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Stress Tests of Capital Requirements

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“Stress Tests of Capital Requirements” [1]

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Abstract: This paper examines the performance of the leading methods for setting capital requirements for securities firms' trading books. Tests are conducted on a large sample of UK equity market makers' books over a substantial number of periods of equity market stress from 1985 to 1995. The comprehensive and building-block approaches, favoured by US and European regulators, fail to provide effective cover. Only portfolio-based, value-at-risk type models are efficient in providing appropriate levels of capital to cover the position risk of equity trading books.

We are grateful for comments from Paul Kupiec and seminar participants at the 22nd Annual Meeting of the European Finance Association (Milan), the Bank of England and the European Institute for Advanced Studies in Management (Brussels). Both authors are at London Business School, Sussex Place, Regents Park, London NW1 4SA, England. Telephone: +44 1712625050. Fax: +44 171 7243317. Email: edimson@lbs.lon.ac.uk pmarsh@lbs.lon.ac.uk

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STRESS TESTS OF CAPITAL REQUIREMENTS

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ABSTRACT

This paper examines the performance of the leading methods for setting capital requirements for securities firms' trading books. Tests are conducted on a large sample of UK equity market makers' books over a substantial number of periods of equity market stress from 1985 to 1995. The comprehensive and building-block approaches, favoured by US and European regulators, fail to provide effective cover. Only portfolio-based, value-at-risk type models are efficient in providing appropriate levels of capital to cover the position risk of equity trading books.

Recent financial disasters have focused the attention of banks, securities houses and investors on market risk. Market risk, the possibility that sharp movements in market prices might erode or destroy an institution's capital base, has proved traumatic for organisations as diverse as Barings Bank, Orange County, Metallgesellschaft, Piper Jaffray, Shell, Proctor & Gamble and Sumitomo. Regulators and international banking supervisors, who have traditionally sought to control such risks by imposing capital requirements to ensure that financial firms can weather adverse market fluctuations, have also been given cause for concern.

Market risk, or more accurately position risk, is the risk which arises from fluctuations in the values of the securities and other assets in which firms hold positions as principals. Despite the importance of position risk, the methods which regulators are currently using to set position risk requirements (PRRs) for banks and securities firms remain simplistic and ad hoc. In particular, regulatory models largely fail to recognise that a firm's "book" of positions is a portfolio, and that higher risk portfolios require greater safety margins. Indeed, in recent years, regulatory progress has been negative, since the only country to use a portfolio-based system, namely the UK, has largely moved over to a non-portfolio-based method as part of the process of European harmonisation.

The incidence of financial disasters, however, has given regulators good reason to re-examine their approaches. At the same time, financial deregulation and innovation has made it more difficult for them to impose capital requirements on market participants. Merton (1995), for example, identifies eleven different mechanisms through which one could obtain leveraged exposure to the S&P 500 Index, each of which has potentially different regulatory requirements. It follows that regulators increasingly find it difficult to impose capital controls, unless their regulations bear some resemblance to good current practice and to the

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internal controls desired by well managed firms. It is with these ideas in mind, that the influential Basle Committee on Banking Supervision now proposes that banks should be allowed to use their own risk models to measure their exposure, and that the use of stress tests, which examine the overall impact of worst-case scenarios, should be encouraged.

The principal concern of regulators is likely to remain the control of risk and the avoidance of default, particularly if the risks are potentially systemic. In contrast, banks and securities firms will view the problem rather differently, seeing it as a trade-off between default risk on the one hand, and the costs of having to operate with higher-than-desired levels of capital on the other. These alternative perspectives can be partially reconciled by ensuring that capital requirements are set using the most efficient methodology available. More specifically, given the choice between alternative methods, all parties should prefer an approach which, for a given safety margin, requires a lower level of capital; or which, for a given level of capital, provides a higher margin of safety.

In this study we compare the efficiency of five models for identifying capital requirements. First, we examine two widely-used regulatory models, namely the comprehensive approach and building-block method. Some variant on one or other of these is used by regulators to set capital requirements in virtually all the world's leading financial markets. We also examine two portfolio-based methods, namely the simplified portfolio model and the historical risk estimation approach. These represent the kinds of model which might underpin the internal risk management systems of the more sophisticated banks and securities firms, and which are typically referred to as value-at-risk or VaR models. Lastly, as a reference point, we also analyse the impact of simply setting capital requirements as a proportion of the value of the net capital at risk. This can be viewed either as a simplified regulatory approach, or as a naive VaR model.

Previous studies (eg, Dimson and Marsh, 1995) have shown that the PRRs generated by the simplified portfolio model have a higher correlation with the historically measured risk of actual trading books than non-portfolio-based approaches, such as the comprehensive and building-block methods. The acid test, however, is not the correlation with historical risk estimates, but how well the different approaches perform in real time, and in particular, under difficult market conditions. In this study, therefore, we analyse the performance of these five methodologies, using a sample of real equity trading books, over periods of market stress from 1985 to 1995. Since our focus here is on equity books, we define market stress as periods of extreme equity market movements. Since trading books can be net short as well as net long, we examine large market rises, as well as sharp market declines.

In their most general form, stress tests of capital requirements for, say, banking organisations are concerned with multiple asset classes, including bonds, stocks, derivatives, and currencies, often across many different countries. In this context, stress tests focus not just on extreme movements in individual markets, but also on changes in inter-market correlations, such as unusual co-movements in exchange rates or bond, stock and FX

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[1] The Basle Committee on Banking Supervision, which meets under the auspices of the Bank for International Settlements, brings together the world's leading bank supervisors and central bankers. The Basle Committee was the original proponent of the European Commission's (1993) capital adequacy directive.

markets. Our study clearly has a more limited objective, since our data covers only a single asset class, namely equities.

Given the objective of our paper, this limited focus may be viewed as a strength. Our aim is to investigate the efficiency of portfolio-based, VaR-type approaches versus the regulatory models currently in use. If portfolio considerations prove to be important within a single asset class, it seems reasonable to assume they will be even more important within a multi-asset class setting. Furthermore, single asset class studies are important in their own right. For many firms, such as equity market makers or securities firms specializing in equities, the type of trading books examined in this study may form the major part of the firm's total risk exposure. It is also striking that, in many of the recent financial disasters, the firms involved were heavily exposed to the price fluctuations of a single asset category. [2]

The results of our study confirm that the Basle Committee's (1996) decision to encourage the use of banks' own (portfolio-based) models is, in principle, correct. [3] A procedure which follows good current practice in taking account of portfolio effects within a trading book dominates other approaches to estimating capital requirements. However, our study also makes it clear that naive use of VaR-type models may underestimate the risk of an undiversified portfolio of positions, and we endorse the Committee's proposals for stringent quality control of internal risk models.

The plan of our paper is as follows. In the next section we provide an overview of the five alternative models for determining capital requirements. In Section II we identify the periods of market stress over which we evaluate the performance of alternative procedures for estimating capital requirements. Our research design is explained in Section III, while the results are presented in Section IV. Finally, we summarise our conclusions and discuss their implications in Section V.

I. Capital Requirements

A. The General Approach

Capital requirements are set by means of an agreed formula. The formula typically demands a multiple of some measure of risk exposure, which has to be held to cover position risk. That is,

$$C_{jmt} = \lambda_m X_m(p_{ijt}) \qquad [1]$$

where C_{jmt} is the requirement for book j based on method m as at date t, λ_m is a parameter that determines the relative magnitude of the capital required by method m, $X_m(p_{ijt})$ is the

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2 For example, Barings bank's exposure was largely to stock index futures, Orange County's was to inverse floaters, and Metallgesellschaft's was to oil FRAs. Details are given in Board of Banking Supervision (1995), Irving (1995) and Culp and Miller (1995).

3 The reason for endorsing the Basle Committee's decision on an "in principle" basis is that the Committee also specifies certain parameters, eg the holding period, confidence limit and multiplier to allow for contingencies, about which there is no unanimity.

measure of exposure utilised by method m, and p_{ijt} is the value of the holding in security i within book j at date t, where p_{ijt} may be either positive (long positions) or negative (short positions). The measure of exposure $X_m(p_{ijt})$ may also incorporate additional parameters.

We examine five alternative methods, m, for specifying capital requirements, denoted by subscripts NC, CO, BB, SP, and HR, as follows: the net capital at risk approach (NC); the two main regulatory models, namely the US comprehensive approach (CO), and the European Union's building-block method (BB); and two portfolio-based, VaR-type approaches, namely the simplified portfolio approach (SP), and historical risk estimation (HR). In the following paragraphs we discuss each alternative in turn.

B. Net Capital at Risk

The simplest measure of exposure is the value of the net capital (NC), or equity, at risk. ie:

$$X_{NC}(p_{ijt}) = \Sigma p_{ijt} \qquad [2]$$

This measure provides a direct estimate of the losses that might be experienced in relation to the capital employed in a securities firm. For example, if the firm's trading book comprises a fully diversified long position in the market in question, then a capital requirement of 10 per cent would be needed to cover a market fall of 10 per cent.

Regulators do not use this approach for setting capital requirements because trading books almost never represent fully diversified market positions. This, together with the fact that Σp_{ijt} can be small, or even zero, for books with balanced long and short positions, makes it impossible to select a single parameter λ_{NC} which could be used to set appropriate PRRs.

Nevertheless, this method is interesting as a reference point. Furthermore, if taken out-of-context and implemented naively, many proprietary risk management systems could be interpreted as advocating the net capital at risk approach, at least for a subset of the book. For example, the most widely publicised and available model is JP Morgan's RiskMetrics system. This focuses on the risk of portfolios with exposures to fixed interest, foreign exchange, equity and/or derivative positions. In its enhanced version, RiskMetrics measures risk on a full-covariance basis for several hundred different asset return series. Because these models analyse risk on a global, multi-asset basis, investment in domestic equities is regarded as exposure to a single asset category. [4] This is equivalent to treating the exposure as if it were a fully diversified position in the equity market in question. If the standard deviation of the equity market at time t is σ_{mt}, and if the RiskMetrics approach were naively applied to a single-equity-market book, this would be equivalent to implementing the net capital at risk approach with $\lambda_{NC} = k\sigma_{mt}$, where k is a constant, indicating the number of standard deviations of "cover".

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4 Publicly available value-at-risk models typically assume that all exposure to an equity market is through vehicles such as a stock index futures contract (with no basis risk), a holding in an index fund, an index option (valued at the appropriate delta), or a diversified portfolio of individual stock options (also evaluated using their delta). They therefore take into consideration exposure to market risk, but ignore residual risk; see Guldimann (1995) and Phelan (1995). Lawrence and Robinson (1995) provide a critique, while a defense is offered in Longerstaey and Zangari (1995); an alternative approach is presented by Reed (1995).

C. Regulatory Methods: The Comprehensive and Building-block Approaches

We also examine two widely used regulatory methods as follows:

The comprehensive approach applies a charge to all positions. Many countries employ this method in its purest form, applying a uniform charge to every long and short position, so the capital requirement is simply a fixed percentage of the book's gross value, $\Sigma\ |p_{ijt}|$. However, in the United States, the Securities and Exchange Commission (SEC) allows an offset of the value of short positions against the value of long positions, for all short positions up to one-quarter of the value of the longs. For any further short positions, and for all long positions, the charge required by the SEC is currently λ_{CO} = 15 per cent of the market value of each holding. [5] Under the US comprehensive approach, the capital requirement of a net long portfolio is thus proportional to the following measure of exposure:[6]

$$X_{CO}(p_{ijt}) = \Sigma\ |p_{ijt}| \ - \ \text{Min}\ (\sum_{p_{ijt}<0} |p_{ijt}|\ ,\ \tfrac{1}{4} \sum_{p_{ijt}>0} |p_{ijt}|\ ) \qquad [3]$$

The building-block approach bases capital requirements partly on the net and partly on the gross value of a trading book. This method is embodied in the European Union's capital adequacy directive (CAD), and is a significant enhancement over the comprehensive approach. In particular, by basing the charge partly on a book's net value, it recognises that balanced books whose net exposure is lower than their gross (long plus short) exposure, provide partial hedging of market risk and are less risky than all-long books with the same gross value. Unlike the net capital at risk approach, it also recognises that books rarely constitute fully-diversified market positions. It therefore imposes a second charge linked to the book's gross value. Under the CAD, the capital requirement is λ_{BB} = 8 per cent of the book's net value, plus a further charge of half this amount, namely 4 per cent, on the gross value to reflect the "specific risk" of undiversified trading books. The PRR under the building-block approach is therefore proportional to the following measure of exposure:[7]

$$X_{BB}(p_{ijt}) = \Sigma p_{ijt} + \tfrac{1}{2}\ \Sigma\ |p_{ijt}| \qquad [4]$$

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5 The charge can be as low as λ_{CO} = 10 per cent for liquid stocks in Japan, 15 per cent in the USA and Australia or 20 per cent in France and Italy. It can be as high as 30 per cent for illiquid stocks in the Netherlands, or 40 per cent in Hong Kong.

6 In equation [3], the first term is the comprehensive charge on all positions (ie, on the gross value of the trading book), while the second term identifies the offset for short positions. The one-quarter maximum offset of the value of short positions against a net long portfolio presumes a book which is net long. For a book which is net short, the one-quarter maximum offset would apply to the long positions. and hence the second term in formula [3] would be $\text{Min}\ (\sum_{p_{ijt}>0} |p_{ijt}|\ ,\ \tfrac{1}{4} \sum_{p_{ijt}<0} |p_{ijt}|\ )$.

7 In equation [4] we assume that the charge for specific risk is at a percentage rate which is one-half of the 8 per cent rate charged for general market risk. That is, we are implicitly assuming that the building block approach demands λ_{BB} = 8 per cent of the book's net value plus $\tfrac{1}{2}\lambda_{BB}$ = 4 per cent of its gross value, with this "4+ 8" system being scaled up or down depending on the overall level of protection which is required. This is consistent with the capital requirements for positions in liquid securities held within a trading book that does not pass the CAD's diversification test. The general formula for the building block approach would involve replacing the constant of ½ in formula [4] by an additional parameter.

D. Portfolio-based, VaR-type Approaches

Finally, we examine two portfolio-based approaches of the kind which might appear in internal risk management systems in sophisticated banks and securities firms.

The simplified portfolio approach was implemented as a regulatory model in the UK, although the UK has now moved over to the building-block approach to conform with the European Union's CAD. The model which we examine here is identical to that required by the UK's Financial Services Act (1986), and employs a simplified version of Sharpe's (1963) market model with the assumptions that all security betas are equal to one, and all residual variances at time t are equal to $\sigma^2_{\epsilon t}$. If the variance of market returns at time t is σ^2_{mt}, and if we assume that the ratio of residual variance to market variance ($\sigma^2_{\epsilon t}/\sigma^2_{mt}$) is 1.5[8], the risk exposure for the simplified portfolio approach is:

$$X_{SP}(p_{ijt}) = \sigma_{mt} \Sigma p_{ijt} \sqrt{[1 + 1.5 \Sigma (p_{ijt}/\Sigma p_{ijt})^2]} \qquad [5]$$

The simplified portfolio approach represents a considerable advance on the two regulatory approaches outlined above, since it is derived from portfolio theory and makes explicit allowance for both diversification and balanced books. This approach also allows firms to select the parameter λ_{SP} in such a way that it relates directly to their target coverage levels. For example, under the UK regulatory system, σ_{mt} was specified as a weekly standard deviation, and, for the most liquid group of equities, the regulators set $\lambda_{SP} = 2$. The PRR was thus set equal to twice the weekly standard deviation of returns. This reflected the fact that UK regulators had taken the view that they wanted to ensure that firms had enough capital to cover one week's fluctuations in security prices. with a confidence interval of 95 per cent.

The simplified portfolio approach does, however, rely on strong simplifying assumptions, notably the market model premise that security returns are related only through a common relationship with a single "market" factor, and the assumption that all securities have identical risk characteristics. Despite these simplifications, and perhaps because of its history as a regulatory approach, the simplified portfolio method is widely implemented within the risk management systems used by UK-based securities firms. Variants of this approach, sometimes allowing risk estimates to vary across securities, are also incorporated in the VaR-type models used by many other securities firms worldwide.

Historical risk estimation is an alternative method of estimating value-at-risk which avoids the assumptions implicit in the simplified portfolio approach. The procedure is based on an estimate of the historical standard deviation of the trading book over an estimation period prior to the date of interest. Although risk is estimated from historical data, the concern is with prospective risk over the days (or at most weeks) immediately following the date of

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8 These assumptions lead to an estimate of the portfolio variance which is equal to $\sigma^2_{mt} + \sigma^2_{\epsilon t} \Sigma (p_{iit}/\Sigma p_{iit})^2$. In equation [5] the ratio of residual variance to market variance is assumed equal to 1.5. This is a market derived estimate (see Dimson and Marsh, 1995) of the ratio which was embodied in the rules of the UK regulator, the Securities and Futures Authority (1992), at the time when the simplified portfolio approach was used to determine capital requirements in the UK. A more general formula for position risk requirements would involve replacing the constant of 1.5 by a second parameter equal to the ratio $\sigma^2_{\epsilon t}/\sigma^2_{mt}$. In fact, although the value of& varies in the UK rulebook from country to country, the ratio of residual variance to market variance was relatively similar across the countries covered by the rules.

interest. Since the composition of trading books varies greatly over time, the standard deviation of the time-series of past returns on the book would give a misleading estimate of short-term prospective risk, since the latter will depend on the *current* composition of the book. To obtain a better estimate of forecast risk for book j at time t, it is therefore more appropriate to estimate the standard deviation, σ_{hit}, of a hypothetical, reconstructed time-series of returns based on the book's current composition. Following this approach, the exposure is equal to: [9]

$$X_{HR}(p_{ijt}) = \sigma_{hjt} \Sigma p_{ijt} \qquad \textbf{[6]}$$

Once again, because we are dealing with a portfolio-based approach, and exposure is based on the book's estimated standard deviation of returns, λ_{HR} can be set to k, which is the number of standard deviations of desired "cover".

E. The Policy Debate About the Alternative Methods

There has been considerable debate amongst academics, regulators and practitioners as to which framework for setting capital ratios is appropriate. Though the comprehensive approach fails to relate capital charges to risk exposure, the SEC has defended its approach as the most "prudent" (see Hirtle, 1992). The portfolio approach, however, appears to generate capital requirements that are more closely linked to historical volatility than either the comprehensive or the building-block method (see Dimson and Marsh, 1995), and is preferred by some institutions as a basis for regulation (eg, LIBA, 1995). Nevertheless, the European Commission (1993) selected the building-block method as preferable to the simplified portfolio approach, and other European countries now have to conform to the EC's capital adequacy directive (see Bank of England, 1995, and Securities and Futures Authority, 1995).

Industry representations (eg, Bralver and Kuritzkes, 1993) and academic papers (eg, Merton and Perold, 1993) favouring variations of the portfolio approach appear to have been ignored until late 1994. At that stage, the new Chairman of the US SEC indicated that the SEC's attitude towards portfolio-based risk controls had softened (see Levitt, 1994), and a few months later the Basle Committee indicated that it no longer favours the building- block approach. It now advocates the use of methods which embody the portfolio approach, such as value-at-risk models (eg, equations [5] and [6]), and it supports the application of proprietary software that embodies backtesting facilities. Despite these changes of position, national regulators around the world still continue to set capital requirements using either the comprehensive or building-block approaches, depending on the country in question. However, there are increasing pressures to amend requirements, so as to reduce the scope for regulatory arbitrage by securities firms (see Dale and Wolfe, 1996). This raises the question of which method(s) perform best over periods of market stress.

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[9] This procedure is relatively straightforward either at the asset class level, or at the individual security level when books contain securities from just a single asset class. However, if historical risk estimation is to be implemented at the security level for, say, multi-asset class, global trading books, then the data and computational burden may be very large. The risk model made available by one firm of consultants, for example, covers some 30,000 securities, but this is only a limited selection of the individual assets that could be held in a global portfolio. For reasons of practicality, we suspect that historical risk estimation, at least for the equities portion of the book, may have to be confined to some kind of simplified procedure (such as equation [5]), at least so far as broadly diversified global portfolios are concerned.

II. Stress Testing

Stress tests measure the sensitivity of an firm's portfolio of positions to adverse market movements. Many stress tests examine the sensitivity of a firm's capital base to hypothetical scenarios; see, for example, Allen (1994). This type of sensitivity analysis, however, is highly dependent on the risk model which underpins the test. For example, consider a global, multi-asset portfolio which is modelled using a standard value-at-risk model such as RiskMetrics, which represents equity exposure by the dollar value of the net investment in each individual equity market. Suppose the net exposure to the US equity market is $lm, comprising both long and short positions in a number of stocks. A stress test which employed the model would indicate that the worst that might happen is a loss on the equity portfolio of up to $1 million, depending on how much the US equity market falls. But if a particular constituent were to rise dramatically in price, and the portfolio were exposed to a short position in this security, a loss of far more than $1 million might be experienced. No form of sensitivity analysis will reveal this risk exposure if the underlying risk model fails to take account of the degree of undiversification within an individual equity market. [10] To be valid, stress tests should not examine scenarios that are in turn dependent on a particular risk model.

Wherever possible, stress tests should therefore reflect periods of extreme market behaviour. The Basle Committee proposes stress testing over periods such as the 1987 Crash, 1993 ERM crisis and 1994 bond market collapse. Such periods may or may not be associated with specific items of news (see Siegel, 1994), but what they all have in common is sharp movements in individual markets, often coupled with changes in, or at least unusual, inter-market correlations. Since this paper is concerned with only a single-asset class, namely equities, we focus simply on sharp market movements. In principle, we would like to identify a large number of instances in which the equity market has moved by a substantial amount over a brief interval. In practice, so as to look at market fluctuations that are meaningful in relation to proposed capital requirements, we consider movements which span a number of days. This ensures we have a reasonably large sample of periods over which we can evaluate the competing capital adequacy rules.

Our sample interval runs from the start of 1985 (when the daily share price history of the London Share Price Database, LSPDaily, begins) to the end of 1995. Over this period, equity market returns are distributed with slight negative skewness, and a greater frequency than normal of extreme returns. [11] We search for all one-day market movements which exceed five percentage points, whether falls or rises, [12] and find only six such movements

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[10] As Alan Greenspan, Chairman of the US Federal Reserve Board, notes: *"Although statistical models of risk are important, and indeed critical, I am concerned that if management does not recognise the limitations of these models, firms could rely too heavily on them in making financial decisions, with adverse consequences for the firms and perhaps also for financial markets"* (Field, 1995).

[11] The distribution of daily (and, for completeness, ten-day) returns on the FTSE-A All Share Index is summarised by a mean return of 4.4 (45.1) basis points with a standard deviation of 85 (321) basis points. There is a skewness of -1.54 (-1 .71) and a kurtosis of 21.3 (14.3). The lowest return is -11.4 (-29.3) per cent, and the highest return is 5.9 (11 .6) per cent.

[12] Sharp falls m the market are an obvious danger to net long portfolios. But since trading books can also be net short, it is equally important to consider the risks to such books arising from sharp market rises.

out of some 2800 daily returns on the FTSE-A All Share Index. Since fluctuations of five per cent or more are rare, we adopt this as our definition of a sharp market movement. [13]

Since we are concerned with sharp market movements extending over several days, we also consider two-day fluctuations that exceed five per cent. There are twelve such returns (see the first column of Table I), and unsurprisingly, most of these span periods that overlap with the previously identified one-day returns. That is, they have the extreme one-day return as the first and/or second day of the interval spanned by our two-day returns. We therefore employ only the four two-day returns which do not overlap with the interval used for measuring one-day returns. In this way, we build up a record of returns measured over increasingly long periods, but where every measurement interval is independent of (ie, does not overlap with) other intervals. We consider returns measured over an interval of up to ten days, since this definition of the period at risk appears to be gaining favour with the supervisory community; see, eg, Corrigan and Heimann (1995) and Basle Committee (1996).

Table I

Number of Market Returns Exceeding ± 5% Over 1985-95

The figures in reman typeface are the number of FTSE-A All Share Index returns, measured over various intervals, falling outside the range ± 5%. Many of these are measured over intervals that overlap. In bold typeface we show the number of returns that do not overlap with returns spanning an equal or briefer interval.

Interval	Total > ±5%		Number < -5%		Number > 5%		Cumulative Total	
Daily	6	**6**	4	**4**	2	**2**	6	**6**
2-day	12	**4**	7	**1**	5	**3**	18	**10**
3-day	20	**3**	11	**2**	9	**1**	38	**13**
4-day	28	**3**	15	**1**	13	**2**	66	**16**
Weekly	48	**8**	22	**5**	26	**3**	114	**24**
6-day	69	**7**	32	**2**	37	**5**	183	**31**
7-day	98	**9**	40	**3**	58	**6**	281	**40**
8-day	125	**3**	42	**0**	83	**3**	406	**43**
9-day	163	**11**	49	**4**	114	**7**	569	**54**
Biweekly	211	**7**	58	**2**	153	**5**	780	**61**

The first two columns of Table I show the total number of returns whose absolute size exceeds five percentage points, measured over intervals of one through to ten trading days.

[13] To provide some indication of the rarity of a five per cent move in the market, Siegel (1994) examines the US history since 1885 of the Dow Jones Industrial Average. He finds 120 days when the index moves by five percentage points or more, but most of these occur in the first half of the period. It would be difficult to construct a sample of market movements in excess of five per cent: of the 31 moves of at least seven percentage points, for example, only four occur after the 1930s. Schwartz and Ziemba (1991) find only nineteen days since 1949 when the Japanese Nikkei Stock Average has a return whose absolute magnitude exceeds five percentage points. Brailsford and Faff (1993) examine daily movements in the Australian equity market over the period 1974-93, finding only ten rises and twelve falls exceeding five per cent.

The first column (in reman typeface) shows the total number of returns, while the second column (in bold typeface) shows the number of non-overlapping returns. Table I also shows how these break down into market falls (columns three and four) and rises (columns five and six), and also the cumulative total number of returns whose absolute size exceeds five percentage points (columns seven and eight). If measurement intervals of up to ten days are considered, the final pair of columns shows there are 780 returns which exceeded five per cent, but only 61 returns that are non-overlapping with returns measured over an equal or briefer interval. We evaluate the competing capital adequacy systems over these 61 periods. [14]

Figure 1 gives details on the timing, magnitude and duration of these 61 intervals of market stress. It shows that these periods are drawn from each of the eleven years from 1985 to 1995, with the number of observations per year varying from one in 1989 and 1995 to eighteen in 1987. The shading of each bar shows the interval over which returns were measured: one-day returns are plotted in black; two to eight days are plotted in successively lighter shades; while nine- and ten-day returns are indicated by unshaded bars.

Over intervals of one to five days there are approximately equal numbers of market increases and decreases in excess of five per cent; but over longer intervals the number of rises exceeds the number of falls, as one would expect when the distribution of returns is approximately lognormal. Of the eight market fluctuations in Figure 1 which exceed six percentage points, there are three one-day returns, four two-day returns and one five-day return. These are drawn from three different years, and comprise five market falls and three market rises.

In using these 61 periods of market stress to test the robustness of alternative capital rules, it is important to note that we have selected the most favorable set of test periods from the perspective of the two regulatory approaches. Trading books are exposed to both market risk and residual risk, but neither the comprehensive [3] nor the building-block [4] procedures take any account of residual risk. By focusing on periods when market risk dominates, these two methods have their best possible chance to perform relatively well. [15]

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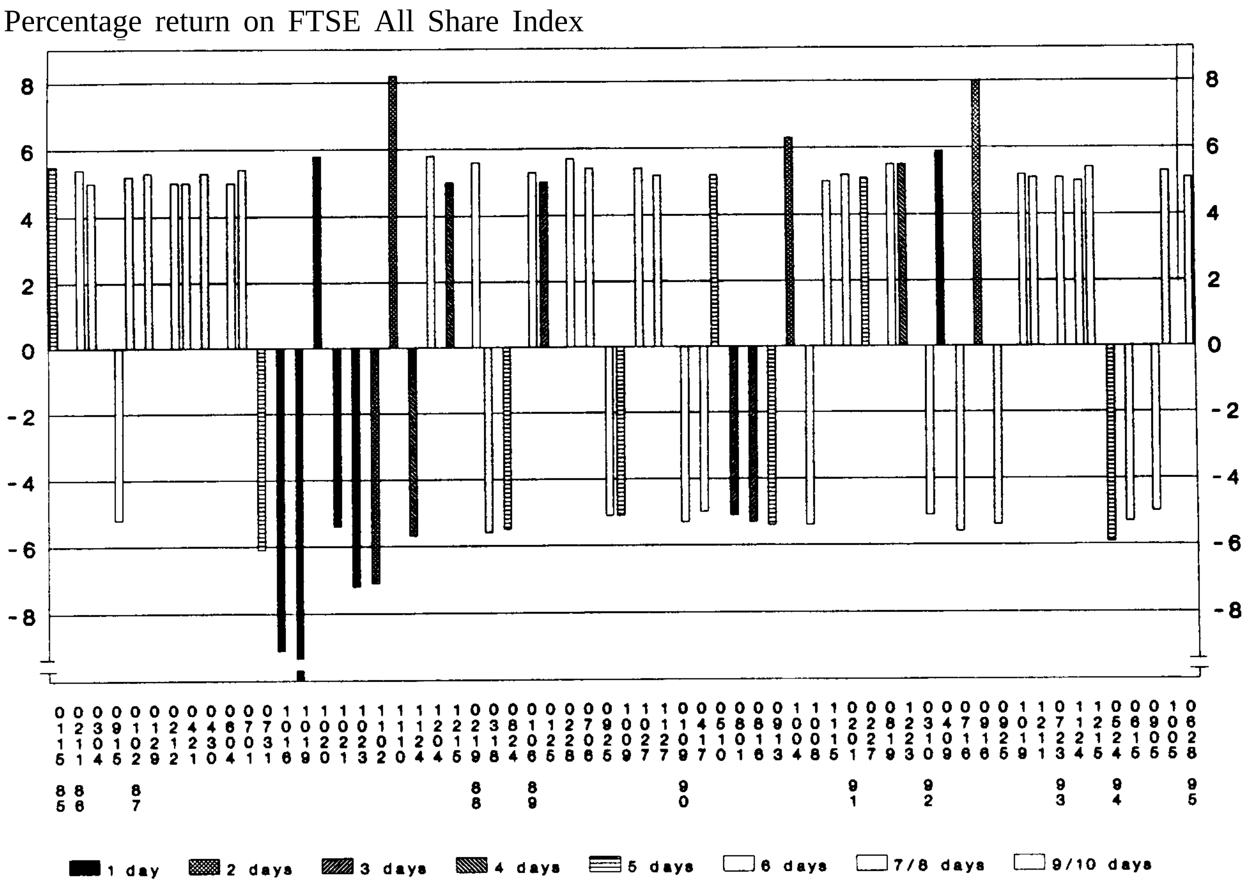
[14] We also considered identifying sharp market movements by focusing first on extreme moves over the longest measurement interval, and supplementing this with further observations drawn from briefer intervals. This gives rise to a sample of 59 periods which include some fluctuations that are more extreme than those reported in Table I. However, all the resulting periods of stress last for at least one week, and 86 per cent of these last for a full ten days. We do not consider it as appropriate to test capital requirements over these relatively lengthy periods, since capital should be adequate at the close of business every day. Part-way through an interval of ten days there would be an opportunity to top up a firm's capital if market fluctuations were to have had a major impact. Nevertheless, we replicate our study using this alternative sample of periods, and the results are reported below when appropriate.

[15] Residual risk clearly matters most for undiversified trading books. One-half of all market makers in our sample run trading books which are less diversified than would be the case if their net capital had been divided equally between three average-risk equities (see Dimson and Marsh, 1994). The most testing periods for such books would thus be the intervals with the greatest cross-sectional variation of returns. While we are not examining such periods here, we would expect these to be the intervals during which the superiority of portfolio-theory based rules over the regulatory approaches was as its greatest.

Figure 1: Chart of 1-10 Day Returns Exceeding 5% Over the Period 1985-95

This chart displays those UK equity market returns whose absolute value exceeds five percentage points measured over an interval which is non-overlapping with extreme returns computed over a briefer interval (see Table I). The return is measured over an interval of 1-10 days starting on the date identified in the graph. Each date is given in the form *mmddyy*, where *mm* denotes the month, *dd* denotes the day of the month and *yy* denotes the year. The measurement interval for the return is indicated by the shading of each bar: black indicates a one-day return, intermediate shades represent two- to eight-day returns, and unshaded is a nine/ten-day return.



III. Research Procedure

Our research procedure involves testing the performance of each method for setting capital requirements for equity trading books over the 61 periods of equity market stress. To do this, we require a record of the likely composition of equity trading books. The most direct approach would be to obtain the composition of the actual books held at the start of each of the 61 periods by competing securities firms operating in the London market. Unfortunately, such information is not available. This is not simply because of concerns over confidentiality, although such data could allow outsiders to draw commercially valuable inferences about trading strategies oversensitive periods. In fact, the data typically no longer exists, and cannot readily be reconstructed.

As an alternative, we analyse 58 UK equity trading books relating to dates other than the sensitive periods in question, and use these as the basis for a simulation study. These books were provided on a confidential basis through the UK's Securities and Futures Authority, for the purposes of our research. They represent the overnight UK equity exposure of a sample of 16 different market makers on 30 different dates between December 1986 and September 1988. They vary in gross value from £1 million to £200 million; in net exposure (value of long positions minus value of short positions) from £104 million down to minus £21 million; in long: short ratio from 97:3 to 36:64; in number of constituents from 18 to 1426 shares; in weighted average market capitalisation of the constituents from £0.1 billion to £5 billion; in marketability from 91 per cent in illiquid "gamma" securities to 100 per cent in liquid "alpha" securities; and in industry sector composition/specialization. Further detail on the characteristics of the books is provided in Dimson and Marsh (1994).

The holdings in each trading book can potentially be used in two alternative ways. First, the characteristics of these books could be analysed and parameterised, and the resultant parameters utilised in a simulation designed to generate similar types of books just prior to the start of each period of market stress. Second, and more simply, the 58 books can be used essentially as they stand, and assumed to represent different firms' positions at the start of each period of interest.

The first approach, where books are generated via a full-scale simulation, has the advantage that any number of books can be generated, so that the research is not constrained by sample size. The drawback, however, is that its efficacy is entirely dependent on the validity of the model used to characterise the books, and on the robustness of the estimated parameters. In practice, we know that, in addition to market risk, there are many sources of extra-market covariances which can influence a trading book's vulnerability, and that many of these are not fully understood, and cannot easily be identified or measured.

Even if the simulation were restricted to attributes which are identified and measurable, it would still be hard to construct a model that generates realistic trading books. This is because of the multiplicity of interacting factors which make the books distinctive, such as the extent to which books are net long or short; the relative weighings and concentration of their positions, and hence the book's degree of diversification; the extent of sector specialisation; the extent to which different securities firms specialise in large, liquid stocks, in small cap securities, or some combination of these; and so on. But the more serious problem arises from unidentified factors. While we can observe the tilt of the 58 books in terms of factors such as sector and size, we simply do not know the extent to which there is a tilt in terms of "value", "quality", "growth", exchange rate or interest rate sensitivity, exposure to real estate values, candidacy for takeover, and so on. Books generated via simulation would, by ignoring such factors, tend to diversify away any such exposures.

Rather than generating books via a full-scale simulation, we therefore adopt the second approach, which is to utilise the composition of the 58 books essentially as they stand. [16] To examine the risk exposure of each of these books at various points in time, we roll the portfolio composition forward or backward to the start-date for each of the 61 test periods. In doing this, we adjust for any intervening stock splits or other capital changes. When the books are repositioned in time, the relative weighings of different holdings will change, depending on relative stock price movements. This could, in turn, alter the extent to which

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[16] This is also the preferred solution of several other researchers; see, for example, Jackson, Maude and Perraudin (1996).

(and whether) a particular book is net long or short. To ensure consistency, we therefore hold each book's long: short position ratio constant over time. This is achieved by rolling the long and short sides of each book forwards/backwards separately, and then recombining them on each of the 61 desired dates in the proportions which were actually held for the trading book under consideration on its date of origin. At each of the 61 dates, this then provides us with information on the composition of 58 trading books.[17] This approach is still clearly a simulation exercise, but one that is more closely tied to real, rather than randomly generated, data.[18] This should help to ensure that the trading books employed in our tests more realistically reflect extra-market covariances.[19]

In order to test the performance of the various methods for setting capital requirements, we calculate the exposure measure, $X_m(p_{ijt})$ for each of the five methods using equations [2] -[6] for each of the 58 books as at the start of each of the 61 periods. For the two portfolio-based approaches, computation of a book's exposure requires estimates of σ^2_{mt}, the variance of market returns at time t, and σ^2_{hit}, the variance of portfolio returns for book j at time t. For each date, and in the case of portfolio variances, for each book at that date, we estimate variances using a sixty-month window terminating at the most recent month-end. 20

In setting PRRs, securities firms and regulators are seeking to ensure that there is sufficient capital to prevent a default. Since PRRs are simply the exposure level times a multiplier (see equation [1]), the likelihood of default depends on the choice of method used to measure exposure and the level at which that method's multiplier, λ_m, is set. Any method can be made as prudent as desired simply by setting λ_m sufficiently high. In this sense, λ_m can be viewed as a "safety" parameter. However, if λ_m is set too high, firms will face costs from having to operate with higher-than-desired levels of capital.

To compare the different methods, we therefore need to assess their relative efficiency by measuring how much capital they require to deliver a given level of protection, where the latter can be expressed in terms of the number of firms likely to default. At least after a period of stress, regulators frequently express interest in the level of capital which would have been needed to ensure zero defaults. We therefore adopt this criterion, and for each

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17 Because of the process of rolling the portfolio forward or backward through time, the precise composition of a particular book may differ slightly between one date and another. For example, when a book is rolled forward through time, some securities are merged or delisted. Similarly, when a trading book is rolled backward through time, certain recently issued stocks may not enter the book at the earlier date. In addition, to ensure fair comparisons between methods for calculating capital requirements, at each date we eliminate from the trading books any securities which do not have a twelve-month stock price history.

18 In this respect, our methodology is in the spirit of the simulation studies carried out by Brenner (1979) and Brown and Warner (1980, 1985).

19 Some of the factors that might enter as unobservable tilts in the trading book may, of course, be transient. If so, they will not be captured by this approach any more than they would be by the full-scale simulation. An obvious example here would be any adverse selection bias to which the market makers are exposed, arising from short-run informational advantages held by (some of) the market makers' counterparties.

20 This follows the Basle Committee's recommendation that *"banks will at the least be required to apply a minimum historical sample period of one year"* and the suggestion that they *"may look back over a historical period of several years"*. Dimson and Marsh (1983) find that estimation over a sixty-month window generates more accurate predictions of risk characteristics than estimation over a shorter period.

period of stress, and for each method m, we calculate the value of λ_m for period t, (ie, λ_{mt}) which ensures that the PRRs generated by method m provide just enough capital to ensure that none of the 58 trading books is in default.

More specifically, for each of the 61 periods of stress, we estimate the loss (or profit) l_{jt} on each of the 58 books. In every period, at least one book experienced a loss. We therefore identify the book J_t which experienced the largest loss, L_t, where:

$$L_t = \underset{j}{\mathrm{Min}}\,(l_{jt}) \qquad [7]$$

To ensure that the PRRs generated by method m are large enough to prevent any defaults, it follows that λ_{mt} must be set high enough to cover the maximum loss, L_t, ie

$$\lambda_{mt} = L_t \,/\, X_m(p_{iJ_tt}) \qquad [8]$$

λ_{mt} thus tells us how high capital requirements would need to have been set for each method m over each period of market stress t if we had enjoyed perfect foresight and wished to ensure that there was just sufficient capital to ensure no defaults.

To estimate the efficiency with which each method achieves this target level of cover, we calculate the aggregate amount of capital that would be needed for each method m if the parameter λ_{mt} were applied to all 58 books at the start of period t. The "full coverage" capital requirement for trading book j for method m at the start of period t would thus be:

$$C^*_{jmt} = \lambda_{mt}\, X_m(p_{ijt}) \qquad [9]$$

Since each trading book has a specific, well-defined gross value, $G_{it} = \Sigma\, |p_{iit}|$, we use this to provide a consistent way of measuring the relative amount of capital required on average by each method m. We thus define F_{mt} to be the average value of the full coverage capital charge for method m over period t expressed as a percentage of the gross value of all trading books at the start of period t, ie

$$F_{mt} = \Sigma_j\, C^*_{jmt} \,/\, \Sigma_j\, G_{jt} \qquad [10]$$

We then compare the average capital requirement, F_{mt} across the five methods, m. In addition to looking at full coverage of all books, we also compare the average capital requirement needed to cover all-but-one books, all-but-two books, etc. 21 Finally, we repeat the experiment across all 61 periods of stress, and calculate the quantiles of the distribution of F_{mt} for each method m. We are then able to compare the requirements demanded by each method in order to cover various "worst case" scenarios, such as full coverage in all periods of stress, all-but-one periods of stress, and so on.

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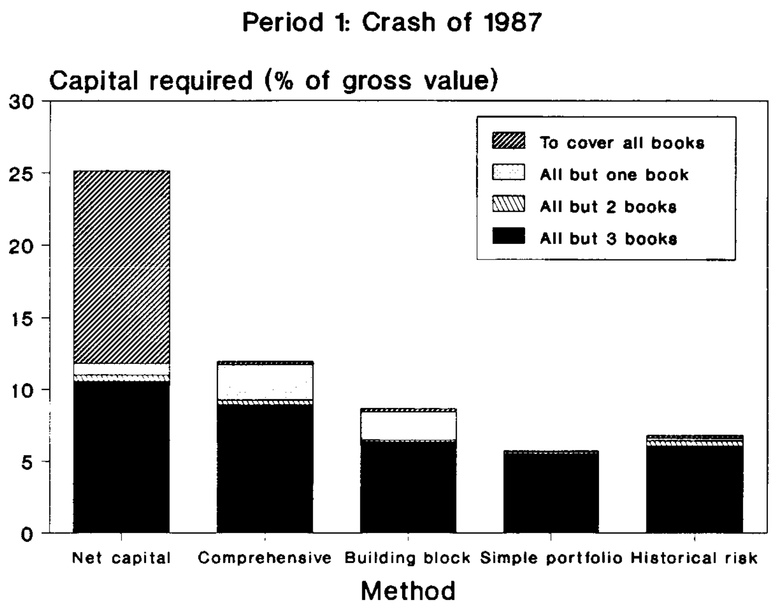
[21] This does not affect the ranking of different methods, which is reported in section 5, and our results are therefore presented primarily on the basis of identifying the capital required to provide full cover for every trading book.

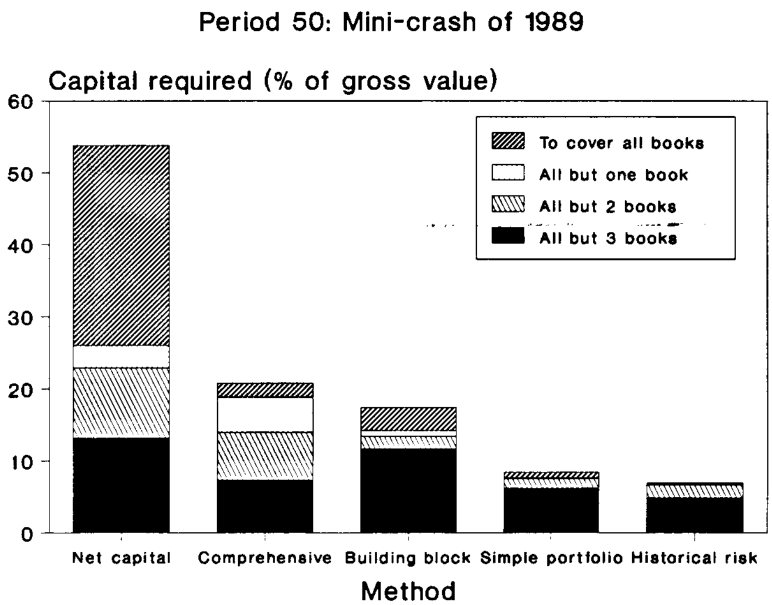
IV. Results

A. Illustrative Results During Two Sample Periods

The top panel of Figure 2 shows the results for just one period of market stress, namely the single worst day of the 1987 crash (October 19-20, 1987), when the UK market fell by 11.4 per cent (shown earlier in Figure 1 as the most extreme period in the sample). The leftmost bar of Figure 2 shows that if capital requirements had been set using net capital at risk as the measure of exposure, then to achieve full *ex post* cover of all books, capital amounting to 25.2 per cent of the gross value of all 58 trading books would have been required. The remaining bars, reading from left to right, show that if the comprehensive approach had been used, capital amounting to 11.9 per cent of the books' gross value would have (just) provided

Figure 2: Illustrative Capital Requirements During Two Sample Periods





full coverage[22], while the corresponding figures for the building-block, simplified portfolio, and historical risk estimation approaches were 8.6, 5.7 and 6.8 per cent respectively.

These results indicate that, if the desired level of protection had been full coverage of all books, then over the day of the 1987 crash, the simplified portfolio method would have provided the most efficient allocation of capital, with a requirement of just 5.7 per cent, closely followed by the other portfolio-based method, historical risk estimation, with a requirement of 6.8 per cent. As might be expected, measuring exposure simply as the net amount of capital at risk leads to the least efficient allocation of capital, by a wide margin.

The top panel of Figure 2 also shows the results of reducing the requirement from full coverage to coverage of all but one, two, and three books. While the average requirement naturally falls for all five methods as the coverage target is successively relaxed, the ranking of the methods stays the same. The two portfolio approaches always lead to the most efficient allocation of capital, while the net capital at risk approach leads to the least efficient.

The lower panel of Figure 2 shows a similar set of results for the so-called mini-crash of 1989. The period spanned here is from 25 September 1989 until 9 October 1989 when the UK market fell by 5.1 per cent. The results are directionally very similar to those described above. If the desired level of protection had been full coverage of all books, then capital equal to a staggering 53.8 per cent of the gross value of all trading books would need to have been posted if exposure had been measured in terms of net capital at risk. The two regulatory approaches performed better, with the comprehensive method requiring 20.8 per cent, and the building-block approach 17.5 per cent. The two portfolio based, VaR-type approaches, however, enjoyed by far the lowest capital requirements, with the simplified portfolio approach and historical risk estimation demanding 8.5 and 7.0 per cent respectively.

B. Period-by-period Results

Table II presents a more comprehensive period-by-period summary of the capital required to achieve full *ex post* cover of the books. Each row of the table refers to a different period of market stress, and the results for the twenty most extreme periods are listed in full, while for brevity, every fifth period is listed thereafter. For each period of market stress, the method which generates the lowest capital requirement is highlighted by printing the requirement in bold typeface. The first row of the table represents the most extreme period in the sample, namely the 1987 crash, and the results shown in this row correspond to those plotted in the top panel of Figure 2, and already discussed above. Similarly, the third row from the bottom of the table, label led period 50, represents the mini-crash of October 1989, and corresponds to the full-coverage results presented in the bottom panel of Figure 2.

The results shown in Table II indicate that over the three largest market declines (periods 1, 2 and 5) the simplified portfolio approach requires the least capital. When the market falls by a lesser amount, the lowest requirement arises with this procedure or with historical risk

22 In other words, one book would have exhausted its position risk capital by the end of the period, whilst the other 57 books would have had some capital left to carry over to the next day.

Table II

Capital Required to Provide Full Cover over Each Period

The table shows the capital required at the start of each period of market stress, in order to cover adverse fluctuations during that period in the value of all 58 books. The capital is expressed as a percentage of the gross value of all the trading positions in the books. It varies according to whether the requirement is specified using the net capital at risk, comprehensive, building-block, simplified portfolio or historical risk estimation approach (equations [2] to [6] respectively). For each period, the system generating the lowest capital is highlighted using bold typeface. Periods are ranked in descending order of absolute market return. The results for the twenty most extreme periods are listed in full, and for brevity, every fifth period thereafter is listed.

Period	Market return	Net capital at risk	Compre-hensive	Building-block	Simplified portfolio	Historical risk estimation
1	-11.4	25.24	11.94	8.64	**5.72**	6.79
2	-9.1	9.05	9.08	6.51	**4.33**	5.46
3	8.2	20.67	3.72	**3.63**	4.54	4.17
4	8.0	274.40	**3.49**	5.63	3.77	4.15
5	-7.2	21.09	8.55	5.84	**4.87**	6.15
6	-7.1	33.57	7.48	5.69	5.11	**4.85**
7	6.3	93.75	3.09	3.00	3.16	**2.87**
8	-6.1	177.10	8.95	8.02	7.41	**5.51**
9	5.9	98.23	**2.55**	3.20	2.58	2.73
10	-5.9	6.91	4.35	3.27	**2.85**	2.94
11	5.8	145.50	3.87	4.95	4.58	**3.49**
12	5.8	95.49	**7.16**	11.75	7.73	9.75
13	-5.7	24.86	6.84	6.09	5.86	**3.94**
14	5.7	12.59	4.62	3.54	**3.53**	3.89
15	-5.6	10.01	5.39	3.86	**2.73**	2.93
16	-5.6	35.35	5.81	6.83	5.60	**4.96**
17	5.6	26.82	4.35	**4.21**	4.51	4.37
18	5.5	100.10	3.94	**3.08**	3.87	3.71
19	5.5	5.98	5.10	3.90	**3.53**	4.07
20	-5.5	14.29	4.75	3.82	3.59	**3.13**
25	-5.4	15.49	7.14	4.91	**2.75**	3.02
30	5.4	40.28	**4.17**	6.66	4.50	4.73
35	-5.3	21.90	8.09	5.92	3.25	**3.03**
40	5.2	82.18	2.05	2.55	**2.00**	2.10
45	-5.1	207.30	8.36	6.58	6.42	**5.49**
50	-5.1	53.80	20.80	17.48	8.47	**6.97**
55	5.0	89.91	**2.38**	2.99	2.46	2.64
60	-5.0	21.64	4.69	3.49	**2.84**	3.13

estimation. Closer scrutiny suggests that the simplified portfolio and historical risk estimation methods generate relatively similar, though by no means identical, capital requirements. These two portfolio based, VaR-type systems perform fairly well. In over two-thirds of the periods, the simplified portfolio and historical risk estimation procedures generate the lowest capital requirement. The net capital at risk approach, as implemented here, never generates the lowest requirement. In the remaining periods, the lowest capital requirements are given by the two regulatory approaches, namely the comprehensive and (less frequently) the building-block procedures.

The good performance of the two portfolio based methods reflects the fact that both these methods apportion capital more generously to those books that are most likely to exhibit extreme performance. At first sight, however, it is less obvious why the simplified portfolio approach appears to be as economical in its use of capital as the more sophisticated historical risk estimation procedure. Historical risk estimation can potentially identify betas that are non-standard, whereas the simplified portfolio approach presumes each share to have a beta of unity, implying a beta for the net books that is equal to the ratio of net to gross book value (see Dimson and Marsh, 1995). Similarly, historical risk estimation can potentially provide an estimate of residual risk that takes account of extramarket covariances amongst constituents of the book, whereas the simplified portfolio approach implicitly assumes that all residual risk arises from stock-specific variance.

In practice, however, even with a sixty-month estimation window, the beta and residual risk of the books is inevitably estimated with error. 23 Although superior procedures for forecasting short-term market volatility are available (eg, Dimson and Marsh, 1990) they still experience significant measurement error. The good showing of the simplified portfolio approach, which assumes all betas are one and all residual risks are identical, therefore serves as a warning against excessive complexity in forecasting methods. The simplified portfolio approach succeeds because noise does not adversely affect estimates of portfolio variability.

Whereas historical risk estimation introduces noise into estimates of a book's residual variance, measuring exposure as the net capital at risk ignores residual variance entirely. We show elsewhere that, relative to their net capital at risk, the trading books in our sample have an extremely high level of residual risk (see Dimson and Marsh, 1994), and this appears to be typical of equity trading books more generally. Since the net capital at risk approach specifies capital in proportion to the overall exposure of each book to the equity market, implicitly assuming perfect diversification of the book, the extremely poor performance of this method is entirely to be expected. Despite its obvious shortcomings, however, this approach is not entirely a straw man. We noted in Section I B that several proprietary risk management systems, designed to provide VaR estimates for global, multi-asset portfolios, treat investment in domestic equities as exposure to a single market index. Until software that follows this method is extended, eg by incorporating the simplified portfolio model into the algorithm, we conclude that all users concerned with equity market risk should avoid adopting this approach to setting equity position risk requirements.

[23] See Dimson and Marsh (1983) for an indication of the measurement error associated with risk measures for equities traded on the London Stock Exchange.

C. The Performance of the Comprehensive Approach

One remaining puzzle about the results reported in Table II is that the comprehensive approach, despite its manifest inadequacies, proves to be the best performing method in around one quarter of the periods examined. Closer scrutiny of Table II reveals that, although the comprehensive approach often requires the least capital, this occurs only when the period is one in which the market index increases. In a declining market, the comprehensive approach always requires more capital than the simplified portfolio approach.

The reason for this pattern merits some explanation. As noted above, the comprehensive approach fails to take adequate account of the net exposure of trading books, as well as ignoring entirely the extent of diversification of positions in the books. On average, therefore, the comprehensive approach requires more capital to provide a given degree of protection. But in terms of effectiveness, the comprehensive approach is a directional strategy for setting capital standards. When market makers tend to run more long positions than short ones, the comprehensive approach provides better protection against upward than against downward movements in the market.

To see why this is the case, imagine that our sample were to contain only net long books, but that the books range from unbalanced, all long books, through to almost balanced books, where the value of the long positions just marginally exceeds the value of the shorts. The degree of balance, measured as the ratio of a book's net value to its gross value, would thus range from + 100 per cent down to zero. The betas of the net positions in these books will range from one for a typical all long book down to zero for the balanced books.

Portfolio based approaches for setting capital requirements demand more capital for the books with the highest market risk, namely unbalanced, all long books, and less for balanced books, since the market risk of the short positions will tend to offset that of the longs. In contrast, the comprehensive approach (in its pure form, ignoring offsets) takes no account of risk, and allocates the same capital to all books, regardless of their degree of balance.

Capital requirements are set *ex ante,* when it is unclear whether the market will rise or fall. *Ex post,* however, in a period when the market rose, we would expect, on average, to find that all-long books with a beta of one would rise in line with the market, while balanced, zero beta books would experience no market-related rise. Books are almost never perfectly diversified, so, even in rising markets, net long books can suffer losses. Losses are most like] y to occur in balanced books, since these do not benefit from the market rise. For books experiencing losses, there will thus be a negative correlation between these losses, and the capital demanded by portfolio-based approaches. For the comprehensive approach, there will be zero correlation, but this nevertheless gives it an advantage.

If regulators are keen to ensure zero (or infrequent) defaults, then λ_{mt} needs to be set so that it provides sufficient capital for the balanced books. But if the portfolio-based approaches provide sufficient capital for the balanced books, this means that, *ex post,* in up-markets, they are over-providing for the all long books. Since the comprehensive method demands similar capital for both types of book, it avoids this over-provision. Note that this advantage which the comprehensive approach enjoys relates solely to market risk. The portfolio-based approaches overcome part of this market risk disadvantage by taking account of diversification, which the comprehensive method ignores.

Still focusing just on market risk, the opposite reasoning applies to periods when the market falls. The capital requirements set by portfolio-based approaches would then be positively correlated with the ex post losses on the books, leading to superior performance versus the comprehensive approach. Similarly, if the sample consisted solely of net short, rather than long books, the position would be reversed, and the comprehensive approach would then tend to perform better in down- rather than up-markets, and vice versa.

Finally, if the sample of books spanned the full distribution of net short, balanced, and net long books, the portfolio-based approaches should tend to perform best in both down- and up-markets. With a full-range sample, the books likely to perform worst in down- and up-markets would be those which were closest to being all-long and all-short respectively, rather than the balanced books "in the middle". The worst performing books would thus tend to be those with the highest market risk. This would be recognised by the portfolio-based methods in terms of higher capital requirements. For the books exhibiting losses, there would thus be a positive correlation between the books' losses, and the portfolio-based capital requirements, leading to superior performance relative to the comprehensive method.

This analysis helps to explain the results obtained for the sample of books examined in this study. As noted above, the results summarised in Table II show that the comprehensive method performs best in a quarter of the periods examined, but only when the period is one where the market rose substantially. This would be consistent with a sample comprising net long books. Even in up-markets, however, the comprehensive approach is by no means the unequivocal winner. In the 37 up-market periods in our sample, the portfolio-based approaches are best in almost as many cases as the comprehensive method (15 versus 16).

There are two reasons for this. First, although the portfolio-based approaches may be disadvantaged with respect to net long books during up-markets in terms of the market risk adjustment, they do make allowances for residual risk, which the comprehensive method ignores (see above). Second, while our sample is certainly biased towards net long books, it also contains net short books. Roughly a quarter of the books (15 out of 58) are broadly balanced with net to gross value ratios ranging from -20 to +20 per cent; seven books are appreciably net short, with ratios ranging from -20 to -56 per cent, and averaging -35 per cent); and the remaining 36 books (nearly two thirds of the sample) are net long, with ratios ranging from +20 to +94 per cent, and averaging +53 per cent.

To confirm this explanation, we conducted three experiments. First, we switched the signs on every holding in the net short books to convert them to net long books, and then reran our analysis. This conversion to a sample of books that are all net long leads to a slightly improved showing for the comprehensive method, with "wins" in 19 (rather than 16) periods, all of them up-markets. Second, we switch the signs on every holding in the net long books to convert them to net short books. The results for this all net short book sample shows 13 "wins" for the comprehensive method, 12 of which are in down-markets (as we would expect), out of the 24 down-markets examined.

Finally, we switch the signs on all the holdings in a random selection of net long books to convert them to net short books, to ensure that the overall sample represents a symmetric distribution of net short and long books. As predicted, the comprehensive method now performs poorly in nearly every period. It is the best method in just two of the 61 periods examined, and in all other periods, is dominated by the two portfolio-based methods.

It is clear, therefore, that the comprehensive approach can provide satisfactory protection against a crash only when the market makers, as a whole, run books that are more likely to be net short than long - an unusual scenario. In practice, however, the proponents of the comprehensive approach - notably the US Securities and Exchange Commission - focus exclusively on the performance of alternative capital adequacy regimes for net long books during intervals when the market falls. Since they assert that the comprehensive approach is a superior procedure to protect against a sudden crash in security prices, it is especially important to note that this method has the potential to work satisfactorily only during a sudden increase in prices - ie, during a frenzy, rather than a crash.

D. The Overall Performance of the Five Methods

For each method of setting requirements, our analysis reveals the level of capital which can provide full cross-sectional cover in every period. By examining the period-by-period results summarised in Table II we can, for each method, identify the largest capital requirement across all periods. For historical risk estimation, the highest requirement occurred in period 12, when capital amounting to 9.75 per cent of the gross value of the books (see Table II) would have been needed to ensure no books defaulted. Thus for the historical risk estimation approach, this represents the capital required to ensure full coverage in every period.

The capital required by the simplified portfolio approach to provide full cover in every period was similar, but slightly lower at 8.80 per cent, with the highest requirement occurring in period 26 (not shown in Table II). For both the building-block and comprehensive approaches, the maximum occurred in period 50, and the requirements for these two methods were much higher than for the two portfolio based approaches at 17.48 and 20.80 per cent respective y (see Table II). In contrast to all four of these methods, however, if requirements were set using net capital at risk as the measure of exposure, this method would have required no less than 292.3 per cent of the gross value of the books (for period 59, not shown in Table II), in order to cover the capital needs of every book in every period. 24

These results are summarised in the last column of Panel A in Table III. The penultimate column shows the corresponding capital requirements needed to provide full coverage of all books in all periods but one, ie, for some 98 per cent of the periods of market stress. For the simplified portfolio and historical risk estimation procedures to cover all periods but one, capital would need to have been 8.5 and 8.1 per cent respectively. For the building-block approach, capital of 12.4 per cent would have covered all periods but one, and for the comprehensive approach a level of 13.3 per cent would have reached this standard. For the net capital at risk method, the figure remains at a very high level of 274 per cent. 25 The

[24] If the target were less demanding, these capital requirements could, of course, be lower. For example, if the intention were to cover all books but one in each period, this could have been achieved with levels of capital of 72.8, 18.8, 14.3, 7.6 and 7.1 per cent for the net capital at risk, comprehensive, building block, simplified portfolio, and historical risk estimation procedures, respectively.

[25] To cover all books but one, in every period but one, the capital requirements would need to have been 29.8, 11.7, 11.7, 7.6 and 6.8 per cent respectively. Using a wide variety of definitions of adequate cross-sectional cover, and of the proportion of periods with adequate cover, the comprehensive and building block approaches proved inferior to (had larger requirements than) the two portfolio based approaches, and the net capital at risk method was systematically the worst.

two remaining columns of Panel A in Table III show the corresponding results for full coverage of all books in 95 and 90 per cent of the periods (all but three, and all but six) respectively. The rankings remain unchanged, with the two portfolio based, VaR-type approaches requiring similar amounts of capital, but considerably less than the two regulatory approaches, and with the net capital at risk approach requiring orders of magnitude more capital, and proving unequivocally the worst method.

Table III

Trade-off Between Capital and Proportion of Periods with Full Cover

Panel A: Capital required to achieve various coverage levels

Method	Capital (as % of gross value of books) required to achieve full coverage in the following % of periods:			
	90	95	98	100
Net capital at risk	196.2	207.3	274.4	292.3
Comprehensive	8.6	10.3	13.3	20.8
Building-block	8.0	10.0	12.4	17.5
Simplified portfolio	5.9	7.4	8.5	8.8
Historical risk estimation	5.5	7.0	8.1	9.8

Panel B: Cover achieved for a given level of capital

Method	Coverage level (% of periods when all books are fully covered) for the following capital requirements (% of gross value):			
	8	10	15	20
Net capital at risk	5	7	14	23
Comprehensive	82	93	98	98
Building-block	88	93	98	100
Simplified portfolio	97	100	100	100
Historical risk estimation	97	100	100	100

Panel A of Table III shows the capital required by each method to achieve various coverage levels. Panel B summarises the period-by-period results in a slightly different way, and shows the coverage levels achieved for a given level of capital. The four columns of Panel B correspond to capital levels of 8, 10, 15 and 20 per cent of the gross value of the books. Each of these columns shows the percentage of periods in which all books would have been covered by each of the five methods if capital of that amount had been posted.

Looking first at the rightmost column of Panel B, this shows that capital of 20 per cent would have been sufficient to provide full coverage in 100 per cent of the periods examined for the building-block, simplified portfolio and historical risk estimation methods. This is confirmed by the corresponding (100 per cent coverage) column of Panel A which shows that the capital required to achieve full coverage was 17.5, 8.8 and 9.8 per cent respectively for these three methods. This indicates that the two portfolio based methods will continue to provide full coverage in 100 per cent of the periods at the 15 and 10 per cent capital levels, but not with 8 per cent, and this is confirmed in Panel B. The building-block approach, however, provides only 98 per cent coverage (all but one period) with 15 per cent capital (see Panel B), since Panel A shows that it would require 17.5 per cent capital for full coverage.

Panel B once again confirms that the net capital at risk approach performs very poorly, and shows that, even with 20 per cent capital, it provides full coverage in only 23 per cent of the periods examined. Panel B also reaffirms the superior performance of the portfolio based, VaR-type approaches, showing that they provide full coverage of all books in all periods of market stress with capital levels as low as 10 per cent. In contrast, of the two regulatory approaches, the comprehensive method fails to provide full cover even with 20 per cent capital, while the building-block approach requires 17.5 per cent. With capital of 8 per cent, a figure often used as a benchmark by regulators, Panel B shows that the only methods that provide potentially acceptable coverage are the two portfolio approaches.

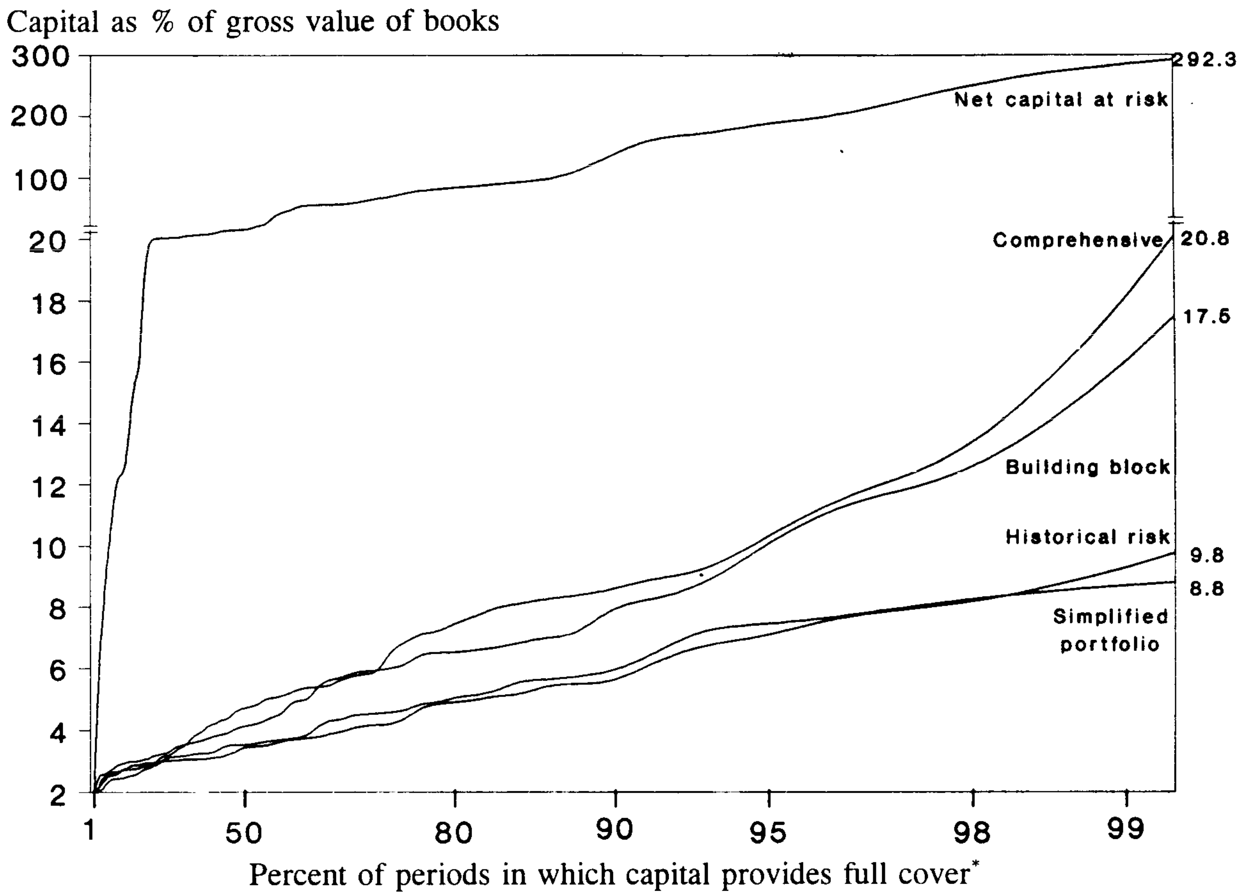
Figure 3 displays this information graphically for all five methods. On the horizontal axis we show the percentage of periods of market stress in which capital provides full cover for all books in the sample. On the vertical axis we show the average level of capital that must be maintained over all periods in order to achieve the chosen level of cover. The figures at the right-hand side of the graph show the levels of capital required to achieve full coverage in all periods, and these are the same figures as those reported in the rightmost column of Panel A of Table III.

Clearly, the methods that use capital most efficiently will plot lower on this graph. Figure 3 shows that for all levels of coverage in which regulators might be interested, the two portfolio based approaches plot lower, and hence dominate, the two regulatory methods (as well as net capital at risk). Regardless of whether one starts (as in Panel A of Table III) with a target level of coverage over time (thereby inferring capital requirements) or (as in Panel B of Table III) a target level of capital (thereby inferring coverage over time), the two portfolio based approaches are preferable. They provide better cover for all possible capital requirements.[26] We can see no justification for persisting with the two regulatory approaches (either the comprehensive or building-block methods) for the purposes of setting equity capital standards.

[26] A counter-argument that has been put to us is that the comprehensive approach, in particular, has more potential to cover very large market crashes, of a magnitude larger than any of those summarised in Figure 1 above. As noted previously in footnote 14, we also construct a schedule of the largest market movements over intervals as long as ten days, giving rise to market returns of -18.5 percent (starting on 19 October 1987) and of -12.1 per cent (starting on 5 October 1987). The comprehensive and building block approaches remain dominated over these long periods as well. For example, over these lengthier periods, the capital required to provide full cross-sectional cover over all periods but one is 20.98 and 17.48 per cent for the comprehensive and building block approaches, and 11.38 and 11.42 per cent for the simplified portfolio and historical risk estimation procedures (for the net capital at risk method, the capital requirement is 338 per cent),

Figure 3: Tradeoff Between Capital and Proportion of Periods With Full Cover

This graph illustrates the tradeoff, for each method of specifying capital requirements, between the level of capital and the proportion of periods in which all books are fully covered. For any given level of coverage, the lowest capital is required by either the simplified portfolio approach [5] or the historical risk estimation procedure [6]. More capital is required by the building-block [4] and comprehensive [3] approaches. The net capital at risk method [2] requires an unacceptably high level of capital for all levels of coverage. For any given level of capital, the net capital at risk method provides the worst coverage, the comprehensive and building block methods are also poor, and the simplified portfolio and historical risk procedures provide the best coverage.



*Reverse log scale

V. Conclusion

In this study, we analyse the performance of competing methods for determining capital requirements. The methods include the two most frequently used regulatory methods - the comprehensive and building-block approaches; and two portfolio based, VaR-type methods. We have also, as a reference point, analysed the impact of simply setting requirements as a proportion of the value of the net capital at risk. This can be viewed either as a simplified regulatory approach, or a naive VaR model. To compare the alternative systems, we have examined their effectiveness in setting capital requirements for a large sample of equity market makers' trading books over intervals in which the equity market moved sharply up or down, focusing on 61 periods of market stress from 1985 to 1995.

Our conclusions are as follows. The comprehensive approach, as used by the US Securities and Exchange Commission, makes the poorest use of capital employed. For a given level of regulatory capital, it exposes market makers to the greatest level of systemic risk. The European Union's building-block approach also fails to generate requirements that adequately reflect the diversification of trading books. It is also an imprudent approach to estimating capital requirements, and provides perverse incentives for equity market makers.

Only the two portfolio based, VaR-type approaches provide acceptable estimates of the capital required for undiversified trading books. Use of these methods should be encouraged, both as a part of the framework for setting regulatory capital standards and as components of good risk management systems. The results of our study confirm that the Basle Committee's (1996) decision to encourage the use of banks' own (portfolio-based) VaR models is, in principle, correct.

Finally, the net capital at risk method, which can be viewed as a misspecification or misapplication of the VaR-type approach, proves to be by far the worst method examined. Our results thus also lend support to the Basle Committee's proposal that there should be stringent quality control of internal risk models.

REFERENCES

Allen M. 1994. Building a role model. *Risk 7(9): 73-77*

Bank of England. 1995. *Implementation in the United Kingdom of the Capital Adequacy Directive.* Bank of England, London

Basle Committee on Banking Supervision. 1996. Overview *of the Amendment to the Capital Accord to Incorporate Market Risk.* Bank for International Settlements, Basle. January

Board of Banking Supervision. 1995. *Report of the Inquiry into the Circumstances of the Collapse of Barings.* Her Majesty's Stationery Office, London, 18 July

Brailsford T J and R W Faff. 1993. Modelling Australian stock market volatility. *Australian Journal of Management* 18(2): 109-131

Bralver C and A Kuritzkes. 1993. Risk adjusted performance measurement in the trading room. *Journal of Applied Corporate Finance 6(3): 104-108*

Brenner M. 1979. The sensitivity of the efficient market hypothesis to alternative specifications of the market model. *Journal of Finance 34(4): 915-29*

Brown S J and J B Warner. 1980. Measuring security price performance. *Journal of Financial Economics 8(3): 205-58*

Brown S J and J B Warner. 1985. Using daily stock returns: the case of event studies. *Journal of Financial Economics 14(1): 3-31*

Corrigan E G and J G Heimann. 1995. *Framework for Voluntary Oversight.* Derivatives Policy Group. March

Culp C L and M H Miller. 1995. Metallgesellschaft and the economics of synthetic storage. *Journal of Applied Corporate Finance 7(4): 62-76*

Dale R and S Wolfe. 1996. EU capital requirements and the level playing field. Working paper AMS 96-111, University of Southampton

Dimson E and P R Marsh. 1983. The stability of UK risk measures and the problem of thin trading. *Journal of Finance 38, 753-783*

Dimson E and P R Marsh. 1990. Volatility forecasting without data-snooping. *Journal of Banking and Finance* 14, 399-421

Dimson E and P R Marsh. 1994. *The Debate on International Capital Requirements.* City Research Project Report 8. Corporation of London

Dimson E and P R Marsh. 1995. Capital requirements for securities firms. *Journal of Finance* 50(3): 821-851

European Commission. 1993. Council directive on the capital adequacy of investment firms and credit institutions. *Official Journal of the European Communities* L 141: 1-26

Field P. 1995. Greenspan gets to the point. *Risk 8(4): 7-9*

Guldimann T. 1995. *RiskMetrics Technical Document,* Third edition. Morgan Guarantee Trust Company, New York

Hirtle. 1992. Equity risk simulation results. Mimeo, Federal Reserve Bank of New York. January 15

Irving R. 1995. Country in crisis. *Risk* 8(3): 27-33

Jackson P, Maude D J and W Perraudin. 1996. Value-at-risk analysis and the proposed Basle Accord amendment. In Schachter B (ed) *Derivatives. Regulation and Banking.* Elsevier-North Holland

Lawrence C and G Robinson. 1995. How safe is RiskMetrics? *Risk* 8(l): 26-29

Levitt A. 1994. Testimony Before the Subcommittee on Telecommunications and Finance of the Committee on Energy and Commerce: US House of Representatives. Securities and Exchange Commission, Washington DC. May 25

London Investment Banking Association. 1995. *LIBA CAD Guide.* June: 1-64

Longerstaey J and P Zangari. 1995. A transparent tool. *Risk* 8(l): 30-32

Merton, R C. 1995. Financial innovation and the management and regulation of financial institutions. *Journal of Banking and Finance 19(3): 461-482*

Merton R C and A F Perold. 1993. Theory of risk capital in financial firms. *Journal of Applied Corporate Finance* 6(3): 16-32

Peston R and T Corigan. 1992. Breedon opposes IOSCO capital standard. *The Financial Times.* October 30

Phelan M J. 1995. Probability and statistics applied to the practice of financial risk management: the case of JP Morgan's RiskMetrics. Working paper 95-19. Wharton Financial Institutions Center, University of Pennsylvania

Reed N. 1995. Backstage mover. *Risk 8(2): 49-50*

Schwartz S L and Ziemba W T. 1991. The Japanese stock market: 1949-91. In Ziemba W T, Bailey W and Hamao Y (eds), *Japanese Financial Market Research.* Elsevier-North Holland

Securities and Futures Authority. 1992. *Board notice No 71: New financial rules.* The Securities and Futures Authority, London

Securities and Futures Authority. 1995. *Board notice No 249: Implementation by SFA of the EC Capital Adequacy Directive.* The Securities and Futures Authority, London

Sharpe W F. 1963. A simplified model for portfolio analysis. *Management Science 9:277-293*

Siegel J. 1994. *Stocks for the Long Run.* Irwin, New York