

# Modelling risk in central counterparty clearing houses:

a review

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Central counterparty clearing houses (CCPs) form a core part of the financial market infrastructure in most developed economies. CCPs were established originally to protect market participants from counterparty risk in exchange-traded derivatives markets, but they now also have an important presence in cash and over-the-counter (OTC) derivatives markets. By interposing themselves in transactions, CCPs help to manage counterparty risk for market participants and facilitate the netting of positions. In performing this role, however, CCPs are themselves exposed to various risks. To protect themselves, they have developed various procedures, amongst which the margining of members' positions plays a central role. This article discusses a range of academic studies which attempt to model the risks faced by CCPs, and which consider how margins and the level of other default resources might be set. It notes that margins alone, calculated to cover losses from typical price movements over one or more days, may not be sufficient to protect CCPs from rare but plausible events. CCPs need to assess the losses they could face on occasions when margin proves insufficient, and ensure that they can meet these losses from extreme events by other means<sup>1</sup>.

**CENTRAL COUNTERPARTY CLEARING HOUSES** first developed in futures markets to help market participants manage the risk of non-performance by their counterparties. Because there is often a lag of some months between the initiation and final settlement of a futures transaction, large unsettled exposures may build up between market participants. If the losing counterparty defaults in the presettlement period, gains accrued by the winning counterparty may be lost.

In order to reduce the risk of non-performance for market participants, futures and other exchange-traded derivatives contracts are typically guaranteed against counterparty failure by a post-trade central counterparty clearing house (CCP), operated either by the exchange or as a service provided to it by an independent company. In essence, the CCP interposes itself in transactions by becoming the buyer to every seller and the seller to

every buyer. The original bilateral contracts between market participants are extinguished and replaced by new contracts with the CCP<sup>2</sup>. As a result, bilateral counterparty risks (of variable quality) are replaced with a (high quality) counterparty risk against the CCP. Diagrams 1a and 1b show how bilateral contracts are substituted by new contracts with the CCP. Diagram 1c illustrates how this allows clearing members to net down their original obligations multilaterally.

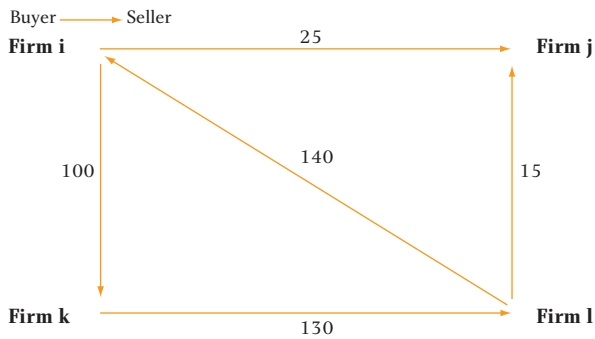
In addition to exchange-traded derivatives markets, the risks associated with non-performance arise in many other markets, including some with a much shorter settlement cycle. In equity markets where an electronic order book is employed to match trades, participants may not be able to manage counterparty risk through their choice of counterparty. As a result, central counterparty services have recently emerged in a variety of cash markets where they deliver other

1: We would like to thank Giovanni Barone-Adesi, Jon Danielsson, Brian Eales, James Moser, Mark Tomsett and colleagues at the Bank of England for helpful comments on an earlier draft of this article. Any remaining errors or omissions are, of course, the responsibility of the authors.

2: Not all clearing houses act as central counterparties. Clearing, defined as the matching, confirming and settling of trades, can be carried out without the clearing house becoming a principal to transactions, in which case the clearing house simply plays an agency role. This type of clearing house is not exposed to counterparty risk in the same way as a CCP, since the members remain exposed to their original counterparties. In what follows, the focus will be on CCPs, and the terms CCP and clearing house will be used interchangeably. This follows usage in the academic literature which concentrates on the clearing arrangements typical of major US and European markets.

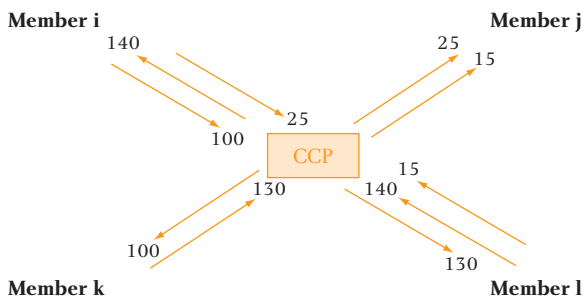
**Diagram 1a:**

**Positions with bilateral clearing**



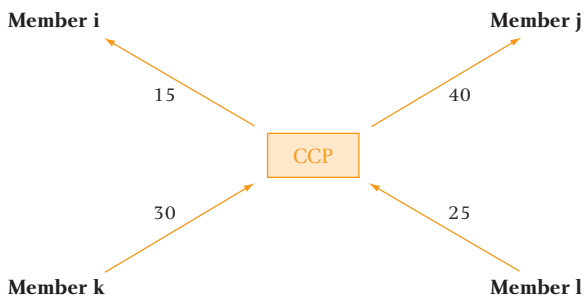
**Diagram 1b:**

**Gross positions with CCP**



**Diagram 1c:**

**Multilateral net positions with CCP**



valuable benefits such as post-trade anonymity, netting, and the reduction of operational risk. Meanwhile, CCPs have also extended the range of their services to derivatives markets, with a number of CCPs now clearing a range of OTC contracts. In practice, CCPs generally provide these services directly to only a limited range of *clearing members*, but other market participants can benefit indirectly, as clients of members.

In assuming responsibility for contract performance, CCPs themselves become exposed to the risk of a

clearing member default. To reduce the risk of a default, and ensure that if one does occur it can be absorbed with the minimum loss, CCPs have evolved a variety of risk management procedures. The primary protection is provided by *initial margin*, a deposit which clearing members are required to place in an account with the CCP. This is intended to protect the CCP against the risk of non-performance. CCPs may also make margin calls to ensure that they remain protected over time as prices change. They usually also have access to additional default resources, such as mutual guarantee funds or insurance cover, and require clearing members to fulfil financial requirements to reduce the likelihood of default.

By helping to manage counterparty risk and by providing netting services, CCPs can allow market participants to economise on collateral, compared to what they would otherwise need to hold to ensure equivalent protection in bilaterally cleared markets. Regulators may also recognise the reduction in counterparty risk by allowing clearing members to hold less capital than if they were exposed directly to other market participants. Clearing members may also reduce the resources spent on monitoring individual counterparties, insofar as their actual counterparty is the CCP.

To protect themselves and the clearing house against client defaults, members are generally required to set a minimum level of margin for their clients according to rules set down by the clearing house. One of two methods is usually used to determine the proportion of margin passed on to the CCP. Under *net margining*, clearing members are permitted to net together the long and short positions of different clients and post margin on aggregate net positions. Under *gross margining*, members are required to deposit margin with the CCP sufficient to cover the gross positions of their clients. In either case, the members must collect the same minimum amount of margin from their clients<sup>3</sup>.

**The systemic importance of CCPs**

Although CCPs reduce counterparty risk for individual market participants, the funnelling of market activity through one institution concentrates risk, and the responsibility for risk management, in

<sup>3</sup>: The main difference lies in the proportion of client margin that they are required to pass through to the CCP. From the CCP's perspective, gross margining has the advantage that if a clearing member defaults as a result of a client default, then all the client margin the member has passed through to the CCP is available to protect the CCP against loss. Gross margining systems, however, reduce the earnings of clearing members on client margin funds, and it is sometimes argued that this makes clearing members more vulnerable to bankruptcy, and more likely to raise clearing fees. In practice, net margining systems predominate.

the CCP. Furthermore, with lower counterparty risk, market participants using a CCP may be encouraged to trade more and establish larger positions, increasing the potential risks to the CCP.

Were a CCP to fail, activities in a wide range of markets might face disruption with the CCP acting as a channel of contagion. Even without outright failure, problems in one market can be transmitted to others via a CCP. For example, if market prices change abruptly, CCPs will typically make margin calls requiring members to put up additional funds which match the price change, to ensure that protection is maintained against member default. But if members have to meet unexpected margin calls in one market, they may be forced to sell assets in a second market, driving down prices there<sup>4</sup>. This may lead to margin calls against positions in the second market. Furthermore, margin payments made to the CCP from 'losing' members must usually be received before disbursements can be made to 'winning' members. If large margin payments are delayed for some reason, this can create severe liquidity pressures for members.

Many CCPs have close financial connections with a range of settlement banks which receive and return margin payments on behalf of members. In a liquidity crisis, where members may be temporarily unable to meet margin calls, banks may be forced to choose between extending additional credit or seeing members' positions declared in default and liquidated by the CCP. Bernanke (1990) discusses this in the context of the 1987 fall in equity markets. In either case, the banks may have to put their own funds at risk. In effect, the CCP may redistribute part of its risk to liquidity providers such as banks. *In extremis*, these financial links create the potential for contagion to spread beyond the immediate membership of the CCP.

Fortunately, CCP failures have been extremely rare, though the examples of Paris in 1973, Kuala Lumpur in 1983, and Hong Kong in 1987 demonstrate that they can, and do, occur<sup>5</sup>. Because of the increasing scale and scope of the business of some CCPs, both in Europe and elsewhere, the potential impact of a CCP failure has grown.

Central banks and regulators have, therefore, taken a keen interest in CCP risk management and in developments concerning CCPs more generally, and so too have academics. The objective of this article is to review the academic literature and address three key questions: (i) How can the core financial risks faced by CCPs be characterised? (ii) What insights does the academic literature provide into the risk management problems faced by CCPs? (iii) What further issues concerning core risks remain to be addressed?

## Main features of CCP risk management

### Core risk faced by CCPs

CCPs require clearing members to post initial margin sufficient to cover all but the most extreme price movements which may occur over a specified time horizon (usually a single day)<sup>6</sup>. A very large single-day price move, nevertheless, has the potential to reduce the value of a member's positions by more than the initial margin. If the 'losing' member were to default under these circumstances, it could leave the CCP with uncovered obligations towards 'winning' members. This is usually called *replacement cost risk* in the CCP literature, and this article follows the same practice. The potential replacement cost exposure for a CCP, however, is limited significantly by the process of daily marking-to-market, by adjusting initial margin requirements, by making intraday margin calls when necessary, and by holding additional default resources.

CCPs usually mark-to-market members' positions at the end of each day, and calculate gains and losses accrued since the last mark-to-market. The actual procedure for settling daily gains and losses may differ to some extent between CCPs. Some directly adjust members' margin account balances to reflect the gains and losses on members' positions. If the funds in a member's margin account balance fall below a specified level, known as the *maintenance margin*, the member receives a margin call. This instructs the member to increase the funds in its margin account back to the level of initial margin within a specified grace period. Other CCPs follow a different model where, following the mark-to-market, they call automatically for additional *variation margin* from 'losing' members and credit these funds directly

4: The impact on market prices will of course depend on the size of positions sold in relation to the liquidity of that market.

5: See Hills, Rule, Parkinson and Young (1999) for further details.

6: In practice, the time horizon used by CCPs for setting initial margin varies depending on the market.

## Box 1: Margin calls and replacement cost risk

Clearing member A buys a single futures contract from B, at a futures price of £100. The contract is for 200 bushels of wheat and is due for delivery in three months time. When member A and B register their contracts with the CCP, they are required to deposit £5 margin per bushel. Each member therefore provides the CCP with £1,000 of initial margin.

Suppose the futures price were to fall from £100 at the end of the first day to £99 by the end of the following day. At mark-to-market, the CCP would require £200 from member A, and would transfer £200 to member B.

Suppose at the end of the month, the futures price returns to £100, before plummeting to an end-of-day price of £90 after a large single-day price fall. For the purposes of illustration, we will assume that there is no intraday margin call. At the end-of-day mark-to-market, the CCP is required to credit £2,000 to member B, and must receive an equivalent amount of funds from member A. Since A only has £1,000 in posted margin, the CCP faces a replacement cost risk exposure of £1,000, which becomes realised if member A fails to meet an end-of-day margin call and defaults. If this occurs, the CCP would close-out A's position, but be left with a shortfall of £1,000 which it would have to meet through its own default resources.

to 'winning' members. In either case, the daily settlement of gains and losses ensures that exposures cannot build up excessively over time.

Under either approach, the failure to meet a margin call will result in the member being declared in default and its positions being closed out. The quicker the CCP is able to close out a defaulter's positions, the less likely it is that prices will move further against the defaulter, and result in a replacement cost risk exposure for the CCP.

In addition, well-designed CCPs monitor members' positions intraday and may make margin calls if large intraday price moves threaten to exhaust the funds in a clearing member's margin account. As with end-of-day calls, the member must meet the margin call within a certain grace period or see their positions closed out. Box 1 illustrates the process of calling margin.

As a further layer of protection, CCPs will also usually have access to additional default resources, which may be used if margin proves insufficient to meet losses. Many CCPs maintain a mutual guarantee or default fund, to which members make an initial contribution when joining the CCP. Insurance policies may provide further cover, and some CCPs have the power to assess members for funds if other default resources prove insufficient.

CCPs may also be exposed to *liquidity risk*, if members do not meet margin calls in a timely fashion. Although no member may formally be declared in default, a

failure to pay margin calls promptly would leave a CCP with liabilities to members who hold the opposite positions and whose margin accounts must be credited. If the CCP has insufficient liquidity to meet these demands, it may have to delay making repayments. The Crash of 1987 and its impact on some US clearing houses provides a case study of the problems that can arise from such a liquidity squeeze (Brady, 1988).

### Additional important risks

CCPs are also potentially exposed to a range of other important risks. Where the legal status of a CCP's netting arrangement is not protected by national law, or where it clears cross-border trades, it may be exposed to significant *legal risks*. Like other institutions, CCPs are also vulnerable to *operational risks*.

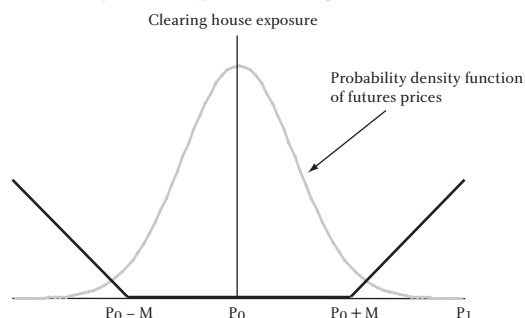
The failure of institutions outside the immediate clearing membership may also create risks for a CCP. Many CCPs use a network of private banks to make fund transfers to and from members and may therefore be exposed to *settlement bank risk*. If margins (and other default resources) are invested in the market by the CCP they may also face *investment risk*. In the remainder of this article, we will concentrate on *replacement cost risk*, but readers are referred to Bank for International Settlements (1997) for further details on these other categories of risk and how they can be mitigated.

### Determining CCP margin requirements

Diagram 2 illustrates the potential exposure for a stylised CCP clearing a single futures contract. If the

initial price of the contract is  $P_0$ , the subsequent price is  $P_1$ , and posted margin per contract is denoted by  $M$ , margin will be exceeded when  $|P_1 - P_0| > M$ . In other words, the CCP is exposed when the change in the contract's price exceeds the required margin per contract. In this section, the main approaches that have been developed to characterise this exposure are described.

**Diagram 2:**  
**Modelling clearing house exposure<sup>(a)</sup>**



(a)  $P_0$  and  $P_1$  are the initial and subsequent prices, respectively.  $M$  is the margin per contract.

In theory, if the opportunity costs to traders of posting margin were zero, clearing houses could set margin requirements high enough to cover any conceivable market move. In practice, however, the cost is not zero. The challenge faced by CCPs is to set initial margin at a level sufficient to provide protection against all but the most extreme price moves, but not so high as to damage market liquidity or discourage use of the CCP.

Telser (1981), in an early study, noted the potential effect on liquidity. Although this seems intuitively reasonable, Anderson (1981) has questioned whether a reduction in trading activity would occur, noting that the opportunity costs for traders may be low because margin can be posted in the form of interest-earning T-bills. In addition, Anderson suggested that margin would have little effect on market liquidity because intraday trading is not constrained by margin requirements. Kalavathi and Shanker (1991), however, argued that there is in fact a significant opportunity cost to posting margin in the form of liquid assets, in terms of the yield forgone.

Empirical evidence generally supports the view that high margins have a detrimental effect on market activity. Using data on futures contracts traded at the Chicago Mercantile Exchange (CME) and the Chicago Board of Trade (CBOT) between 1977 and 1981, Hartzmark (1986) compared open interest and

trading volumes before and after an initial margin change. In general, he found that open interest declined after an initial margin increase, but there was only a weak effect on volumes. Hardouvelis and Kim (1995) found clearer evidence of an effect on both volumes and open interest. By examining 500 initial margin changes on eight metals futures contracts on the New York Commodity and Mercantile Exchanges and the CBOT, they found that a 10% increase in initial margins reduced average volumes traded by 1.4%.

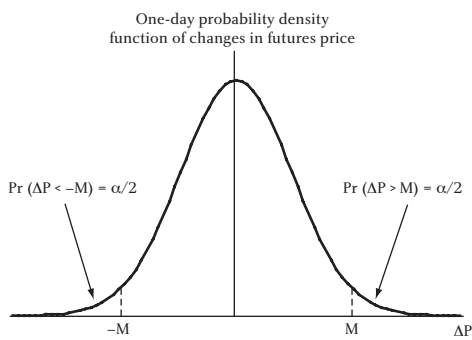
In principle, since CCPs mark-to-market positions daily, they should be exposed only to the extent that a one-day price movement exhausts all of a clearing member's initial margin. In practice, CCPs may be exposed over a longer period as it may take time to decide whether a member should be declared in default, and then to close-out positions. A wide range of studies have therefore attempted to quantify the potential exposure of clearing houses over one or more days. These studies adopt modelling approaches which are of three main types (a) statistical models, (b) optimisation models, and (c) option pricing models. Each of these approaches is described, in turn, below.

#### (a) Statistical models

Studies taking a statistical approach usually assume that initial margin should be set at a level that produces a prespecified and acceptably small probability of exhaustion, over a time horizon which reflects the period of potential exposure for the CCP. Diagram 3 shows how initial margin might be set so that the probability of non-coverage (ie of a price change exceeding initial margin) is equal to a prespecified level,  $\alpha$ . Statistical coverage approaches typically assume a simple model of asset price dynamics (eg geometric Brownian motion) which can be used to derive the probability that initial margin will be exhausted within a specified time horizon.

Figlewski (1984) estimated the degree of coverage provided by a range of different rates of initial and maintenance margin on stock and stock index futures. For contracts which required an initial margin of 6% of the underlying asset and a maintenance margin of 2%, Figlewski calculated that maintenance margin would be breached and a margin call made within three days on approximately 1% of contracts. In the event of a margin call, the probability of maintenance margin being exceeded over the following day (the usual grace period) was around 3%.

**Diagram 3:**  
**Setting margin under a statistical coverage approach<sup>(a)</sup>**



(a)  $M$  is initial margin per contract which is set so that the total probability of non-coverage =  $\alpha$ .  $\Delta P$  is the price change over one day.

Gay, Hunter and Kolb (1986) constructed a similar model of futures prices, and evaluated the coverage provided by initial margin. Applying their model to commodities traded at the Chicago Board of Trade between 1979 and 1983, they estimated the probabilities of price movements exceeding initial margin. Whilst these probabilities generally remained consistent across time for futures contracts, they varied significantly between some closely related contracts such as gold and silver<sup>7</sup>.

**(b) Optimisation models**

As explained above, a dilemma for clearing houses in setting margins is how to balance prudence against the higher costs to members. Lodging high-quality assets with the clearing house as margin represents an opportunity cost to traders. Marking positions to market and settling gains or losses, on either a daily or more frequent basis, also entails costs. To arrive at an optimal margin level the clearing house must balance these costs against the potential losses resulting from a default<sup>8</sup>.

Fenn and Kupiec (1993) developed a model that aimed to minimise the total sum of margin, settlement costs and the cost of settlement failure. Unlike the statistical models described above which prespecify acceptable coverage levels, appropriate coverage emerges endogenously in their model. Overall costs were minimised when the ratio of margin to price volatility was held constant. Fenn and Kupiec applied their model to the margining of the Standard & Poor's (S&P) 500 futures contract before and after the Crash of 1987. The results suggested that CCPs were

generally less active in altering margins in response to changing market conditions than might have been expected on the basis of their cost-minimising model, particularly before the Crash. Fenn and Kupiec suggested that this indicated inefficiencies in the margin setting process, although they noted three possible alternative explanations: (i) there were significant costs to changing margins that were not recognised in their model, (ii) given other safeguards, eg membership standards, the costs of over- or under-margining were not sufficient to require fine-tuning of margin levels, or (iii) regulatory pressures may have already led to some degree of over-margining.

Baer, France and Moser (1996) developed a margining model for a market which sought to minimise the costs of contracting, again by trading off the opportunity costs of posting margin against the potential costs following a counterparty default. By theoretical modelling, they arrived at the conclusion that margin should be set so that the probability of non-coverage is equal to a ratio representing the opportunity cost of margin divided by the cost of recontracting (ie finding a new counterparty at the prevailing market price) following a member default.

**(c) Option pricing approaches**

Diagram 2 offers a graphical characterisation of the CCP's exposure to a member holding a single futures contract. This simple characterisation ignores many other types of protection that a CCP typically employs, but it nevertheless offers a useful starting point for developing a theoretical model of the core risks that CCPs face. The exposure profile is equivalent to the payoff of a strangle – a trading position created by the combination of a call and a put option. In theory, a buying clearing member might choose to default strategically if the reduction in the value of the contract is greater than their posted margin, ie  $P_0 - P_1 > M$ . Similarly, the selling member might default when  $P_1 - P_0 > M$ .

Kupiec (1997) argued that since the clearing house does not charge counterparties for this default option, margins should be set high enough to ensure that it is effectively valueless. Several studies have developed

7: In the wake of the Crash, the Presidential Task Force on Market Mechanisms (Brady, 1988) recommended that margin levels in different markets should be set consistently, so that clearing houses have equivalent protection from adverse price movements in different markets.

8: This notion of 'optimal' takes into account the opportunity costs of margin, daily settlement costs and the potential costs of default, but not beneficial effects on markets as a whole which are harder to quantify, eg enhanced anonymity and liquidity.

this intuition into theoretical models for setting prudent margin levels, notably Day and Lewis (1999).

Day and Lewis modelled margined futures positions as barrier options<sup>9</sup> and used their model to estimate prudent margin levels for New York Mercantile Exchange (NYMEX) crude oil futures between 1986 and 1991, a period which included Iraq's invasion of Kuwait. Thirty changes in initial margin requirements took place during this period, 19 of them prior to the invasion. On average, historical NYMEX margins were found to be significantly above the levels implied by the model. In the period immediately following the invasion of Kuwait, however, margins were occasionally below the model values, particularly for short futures positions.

In practice, however, well-managed CCPs employ a range of additional safeguards (eg intraday margin calling, netting and assessments of member creditworthiness) that make such option to default models generally rather unrealistic. The price of a contract would also have to change by substantially more than  $|P_0 - P_1|$  before a clearing member would in fact have incentives to default strategically. This arises in part because a clearing member's winning positions would be available to offset some of its losing positions, and in part because there are clear economic benefits, in terms of reduced collateral costs and reduced credit risk, from remaining a clearing member.

### Limitations of modelling approaches

A number of more general limitations, common to all the classes of model can be noted. Each modelling approach makes certain strong assumptions about the distribution of asset prices, and all focus on the margining of single assets, usually futures, rather than on a portfolio of assets. Little consideration is given in the literature to margining non-linear instruments, such as options.

Equally important, none of these techniques provide any guidance on how large potential losses could be following a margin-exhausting price move, and whether a clearing house would have sufficient resources to cope in the event of a default. These general limitations are discussed in more detail in the following sections.

### The shape of the underlying distribution

As noted above, statistical models often make assumptions about the distribution of price movements which limit the conclusions that can be drawn from them. Figlewski (1984) and Gay, Hunter and Kolb (1986), for example, make the assumption that either returns or price changes are normally distributed. Considerable evidence, however, indicates that return distributions, particularly in futures markets, exhibit fatter tails, indicating a greater probability of extreme price moves (Cornew, Town and Crowson (1984); Cotter and McKillop (2000); Venkateswaran, Brorsen and Hall (1993)).

The potential inaccuracy of assuming a normal distribution was illustrated by Warshawsky (1989), who calculated the maintenance margin level required to produce a given level of protection against further price moves on S&P 500 index contracts. Warshawsky compared the margin levels implied by the parametric model of Figlewski, which assumes a log-normal distribution of prices, with levels derived directly from the empirical distribution. Whilst at a modest coverage level of 95%, the parametric approach predicted equivalent levels of margin, at a more stringent coverage level of 99% the margin requirements derived from the empirical distribution of prices were found to be consistently higher.

### Portfolio margining

The models described so far have focused on the margining of positions, in individual, usually single futures, contracts. Whilst the single asset approach provides important insights into the complexities of computing optimal margins, it does not take account of the additional benefits and risks associated with the margining of portfolios.

A well-constructed portfolio may provide significant diversification benefits to both the member and the CCP. These are recognised to an extent in practical margining approaches, such as the Federal Reserve Board's Regulation T, which governs the margining of portfolios of equities and equity options in the USA, and Systematic Portfolio Analysis of Risk (SPAN), a methodology employed by US futures clearing houses and by the London Clearing House. In each case, the ability to offset long and short positions reduces overall margin levels. Further details on how SPAN calculates margin are given in Box 2.

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<sup>9</sup>: An option with a payoff determined by whether the path of the underlying asset has reached a predetermined level – the barrier.

## Box 2: Margining under SPAN

SPAN is a margining system, introduced by the CME in 1988, which is used by a wide range of clearing houses (including the London Clearing House) to set margin for portfolios of contracts. It was originally designed for margining portfolios of futures and options on futures, but it can also be applied to the margining of other types of option. SPAN is not, however, a true global portfolio margining system. Rather it sets a margin for a contract family defined as a group of contracts (eg options, futures etc) all sharing the same underlying commodity or security.

### How SPAN calculates margin

To arrive at a margin level, SPAN simulates the possible change in value for the contract family using a series of scenarios representing potential changes in the underlying security's price and volatility. Potential price movements are defined in terms of *scanning ranges* which are derived from historical data. Typically, the scanning range would represent a price range which would cover 99% of historical one-day price movements observed within the data window. Some adjustment may also be made to take into account historical market moves not captured in the data window but that may be repeated, and the potential effects of anticipated future events.

For each contract within the contract family, prices and volatilities are separately and independently varied along their scanning ranges to produce a matrix of possible outcomes. Using this matrix, the predicted losses across contracts are aggregated to find the scenario that generates the worst-case loss for the contract family as a whole. This is then used to determine the margin requirement. Since the portfolio may contain non-linear instruments such as

options, the worst-case scenario for the contract family as a whole need not be the scenario which results from the largest price movement for the underlying security.

### Valuing non-linear instruments

Implementations of SPAN usually rely on a full valuation method such as Black's (1976) pricing model to calculate price changes for options. Where a portfolio contains short options positions, a minimum short option charge is also applied. Since options pricing models sometimes underestimate the risk of deep out-of-the-money short options, the minimum short option charge specified by SPAN provides additional protection.

### Spread charges

Since SPAN initially makes the simplification that long positions in one month entirely offset short positions in the same contract in another month, a calendar spread charge is applied to recognise the fact that inter-month prices are not perfectly correlated.

### Margin offsets

Where holding different contract groups reduces overall portfolio risk, SPAN also allows a limited range of offsets through a system of inter-commodity credits. The range of permissible offsets and the magnitude of credit available is, however, determined by the clearing house. This illustrates an important general characteristic of SPAN. Parameters that determine the overall margin coverage for a portfolio are set at the discretion of the individual CCP's risk managers, and may therefore vary between CCPs.

The protection afforded by portfolio-based margining systems such as SPAN has received relatively little consideration in the research literature. Two exceptions are Kupiec (1994) and Kupiec and White (1996). Kupiec and White considered a range of hypothetical positions constructed from options on stock index futures. They compared margin requirements based on SPAN with those required under Regulation T, which provides for margin offsets only on specific predefined combinations of positions. They found that for the same overall degree

of risk protection, the margin requirements emerging from SPAN were considerably smaller than from Regulation T.

Kupiec (1994) also estimated the historical degree of risk protection provided by SPAN for contracts and contract families based on the S&P 500 futures traded on the CME. For the period considered (December 1988 – December 1992), initial margin provided historical one-day protection levels in excess of 99% for single futures and simple portfolios. The

'weak-spot' identified in Kupiec's analysis was the offsetting of contracts in the same commodity but with different maturities (calendar spread positions). Such positions were found to have protection levels of significantly less than 95%.

SPAN is currently the most widely used margining system<sup>10</sup>. As CCPs expand into new markets, however, there is a question about how effectively SPAN can be adapted to deal with the more complex portfolios that result. The approach that SPAN takes of varying risk factors separately, such as prices and volatilities, is tractable for portfolios of futures and options but, as the number of types of instrument in the portfolio expands, and the range of risk factors increases, the approach may become unwieldy (Jorion, 2001).

One possible future development may be more widespread use of margining systems based on value at risk (VaR) techniques. VaR models estimate the maximum loss that a portfolio will suffer over a given time interval, such that there is a low prespecified probability that the actual loss will be larger. The potential advantage of VaR models is that they generally take fuller account of the correlations between the prices of assets in a portfolio, and this may permit more efficient margining. If correlations change, however, there is a risk that VaR models may underestimate losses.

Several recent papers apply new VaR methods to the kind of complex derivatives portfolios typically held by CCPs (Barone-Adesi, Giannopoulos and Vosper (1999, 2002)). These papers pay explicit attention to the fact that traditional models have been poor at estimating VaR losses under extremes. Barone-Adesi et al develop a new simulation approach known as Filtered Historical Simulation which is aimed at addressing this weakness. By sampling standardised returns over multiple days this technique is able to simulate extreme events not present in the historical data, which enables the true tails of the distribution to be more effectively replicated.

### Losses in excess of margin

Since margin provides the primary means of financial protection for CCPs, most clearing house studies have naturally focused on the protection which margin

affords. CCPs recognise, however, that under the most extreme market conditions, a defaulter's margin may still prove insufficient. The majority of CCPs therefore hold additional default resources, which individual members contribute towards, usually according to the scale of their clearing business.

Gemmill (1994) offered one of the few published studies to address the combined adequacy of margin and other default resources. He derived a rough estimate for the size of the default fund of a stylised clearing house assumed to clear three generic contracts – a soft commodity, a metal and a financial contract. Gemmill's study was practical rather than theoretical, and he was forced to make a number of assumptions to derive an exposure estimate: first, to account for the changes in intermarket correlations commonly observed under extreme market conditions, Gemmill assumed correlations observed at the time of the Crash of 1987; and second, to estimate the scale of potential credit exposure, he assumed the default rate amongst members was exogenous.

Gemmill's most striking conclusion was that the clearing house derived a substantial diversification benefit from clearing several weakly correlated markets, with clearing risk being at least halved. This conclusion provides an interesting counterpoint to the observation that clearing houses concentrate risk by clearing multiple markets. But Gemmill's study also highlighted an important problem in estimating potential CCP exposure; namely, how to assess the likelihood of individual member default given a margin-exhausting price move, and what assumptions to make about the extent of correlation between individual defaults.

### Recent advances

More recent work on clearing house margining has made progress in addressing some of the problems outlined above. This section considers developments addressing two main areas (i) the shape of the underlying price distribution, and (ii) the potential scale of losses when price movements exceed initial margin.

### Modelling the tails of the distribution

In common with risk management work in other areas of finance, recent studies of clearing house margining

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10: A smaller number of clearing houses, however, use TIMS (Theoretical Intermarket Margining System), a margining system developed for options by the US Options Clearing Corporation.

have given greater attention to the shape of the underlying distribution of prices, particularly under extreme market conditions when margins are most likely to be exhausted.

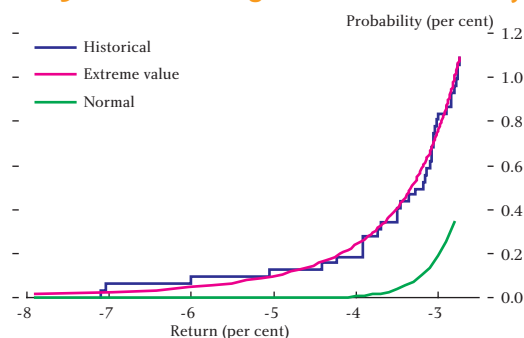
In calculating margin for individual futures positions, clearing houses typically set margin at a level that will provide protection against 95–99% of one-day price movements<sup>11</sup>. Most clearing houses make an estimate of the appropriate margin level by inspecting the distribution of price movements over recent months. But this will not always provide an adequate estimate of the size of future extreme price moves. To counter such problems, CCPs will usually adjust their empirical estimates using subjective judgements on whether previously observed extreme moves are likely to be repeated, and the potential impact of possible future events. Cotter (2001) notes the potential for inconsistency in this approach, advocating instead a statistical modelling approach based on Extreme Value Theory.

Extreme Value Theory (EVT) provides a way of estimating the potential for extreme market moves which, instead of considering the entire distribution, focuses only on the parts that provide information about extreme behaviour – the tails of the distribution. (See Embrechts et al (1997) for a comprehensive discussion of EVT techniques.) Since margin is only likely to be exceeded under extreme price moves, EVT provides a potentially useful framework for assessing the adequacy of clearing house resources. A variety of recent studies have applied EVT to estimating margin levels for futures contracts (Booth, Broussard, Martikainen and Puttonen (1997); Broussard (2001); Longin (1999)). Dewachter and Gielens (1999) show how these techniques can be incorporated into an optimisation model of margins. Diagram 4 illustrates how EVT is able to provide a more accurate characterisation of fat-tailed behaviour than the normal distribution.

Despite its theoretical appeal, clearing houses may not be convinced that EVT should be used to set initial margins directly. Although it can be applied straightforwardly to single instruments, calculating a portfolio margin reflecting the distributions of a large

number of instruments may present serious practical difficulties. Also, the higher initial margins generally implied by EVT analysis could have adverse effects on market liquidity<sup>12</sup>. Nevertheless, EVT analyses may offer a useful source of information to clearing houses when assessing the overall levels of protection provided by the different types of default resource available to them.

**Diagram 4:**  
**Modelling the lower tail of the distribution of S&P 500 returns using Extreme Value Theory<sup>(a)(b)</sup>**



Sources: Datastream and Jon Danielsson.

(a) See Danielsson and de Vries (2002) for a description of the methodology.

(b) Daily returns from 1990 to 2000.

### Modelling losses conditional on exceeding margin

Irrespective of the way margins are set, there will be a non-zero probability that circumstances arise under which margin is exhausted. CCPs therefore need to be able to make an accurate estimate of their losses in such cases.

Bates and Craine (1999) examined this problem by studying the margins set by the CME before and during the Crash of October 1987. Given the prevailing margin levels, they calculated the expected losses conditional on margin being exceeded for S&P 500 contracts. Potential losses were estimated using historical margin levels and a probability distribution of futures prices which was reparameterised each day<sup>13</sup>. Bates and Craine found that immediately following the Crash, both the probability of margin being exceeded and the expected losses conditional on this occurring increased by more than an order of magnitude. By the end of November, aggressive increases in margin

11: Kupiec (1994) found that margin protection on portfolios cleared through the Chicago Mercantile Exchange often exceeded 99%.

12: A reviewer of this article also noted that in practice some clearing houses prefer to focus their attention on a relatively small sample of historical data consisting of only the most recent N months. This would limit the feasibility of an EVT analysis.

13: Return distributions were estimated from time series and option prices.

levels had successfully reduced the probability of exceeding margin back to pre-Crash levels. Despite these margin increases, however, the expected losses faced by the clearing house, if a margin-exhausting price move were to have occurred, were still an order of magnitude higher than before the Crash.

Bates and Craine's study highlights the fact that it is important to consider other measures of clearing house exposure in addition to the coverage provided by margin. Indeed, their study shows that, when considered alone, margin coverage probabilities may provide a misleadingly comforting picture of clearing house exposure. A given coverage level may, in fact, involve much larger expected losses under extreme market conditions. Finally, the study emphasises the importance of modelling the shape of the tail of the distribution, and taking into account how it may change in extreme market conditions.

### Conclusions and implications for future research

Clearing houses have developed risk management procedures that have proved remarkably robust. Nevertheless, as the nature of CCP business becomes more complex, through expansion into new markets, and more centralised through consolidation, the risks to clearing houses are likely to grow. As the systemic importance of CCPs grows in parallel, it will be important for CCP risk management practices to address the changing nature of these risks. Summarised below are some of the main implications for CCP risk management which can be drawn from the research literature discussed in this article.

#### Estimation of conditional losses

Initial margin protection should be supplemented with sufficient additional default resources to cover the losses that could be incurred if a member (or members) were to default following a margin-exhausting price move. As Bates and Craine showed, setting the margin level to achieve a given level of coverage is likely to be an inadequate response to extreme market volatility. In such conditions, CCPs may face much larger losses if one or more members default after price movements which exhaust their margin. CCPs therefore need to be able to estimate potential losses in order to assess accurately the required scale of default resources.

EVT may have a role in helping CCPs assess the size of expected losses. Academic studies to date, however, have focused more on the application of EVT to

estimating margins. But in either context, EVT techniques may have important practical limitations. Not only is EVT difficult to apply to complex portfolios, it is also still reliant on theoretical extrapolations from historical data, which may fail to take account of structural changes in markets. To assess the scale of margin-exceeding losses in practice, it will be important for CCPs to develop and enhance scenario-based stress-testing procedures which assess the impact of low probability, but nonetheless plausible events, which may have no precedent in the current historical record.

#### Assessing the optimal balance between margin and other default resources

Setting margins at an optimal level requires striking a balance between prudence and the opportunity costs to clearing members and their clients. High margin levels, sufficient to cover very extreme events, can discourage trading and potentially damage market liquidity. Establishing very high margin levels may also be an inefficient way of ensuring protection – at some point, it may become more efficient to mutualise the residual risks through a default fund or other guarantee arrangement. Ensuring that CCP members maintain some residual exposure to the uncovered losses of the CCP also has an added benefit, as it creates an incentive for clearing members to take an active interest in the overall standard of a CCP's risk management. Further research is needed on the factors that determine the optimal structure and allocation of CCP resources.

#### Development of more sophisticated portfolio models

Over the last five years, CCPs in Europe have rapidly developed new lines of business. To keep pace with these changes, new margining methodologies have also been introduced. An important goal for CCPs which clear many different markets will be to develop integrated modelling techniques that can provide a sophisticated assessment of the aggregate risks to the CCP. As noted above, there is little published research work which considers the margining of portfolios, and even less which considers other default resources. Longin (1999) suggests applying EVT methods to the margining of spread and hedge positions. Keppo (1997) offers a more general model of portfolio margining that also takes into account the conditional probability of member defaults.

Existing theoretical and empirical techniques provide useful insights and practical tools for CCPs, and for

regulators, as well as for others such as central banks concerned with systemic stability. These techniques can be used to assess, monitor and control the risks CCPs face. But they can be improved upon. A challenge for future research will be to develop models of margining, and more generally models of

default provision, which can estimate accurately the potential for tail events and take into account not only the enhanced patterns of market correlations that often accompany these extreme events, but also the extent of correlation between defaults by members.

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