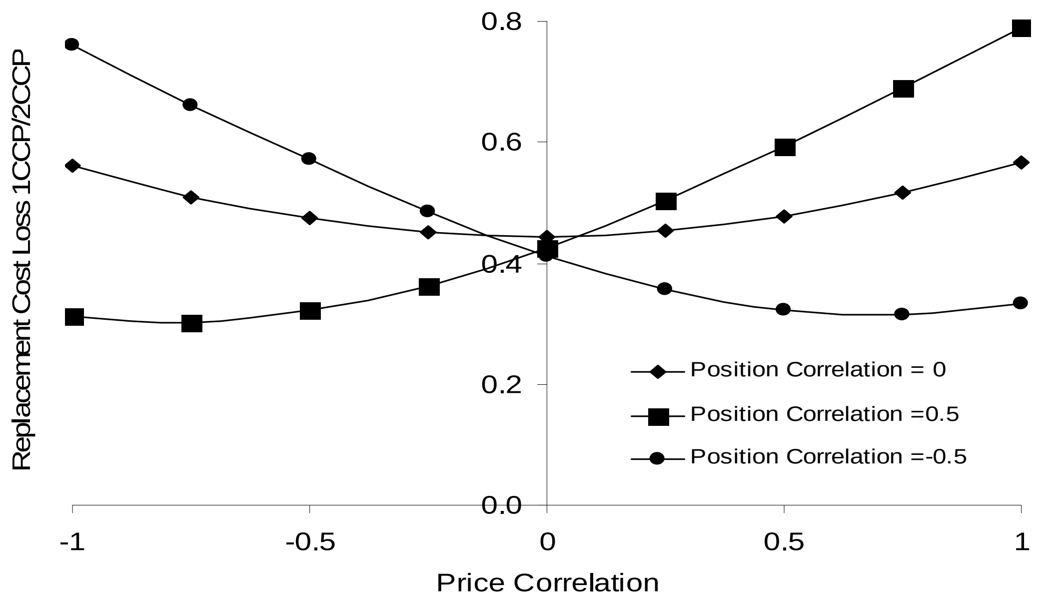
It follows, therefore, that the ratio of replacement cost losses between the single-product and multi-product CCP-clearing cases will depend on the degree of correlation in trading positions and asset prices. We therefore turn to simulation analysis in an attempt to quantify this ratio for differing correlations between price changes in two assets, *k* and *l*, $\rho_{\Delta p}$, and trading positions in the two assets, ρ_T . Assuming Δp^l and Δp^{ind} are independent draws, Δp^k may be calculated, as follows:

$$\Delta p^k = \frac{\sigma^k_{\Delta p}}{\sigma^l_{\Delta p}} \rho_{\Delta p} \Delta p^l + \Delta p^{ind} \sqrt{(1-\rho^2_{\Delta p})} \qquad \textbf{(10)}$$

Correlated trading positions are calculated in an analogous fashion. It is clear that with $\rho_{\Delta p} = 0$, $\Delta p^k = \Delta p^{ind}$, and Δp^k and Δp^l are completely uncorrelated; while with $\rho_{\Delta p} = 1$, $\Delta p^k = (\sigma^k_{\Delta p} / \sigma^l_{\Delta p})\ \Delta p^l$ and Δp^k and Δp^l are perfectly correlated. In our exercise, we start by assuming that the two asset prices are equally volatile, each being drawn from a normal distribution with N(0, $\sigma^k_{\Delta p}$)= N(0, $\sigma^l_{\Delta p}$)=N(0, $\sqrt{2}$); and that trading positions are also drawn from the same distribution: N(0, σ^k_T)=N(0, σ^l_T) =N(0, $\sqrt{20}$).

The important message from this analysis is that the most significant margin-pooling benefits from CCP consolidation will occur when one of the following holds: (i) the correlation between either price changes or trading positions is low; or (ii) the correlations between price changes and trading positions take opposite signs. These effects are illustrated in Chart 1. Chart 1 plots the ratio of replacement cost losses under single-product CCP clearing (2 CCPs) to those under multi-product CCP clearing, for alternative combinations of price-change and position correlations.

Chart 1. Ratio of replacement cost losses under single- and multi-product CCP clearing for alternative position and price correlations
(Benchmark: multi-product CCP)



With $\rho_{\Delta p} = 0$, extreme price changes in both assets are unlikely, and hence multi-product CCP clearing generates significant margin-pooling benefits.[20] As $|\rho_{\Delta p}| \to 1$, the likelihood that extreme price moves will occur in both assets simultaneously increases, and therefore the benefits of margin-pooling are determined increasingly by the degree of position correlation, and the interaction between price change and position correlations. If these correlations have the same sign, then margin-pooling benefits will be reduced; if they have different signs, then these benefits will be increased (hence the asymmetric pattern evident in Chart 1).

The extreme cases are not shown in the chart, but are worthy of note. With $\rho_{\Delta p} = \rho_T = 1$, expected replacement cost losses are equivalent in the single- and multi-product cases, whereas with $\rho_{\Delta p} = -\rho_T = 1$, replacement cost losses fall to zero in the multi-product case, leaving the ratio undefined.

The impact of consolidation on total pre-settlement costs is less significant than the impact on replacement costs described above. As margin setting is carried out on an asset by asset basis, the opportunity cost of posting collateral is equal in both clearing arrangements. This implies a significant source of potential divergence between the interests of agents, who we have assumed to be risk neutral, and a risk averse policymaker with a financial stability objective, who might be expected to attach more weight to the replacement cost risk-mitigation benefits of margin-pooling.

In order to complete the picture, we can also compare outcomes in the single-product CCP case with those in the ringing and bilateral clearing cases. In the ringing case, the results identified in the CCP case are directly applicable: a ringing arrangement will equally be able to capture margin-pooling benefits, the only difference between the results obtained for a multi-asset CCP and a multi-asset ring being the greater concentration of losses in the ringing case (as identified in Corollary 1 of Section 3.1).

The comparison with the bilateral clearing case provides some insight into the relative effects of margin-pooling and netting. While the multilateral netting result established in Section 3.1 (Bilateral/CCP replacement cost losses = 4.4 for n=20) stands in the cases in which no margin-pooling is available (e.g. $\rho_{\Delta p} = \rho_T = 1$), the margin-pooling effects on replacement cost risk captured in bilateral clearing outweigh the netting benefits of CCP clearing when $|\rho_T| \to 1$ *and* the correlations between price changes or trading positions take opposite signs. However, the benefits of CCP clearing in total pre-settlement cost terms are still significant, the lowest ratio observed being that total costs are 2.8 times higher in the bilateral case.

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[20] A finding not clear from Chart 1 is that this effect increases as $|\rho_T| \to 1$. This reflects the fact that, with positions drawn from the same distribution, it becomes increasingly likely that the trader's positions in each asset will be of similar size. This makes it more likely that, for a given correlation in price changes, sufficient margin will have been posted in respect of a position in which no loss has been incurred to offset replacement cost losses on a position suffering an adverse price shock.

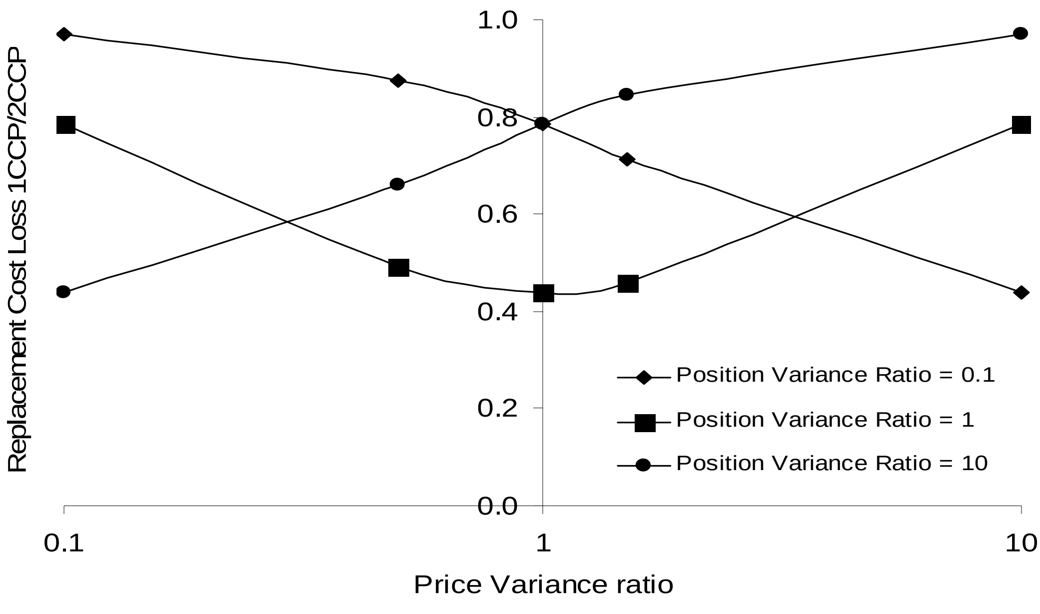
3.2.2 Asset-by-asset margining - unequal price-change variances and unequal position variances

So far, we have assumed equal price change variances, and equal position variances. Relaxation of this assumption has a significant effect on potential margin-pooling benefits; this is summarised in Corollary 3.

Corollary 3: Margin pooling benefits are maximised when: (i) the variances of the price-change distributions for the assets being cleared are equal; and (ii) the variances of the position distributions for the assets being cleared are equal. The more the ratio of either of these variances deviates from 1, *ceteris paribus*, the greater the loss of margin-pooling benefits. Where the ratio of both variances changes in an off-setting manner, margin-pooling benefits tend back towards the maximum.

This is illustrated in Chart 2, below, which traces the effect of deviation from 1 in the price-change variance ratio, for alternative position variance ratios. The chart is drawn for zero price-change and zero position correlations in the two assets. Again, the vertical axis traces the ratio of replacement cost losses between single-product and multi-product CCPs.

Chart 2. Ratio of replacement cost losses under single- and multi-product CCP clearing for alternative price-change and position variance ratios
(Benchmark: single-product CCP)



3.2.3 Portfolio-based margining

Finally, in this section we consider how these results might be affected if margin were calculated on a portfolio basis. This is becoming increasingly common in bilateral clearing relationships, but remains limited in the CCP context. Indeed, in the CCP case, offsets are often granted only within distinct families of assets (under SPAN-type procedures), which likely reflects the fact that in these cases correlations tend to be more stable and predictable. It should be noted, however, that, to the extent that bilateral arrangements are, in practice, most prevalent in OTC derivatives markets, which are covered by complex, often product-specific, legal agreements, there may in some cases be a legal barrier to the full adoption of cross-product portfolio-based margining.[21]

In our simulation exercise, we assume that a bilateral trader (or a consolidated CCP) calculates margin on the basis of the portfolio variance of its outstanding positions vis-à-vis a particular counterparty, taking into account *actual* trading positions and the *actual* covariance of price changes (assumed observed). The calculation for the two-asset case considered here is given in expression **(11)**, below:

$$\sigma^{port}_{\Delta p\ i} = (\sigma^{k}_{\Delta p})^2 \left(\frac{T_i^{b,k}}{\left|T_i^{b,k}\right| + \left|T_i^{b,l}\right|} \right)^2 + (\sigma^{l}_{\Delta p})^2 \left(\frac{T_i^{b,l}}{\left|T_i^{b,k}\right| + \left|T_i^{b,l}\right|} \right)^2 + 2\rho_{\Delta p} \frac{T_i^{m,k} T_i^{m,l}}{\left(\left|T_i^{b,k}\right| + \left|T_i^{b,l}\right|\right)^2} \sigma^{k}_{\Delta p} \sigma^{l}_{\Delta p} \quad \textbf{(11)}$$

The optimal margin level, $m_i^{port}*$, is then calculated using expression **(4).**

Our analysis of this case leads us to Corollary 4:

Corollary 4: When margin is set on a portfolio basis, allowing offsets to reflect diversification in an agent's trading positions, the replacement cost risk-mitigation benefits associated with margin pooling will be significantly diminished. Total pre-settlement costs will, however, decline as collateral posting requirements are reduced.

Our simulations reveal that replacement cost risk benefits from margin pooling are significantly reduced once margin is calculated on a portfolio basis, though total pre-settlement costs are generally lower, due to the fact that agents are required to post much less margin up-front.

When absolute correlations in both price changes and trading positions are low, the reduction in total costs from adopting a portfolio approach is very small; indeed, with zero correlation in both price changes and trading positions, portfolio margining reduces total pre-settlement costs by just 2%, reflecting the fact that replacement cost losses rise 70% relative to the asset-by-asset margining alternative. It is only when absolute price-change correlations are high that significant cost reductions are captured by adopting a portfolio-based margining approach. This accords with observed CCP behaviour: as noted, margin offsets are typically only granted on positions where price-change correlations are significant, stable and justified by economic relationships.

3.3 Summary and policy implications

The analysis of Section 3.1 shows that multilateral netting arrangements, both under ringing and CCP-clearing, offer significant mitigation of both costs and risks when

[21] An annex to the Master Agreement governing an OTC trade will typically specify the terms and conditions associated with collateralisation of pre-settlement exposures.

compared to bilateral arrangements. The scale of these benefits depends solely on the netting ratio; which in turn is solely determined by the effective number of counterparties with whom each agent transacts. Agents' incentives to adopt multilateral clearing arrangements are likely to be strongest where trading is centralised (for example on an exchange), as this will tend to broaden the number of potential counterparties. Where trading is decentralised, as in OTC markets, such that each agent typically only transacts with a small number of counterparties, potential multilateral netting benefits will be diminished.(22) Under our risk-neutrality assumption, agents will be indifferent between ringing and CCP-clearing arrangements. However, according to Corollary 1, a risk-averse policymaker with an interest in preserving financial stability might favour a CCP clearing solution, given the greater concentration of losses under ringing.

Extending our modelling framework to encompass the clearing of two assets, some important insights are offered with regard to the risk implications of consolidation. The principal benefit in this regard derives from margin-pooling, with its scale depending on the extent to which margin is calculated on an asset-by-asset or a portfolio basis, and, if the former, on the variances and covariances of both price changes and agents' positions in the two assets.

This implies that, when considering the replacement cost risk implications of a specific proposal to consolidate CCPs, a detailed analysis of relative variances and measures of comovement would be warranted. By way of illustration of this type of analysis, an empirical example is included in the Annex using data on LIFFE traders' open-interest in the EURIBOR and FTSE 100 futures contracts. Under consistent assumptions for default probabilities, margin-setting policy and the unit cost of margin, we show that expected replacement cost losses would more than 20% higher were these contracts cleared through separate CCPs. These findings are consistent with those presented in Gemmill (1994)(23).

4. Exploring heterogeneity

In this section, we return to a single asset environment, but introduce heterogeneity in trader types. This allows us to investigate agents' individual incentives to participate in particular clearing arrangements. Specifically, we would like to explore the extent to which individual and collective preferences differ; and, to the extent that they do, what this might imply for the topography of the clearing landscape.

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(22) Of course, multilateral netting may be infeasible. Barriers not included in our model, but potentially important, might include: insufficient standardisation of the underlying contracts; difficulties in price-discovery; legal barriers; problems in asset liquidation in the event of default (particularly important for a CCP, which must maintain a balanced book); and upfront technology/development costs.

(23) In a simple model of 3 assets with low correlations, Gemmill (1994) concludes that the diversification benefit of clearing all 3 assets simultaneously results in a halving of the risk faced by the CCP as compared with the case in which all 3 assets are cleared separately.

The margin-setting methodology described in Section 2 allows margin to be tailored according to individual credit quality. Working with homogeneous trading agents in the analysis of Section 3, this was not a relevant factor. Here, however, the results rest, to a significant extent, on whether margin is tailored in this way. While margin will always tend to be tailored to individual participants' default probabilities in bilateral clearing arrangements, this is rarely the case in CCP arrangements. Baer et al. (2004) argue that this reflects several factors, including the potentially high cost to the CCP of intensive monitoring of its members. Furthermore, the incentive to monitor may be dampened by the fact that multilateral netting reduces individual agents' risk exposures to relatively low levels. We show in this section that if agents have heterogeneous credit qualities, but a CCP or ring sets a single margin level, high credit quality agents will face disproportionately high pre-settlement costs and may not wish to participate. Multilateral arrangements with restricted membership may be a natural response to this adverse selection problem.

To explore agents' individual incentives to join particular clearing arrangements, we extend our model by allowing agents to be of two types: high credit quality and low credit quality. We compare cost and risk outcomes for cases in which margin is fully tailored to credit quality and cases in which a single margin rate is imposed on all participating agents. We analyse two distinct configurations of membership: first we consider unrestricted access, with *all* trading agents being direct members of the clearing arrangement; we then consider arrangements with access restricted to high-quality traders only.(24)

4.1 Unrestricted access

If fully tailored margining is feasible and costless under all three alternative clearing arrangements, it can easily be shown that relative replacement cost losses and total pre-settlement costs will be as in the single asset/homogeneous agent case described in Section 3.1; i.e. only the netting ratio will matter. And, as before, the outcome in a ringing arrangement with tailored margining will be equivalent to that in the CCP case, but with a marked increase in the concentration of replacement cost losses.

But fully tailored margining is rarely, if ever, observed in existing multilateral arrangements, implying that this may either be infeasible or incentive-incompatible when monitoring/tailoring costs exist. We therefore consider the implications of alternatives in which the multilateral arrangement sets a single margin rate per asset, and hence no such costs need be incurred.

4.1.1 Unrestricted access - single margin level

In this sub-section we consider cases in which a single margin level per-asset is set on the basis of the mean default probability of members, $\bar{\delta}$. This probability is assumed

(24) In principle, any group of sufficiently homogeneous traders could populate the first tier. However, in practice, direct members are always drawn from the highest quality group, perhaps because these are more likely to be the 'most important' players in a market.

observable at no cost. Table 2, below, presents simulation results for a case with 20 agents, split equally between high- and low- quality agents, with default probabilities δ_h=1%, and δ_l=10%, respectively. Margin in this case is therefore set on the basis of a mean default probability of 5.5%, which with an assumed collateral cost of 15bp, and asset price changes normally distributed with variance 2, implies coverage of 97.3% on all positions. This compares with coverage of 85% on high-quality agents' exposures; and 98.5% on low-quality agents' exposures, when margin is fully tailored to default probability. The benchmark for the results in the table is the case of CCP clearing with unrestricted access and costless fully tailored margining.

The important thing to note here is that, given the shape of the normal distribution, the application of a margin rate consistent with mean group default probability implies a sharp increase in coverage on high-quality agents' positions and hence a significant reduction in replacement cost losses. This more than offsets the increase in replacement cost losses on low-quality agents' positions, where coverage declines, but by proportionally much less. Therefore, purely on a comparison of replacement cost losses, this arrangement dominates the full monitoring arrangement, and hence might be favoured by a risk-averse policy-maker. Furthermore, the results in Table 2 also imply that the total cost of the arrangement to agents is only marginally higher than in the fully tailored case, with the difference sufficiently small that it could be removed if monitoring/tailoring were costly.

Table 2. Unrestricted access/single margin rate: ratio of replacement cost losses, total costs and concentration under alternative clearing arrangements

Benchmark: CCP with tailored margining
Position matrices evaluated: 2500
Default scenarios: 2500
Number of agents: 20 (10 high quality, 10 low quality)
Default probability – high credit quality: 1% (coverage: 97.3%)
– low credit quality: 10% (coverage: 97.3%)

	Ratio
Replacement cost loss	
All agents – CCP	0.9
All agents – Ringing	0.9
Total pre-settlement cost	
All agents – CCP	1.1
All agents – Ringing	1.1
Concentration	
All agents – CCP	1.0
All agents – Ringing	5.7

Table 3 disaggregates the results in Table 2, separately identifying the costs and risks faced by high- and low-quality agents. It is immediately clear that a single margin rate places a disproportionate cost burden on low-risk (high-quality) agents: these agents are required to post a higher level of margin per-unit than would be the case under tailored margining. Therefore, absent very high monitoring/tailoring costs, and other ancillary benefits to subsidising the participation of low-quality counterparties, high-quality agents would strongly favour full tailoring in any multilateral arrangement.

Table 3. Unrestricted access/single margin rate: ratio of replacement cost losses, total costs and concentration under alternative clearing arrangements – disaggregated results

Benchmark: CCP with tailored margining
Position matrices evaluated: 2500
Default scenarios: 2500
Number of agents: 20 (10 high quality, 10 low quality)
Default probability – high credit quality: 1% (coverage: 97.3%)
– low credit quality: 10% (coverage: 97.3%)

	Ratio
Expected replacement cost loss	
High credit quality – CCP	0.9
High credit quality – Ringing	0.9
Low credit quality – CCP	0.9
Low credit quality – Ringing	0.9
Total pre-settlement cost	
High credit quality – CCP	1.56
High credit quality – Ringing	1.55
Low credit quality – CCP	0.88
Low credit quality – Ringing	0.89
Concentration	
High credit quality – CCP	1.0
High credit quality – Ringing	3.6
Low credit quality – CCP	1.0
Low credit quality – Ringing	3.6

4.2 Restricted access

Given the adverse selection effect noted above, it is likely that, if a multilateral arrangement with tailored margining is not feasible, traders with high credit quality will wish to exclude agents of significantly lower credit quality from any multilateral arrangement. A restricted access arrangement may then emerge, in which objectively determined access criteria are set, which allow only traders with sufficiently high credit quality to participate directly. To the extent that access criteria are based upon objective measures, such as credit ratings set by the ratings agencies, they may be almost costless to apply. This is not unrealistic in the case of large, high-quality financial firms who would certainly be rated. With membership restricted to a subset of near-homogeneous agents, it would be possible to set a single margin rate that was acceptable to all direct members, allowing margin tailoring costs to be avoided.

Two alternative restricted access configurations might then emerge: (i) restricted access *without* tiered membership; and (ii) restricted access *with* tiered membership.

Under the first of these, only trades between direct members are multilaterally cleared; those between a member and a non-member, or between two non-members, would be cleared bilaterally.

In tiered arrangements, direct members clear on behalf of a body of second tier indirect participants. Each indirect participant clears through a single direct member, who commits to honouring that participant's obligations as if they were its own. By taking responsibility for margin payments associated with the positions of a second-tier participant, a direct member essentially provides insurance to other members of the multilateral arrangement against that participant's counterparty credit risk. However, we assume that direct members do not provide insurance to indirect participants against default of their counterparty; hence under a tiered ringing arrangement second tier members would remain exposed to any counterparty credit risk associated with their positions vis-à-vis direct members of the ring, while under a tiered CCP arrangement second tier members remain exposed to their share of any additional contributions required from survivors to cover losses incurred by the CCP.(25) Tiered arrangements preserve multilateral netting for all trades, while still ensuring that the CCP or ring can operate with a single margin rate. Furthermore, to the extent that it is difficult and costly for a CCP or a ring clearinghouse to monitor and effect tailored margining for lower quality agents (on whom there may be limited public information), such an arrangement has the effect of delegating monitoring of second-tier participants, and associated margin setting, to direct members. As assumed in the bilateral case, the direct member may be able to accumulate private information via its trading relationship with the second-tier member.

4.2.1 Restricted access with tiering - single margin level

In Table 4, below, we present simulation results for tiered multilateral arrangements, assuming that direct and indirect members carry the rights and obligations described above. We again assume equal numbers of high- and low-quality agents, with only high credit-quality agents gaining access to the arrangements as direct members, and each clearing for one low-quality indirect member.(26) In each case, a single margin rate is set, providing 85% coverage. It is immediately clear that these tiered arrangements have, in aggregate, the same replacement cost loss and total cost implications as the full monitoring CCP benchmark. However when disaggregating the results by agent-type, significant differences emerge.

In the tiered CCP, pre-settlement costs exceed the unrestricted access/full-tailoring benchmark for high-quality agents, but they are still lower than in the case with unrestricted membership and a single margin rate. As direct members take responsibility for the default of their second tier participants in both tiered arrangements, losses fall disproportionately on direct members; hence, a significant increase in concentration of losses is observed. This effect is particularly marked in

(25) In practice only direct members would be called upon to make additional default fund contributions where a CCP faced losses. However, we assume direct members pass through the portion of these expected costs associated with second tier members' positions.

(26) This is the most diversified tiering arrangement possible. In practice, tiering is likely to be more concentrated, with some first-tier members acting for several second-tier members, and other first-tier members only clearing on their own behalf. Such concentration would increase the impact of the adverse selection and concentration effects we observe in tiered arrangements.

the CCP case, where we assume that second-tier members can only incur losses when the CCP calls for additional margin.[27] In the ring case, because direct members do not provide counterparty credit insurance to the second tier, costs and risks are shared more evenly between the high- and low-quality agents. Similar effects may be observed in the case of the tiered ringing arrangement. However, in this case, because direct members do not provide counterparty credit insurance to the second tier, costs and risks are shared more evenly between the two types of agent. These results reflect the essential fact that, under CCP clearing, the counterparty to a second tier member's trades is the CCP, while in the ringing case, direct counterparty risk is preserved.

Table 4. Tiered membership/single margin rate: ratio of replacement cost losses, total costs and concentration under alternative clearing arrangements

Benchmark: CCP with tailored margining
Position matrices evaluated: 2500
Default scenarios: 2500
Number of agents: 20 (10 high quality, 10 low quality)
Default probability – high credit quality: 1% (coverage: 85%)
– low credit quality: 10% (coverage: 98.5%)

Tiering: Only high credit quality agents are direct members of the CCP/ring

	Ratio
Replacement cost loss	
All agents – Tiered CCP	1.0
All agents – Tiered Ringing	1.0
High credit quality – Tiered CCP	1.4
High credit quality – Tiered Ring	1.3
Low credit quality – Tiered CCP	0.6
Low credit quality – Tiered Ring	0.7
Total pre-settlement cost	
All agents – Tiered CCP	1.0
All agents – Tiered Ring	1.0
High credit quality – Tiered CCP	1.11
High credit quality – Tiered Ring	1.11
Low credit quality – Tiered CCP	0.93
Low credit quality – Tiered Ring	0.94
Concentration	
All agents – Tiered CCP	3.5
All agents – Tiered Ring	5.9
High credit quality – Tiered CCP	3.9
High credit quality – Tiered Ring	4.9
Low credit quality – Tiered CCP	0.5
Low credit quality – Tiered Ring	2.1

[27] In reality, there also exists some potential for the second-tier member of a CCP to be adversely affected in the event of default by its first-tier clearing member. In this case, the CCP could legitimately draw upon margin posted in respect of a defaulting member's second-tier clients' positions to cover any losses. Experience varies in this regard. For example, in the case of the default of Griffin Trading Company, at the London Clearing House, approximately 50 of Griffin's customers incurred a loss, while around 70 others were unaffected. For simplicity, we do not model this effect.

4.3 Agents' preferences among alternative multilateral clearing arrangements

We can use the results above to examine which clearing arrangement might ultimately emerge. A thorough treatment of this question would require a more sophisticated analysis of monitoring costs and incentives, as well as costs associated with margin-tailoring, which is out of the scope of this analysis. Nevertheless, the indicative results presented here may constitute a useful starting point for any future analysis of this question.

We define γ as the cost per member that agents incur if margin requirements are tailored to individual members' default probabilities. γ can be interpreted as comprising the costs of intensive monitoring of agents *plus* the cost of installing and operating the technology required to apply margin on a tailored basis by participant, rather than by contract. We assume that, under a tiered arrangement, it is costless to set an objectively determined access criterion to exclude low credit-quality agents. Furthermore, consistent with our earlier analysis of bilateral relationships, we assume that direct members can monitor indirect members costlessly. In our 20-agent example, netting is sufficient to ensure that multilateral arrangements always dominate bilateral arrangements, for both trader types.

Under these assumptions we obtain the following expressions for each agent's total expected pre-settlement costs, where TC^{Full} denotes the total pre-settlement cost, excluding monitoring/tailoring costs, in the CCP with fully tailored margin.

The results show that in all cases agents will be indifferent between CCP and ringing arrangements. As observed in previous sections, the only difference between these arrangements is that replacement cost losses are more concentrated under a ringing arrangement.

Table 5. Comparison of total pre-settlement costs for agent *i* under alternative clearing arrangements, assuming a cost to performing tailored margining

	Total Pre Settlement Costs			
	CCP clearing		**Ring Clearing**	
Clearing Arrangement	**High Credit**	**Low Credit**	**High Credit**	**Low Credit**
Unrestricted/ tailored margining	$TC^{Full} + \gamma$	$TC^{Full} + \gamma$	$TC^{Full} + \gamma$	$TC^{Full} + \gamma$
Unrestricted/ single margin rate	$1.56\ TC^{Full}$	$0.88\ TC^{Full}$	$1.55\ TC^{Full}$	$0.89\ TC^{Full}$
Restricted/ single margin rate	$1.11\ TC^{Full}$	$0.93\ TC^{Full}$	$1.11\ TC^{Full}$	$0.94\ TC^{Full}$

For high credit-quality agents, an arrangement with unrestricted access and a single margin rate will always be dominated by a tiered arrangement. The relative attractiveness of the tiered and fully tailored arrangements will depend on the scale of monitoring/margin-tailoring costs.

In this regard, if the inequality in **(12)** holds, a high-quality agent's favoured arrangement will be one in which membership of the multilateral netting arrangement is restricted:

$$\gamma > 0.11\ TC^{Full} \qquad \textbf{(12)}$$

For low-quality agents, an unrestricted clearing arrangement with a single margin rate is, for all γ, the lowest cost alternative; followed by a restricted arrangement with tiering. While high- and low-quality agents' preferences do not fully coincide, the non-cooperative equilibrium here will, for all γ, be the emergence of a tiered arrangement.

Take the case where **(12)** holds. Here, high-quality agents, in accordance with their own preferences, would exclude low-quality traders from the clearing arrangement. The choice faced by low quality agents would then be between taking part indirectly or continuing to clear bilaterally, both within the low-quality group and when trading with high-quality agents. The benefits of multilateral netting in the tiered arrangement clearly make participation the preferred alternative, so a tiered arrangement would naturally emerge.

When **(12)** does not hold, high-quality agents would optimally choose an unrestricted CCP or ring arrangement with fully tailored margining. But, in this case, it would not be optimal for low-quality agents to participate directly: they would prefer to clear indirectly through the CCP or ring. Thus, unless high-quality agents refused to allow/facilitate indirect membership, a tiered arrangement would again naturally emerge.

4.4 Summary and policy implications

Our simulations provide a plausible explanation for the empirical observation that multilateral netting arrangements apply a single margin level per asset for all direct members and impose membership requirements that restrict direct participation to a subset of members with similar (and relatively high) credit quality. Our results suggest that for such an arrangement to be optimal for members, significant costs must exist that prevent the implementation of fully tailored margining.

We find that, where tiered solutions are likely to emerge, high credit quality agents will be indifferent between CCP and ringing arrangements. This gives a rationale for calls from some sources for the clearing of OTC derivative products to move to multilateral netting through a ring-type arrangement. However, the fact that no such arrangements currently exist, while there are numerous examples of tiered CCP arrangements, suggests that there are other benefits from CCP clearing that we do not capture in our simulations. These might include the benefits of anonymity, or the advantage of having a much broader level of participation in a market than is consistent with ring clearing. Both of these arguments are likely to hold for exchange-traded products, where liquidity is dependent on broad participation and anonymous trading. For OTC products, on the other hand, these arguments are less persuasive, and hence a ringing arrangement might indeed be considered by trading agents.

Once again we find that agents' private incentives may not generate a risk-averse policy-maker's preferred outcome. In particular, the greater concentration of losses observed under a tiered clearing arrangement imply that a policy-maker might prefer an unrestricted clearing arrangement with tailored margining for a greater range of monitoring/tailoring costs than would high credit-quality agents.

5. Conclusions

In this paper, we quantify the benefits of moving from bilateral to multilateral clearing arrangements and show how these depend on the number of agents involved in trading assets. We also identify a difference in the risk implications of multilateral ringing and CCP arrangements due to the greater concentration of losses in the ringing case.

We show that margin-pooling benefits exist where multiple assets are cleared through the same clearing arrangement, with these benefits exploitable through the consolidation of CCPs. The scale of any risk-reduction available through margin-pooling will depend, however, on the variances and covariances of both price-changes and trading positions in these assets, and also on whether margin is set on an asset-by-asset or portfolio basis. Indeed, we show that portfolio-based margining can erode the replacement cost risk-reduction benefits of margin pooling, though we note that a CCP would not typically extend portfolio-based margining beyond products with high and stable absolute price-change correlations.

Throughout the paper, we highlight areas in which the pure total cost-driven choices of risk-neutral agents may differ from those of a risk-averse policy-maker. In the context of tiering, for example, we note that high-quality agents may have a strong incentive to restrict access to a CCP or ringing arrangement, while a risk-averse policy-maker might wish to exploit the full mutualisation benefits of unrestricted CCP membership.

There are several directions in which the framework and ideas developed in this paper could be usefully extended.

First, the monitoring costs and incentives faced under different CCP clearing arrangements could be modelled in a more detailed and sophisticated manner, including examination of cases with greater heterogeneity in agents' credit quality; this might provide more insight into the emergence of tiering in CCPs.

The treatment of ringing in this paper is necessarily constrained by the fact that no formal such arrangement currently exists. As a result, we have worked with one of perhaps many possible configurations of a ringing arrangement. It might, therefore, be valuable to carry out a more comprehensive analysis of ringing, exploring, in particular, other feasible participation rules, loss-sharing arrangements or ringing algorithms. This might allow us to better compare outcomes with CCP clearing.

We allude to the fact that the potential benefits of CCP consolidation rest on the variances and covariances of asset prices and positions in the two CCPs to be merged. We illustrate the nature of such an analysis in the Annex, with a simple example based on two assets traded on LIFFE; applying this framework to a larger and more comprehensive dataset would offer greater insight. Furthermore, a more complete treatment of the financial stability implications of different clearing arrangements could be effected if realistic data on the size and correlation of agents' trading exposures, and their total capital resources, could be incorporated, thereby also allowing contagious default to be modelled explicitly.

Finally, clearing infrastructure is often very closely related to securities settlement infrastructures; indeed, in some cases, CCPs and Central Securities Depositories (CSDs) are part of the same entity. Therefore, extending this framework to encompass the settlement arrangements for securities would allow the implications of vertical consolidation of infrastructures to be analysed.

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Annex - Application to LIFFE data

In order to illustrate the effect of margin-pooling in a practical trading scenario we obtained data on multilateral net positions in the LIFFE FTSE 100 and EURIBOR contracts (the most heavily traded contracts on LIFFE) held by 19 traders over 6 consecutive months in 2004. Using observed price data for the period 2001-2004 in these two assets, and assuming that traders have homogeneous ex-ante default probabilities of 1% and face unit collateral costs of 0.0015, we run a series of simulations to estimate the pre-settlement costs faced by these traders under both single-asset and multi-asset CCP clearing scenarios. That is, for each of the 6 monthly multilateral position matrices, we apply, in turn, 1282 pairs of price changes, and for each price-change pair we calculated 1500 realisations of realised replacement cost losses using default vectors generated from our assumed ex ante default probabilities. The price changes of the two assets have a small negative correlation of -0.12, while the mean position correlation of agents' exposures in the two assets is -0.28 over the 6 months.

Table A1, below, presents the results of this exercise. Replacement cost losses are significantly reduced in the multi-asset CCP clearing arrangement, being about 23% lower than in the single asset clearing arrangement. However, as we assume margin is being set on an asset-by-asset basis, and hence collateral costs are large relative to expected replacement cost losses, the difference in total expected pre-settlement costs between the two clearing arrangements is again not so large.

These results may be compared with those obtained using randomly-generated price-change and position series. Based purely on correlations, we might expect a replacement cost ratio of between 0.4 and 0.5. However, with a sizeable differential in the volatility of both price changes and positions in the two assets the margin-pooling benefits would be expected to be reduced; the standard deviation of price changes for the FTSE contract is 300 times larger than that for the EURIBOR contract, with only a partial offset in that its position standard deviation is just a tenth that of the EURIBOR contract. This illustrates the importance of considering multiple sources of heterogeneity when assessing practical examples of CCP consolidation.

Table A1. Ratio of total costs and replacement cost losses under multi- and single-product CCP clearing for EURIBOR and FTSE 100 futures contracts

Benchmark: Single-product CCP
Position data (EURIBOR and FTSE 100 contracts): 6 monthly observations
Price changes (EURIBOR and FTSE 100 contracts): 4 years' daily data
Default scenarios: 2000
Number of agents: 19

	Ratio
Expected replacement cost loss	0.77
Total cost	0.93
Concentration	0.99