This module should be read in conjunction with the Introduction and with the Glossary, which contains an explanation of abbreviations and other terms used in this Manual. If reading on-line, click on blue underlined headings to activate hyperlinks to the relevant module.

Purpose

To prescribe the standards and criteria that the HKMA will use in assessing AIs' eligibility for adopting the internal models approach to the measurement of market risk for the purpose of capital adequacy

Classification

A technical note issued by the MA

Previous guidelines superseded

Technical paper "Use of Internal Models to Measure Market Risk" dated October 1997[1]

Application

To locally incorporated AIs which use internal models to measure market risk for capital adequacy purposes

Structure

[1] The HKMA only issued the technical paper to AIs intending to adopt the internal models approach.

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1. Introduction

1.1 Terminology

1.1.1 For the purpose of this module:

- "VAR" means value-at-risk; and
- "market risk" means the risk of losses in on- and off-balance sheet positions arising from movements in market prices.

1.1.2 Market risk capital charges are expressed in terms of two separately calculated charges, covering:

- "general market risk" of the portfolio that captures the risk of loss arising from changes in general market risk factors such as interest rates, exchange rates, equity prices and commodity prices (see section 3 for details); and
- "specific risk" of each trading book position in interest rate and equity related instruments that captures the risk of adverse movement in the price of these instruments owing to factors related to individual issuers (see section 5 for details).

1.2 General criteria

1.2.1 CA-G-2 "Maintenance of Adequate Capital against Market Risk" sets out the HKMA's framework for determining the adequacy of capital to support potential losses arising from market risk. The use of internal models is one of the approaches allowed for calculating market risk.

1.2.2 The internal models approach specified in this module is based on the use of VAR techniques. The use of this approach for capital adequacy purposes is subject to the prior approval of the HKMA.

1.2.3 The HKMA will only give its approval if at a minimum:

- it is satisfied that the AI's risk management system is conceptually sound and is implemented with integrity;
- the AI has in the HKMA's view a sufficient number of staff skilled in the use of sophisticated models not only in the trading area but also in the risk control, audit and back office areas;
- the AI's models have in the HKMA's judgement a proven track record of reasonable accuracy in measuring risk; and
- the AI complies with all relevant requirements detailed in sections 2 to 10 below.

1.2.4 The HKMA may insist on a period of initial monitoring and live testing of an AI's internal model before it is used for capital adequacy purposes. AIs that wish to use their internal models should be prepared to participate in testing exercises to provide the HKMA with any additional information it may require to satisfy itself with the adequacy of the model.

2. Qualitative standards

2.1 General

2.1.1 AIs that use a model-based approach to measure market risk for the purpose of capital adequacy need to comply with the qualitative criteria set out in this section. The extent to which they meet these may influence the level at which the HKMA will set the multiplication factor in

subsection 4.4 below. Only AIs whose models comply fully will be eligible for application of the minimum multiplication factor.

2.2 Board and senior management oversight

2.2.1 The Board of Directors and senior management should be actively involved in the risk control process and should regard risk control as an essential aspect of the business to which significant resources need to be devoted. In this regard, the daily reports prepared by the independent risk control unit (see subsection 2.3 below) should be reviewed by senior management and relevant business managers. Besides, the Board should be provided with regular reports on the level of market risk exposure and the performance of the internal risk measurement model (say on a quarterly basis).

2.3 Independent risk control unit

2.3.1 AIs using internal models should have a risk control unit which is independent from business trading units and reports directly to senior management of an AI. This unit should be responsible for:

- designing and implementing the AI's risk management system;
- producing and analysing daily reports on the output of the AI's risk measurement model, including an evaluation of the relationship between measures of risk exposure and trading limits; and
- conducting a regular, at least quarterly, back-testing programme, i.e. an ex-post comparison of the risk measures generated by the model against actual daily changes in portfolio value over time as well as hypothetical changes in portfolio value based on static positions[2].

2.4 Risk measurement system

2.4.1 The internal risk measurement model should be closely integrated into the day-to-day risk management process of the AI. Its output should accordingly be an integral

[2] This assumes that end-of-day positions remain unchanged during the holding period (say one day).

part of the process of planning, monitoring and controlling the AI's market risk profile.

2.4.2 The risk measurement system should be used in conjunction with internal trading and exposure limits. In this regard, trading limits should be related to the AI's risk measurement model in a manner that is consistent over time and that is well understood by both traders and senior management.

2.4.3 A regular and rigorous programme of stress-testing should be in place as a supplement to the risk analysis based on the day-to-day output of the AI's risk measurement model (see section 10 below for more details). The results of stress-testing should be reviewed regularly by senior management and periodically by the Board of Directors. Such results should also be reflected in the policies set by senior management and the Board of Directors. Where stress tests reveal particular vulnerability to a given set of circumstances, prompt steps should be taken to manage those risks appropriately (e.g. by hedging against that outcome or reducing the size of the AI's exposures).

2.5 Compliance and documentation

2.5.1 AIs should have a system in place for ensuring compliance with a documented set of internal policies, controls and procedures concerning the operation of the risk measurement system. The AI's risk measurement system should be well documented, for example, through a risk management manual that describes the basic principles of the risk management system and that provides an explanation of the empirical techniques used to measure market risk.

2.6 Internal validation

2.6.1 An independent review of the risk measurement system should be carried out in the AI's regular internal auditing process. This review should include the activities of both the business trading units and the independent risk control unit. A review of the overall risk management process should take place at regular intervals (ideally not less than once a year) and should specifically address, at a minimum:

- the adequacy of the documentation of the risk management system and process;
- the organisation of the risk control unit;
- the integration of market risk measures into daily risk management;
- the approval process for risk pricing models and valuation systems used by front- and back-office personnel;
- the validation of any significant change in the risk measurement process;
- the scope of market risk captured by the risk measurement model;
- the integrity of the management information system;
- the accuracy and completeness of position data;
- the verification of the consistency, timeliness and reliability of data sources used to run internal models, including the independence of such data sources;
- the accuracy and appropriateness of volatility and correlation assumptions;
- the accuracy of valuation and risk transformation calculations; and
- the verification of the model's accuracy through frequent reviews of back-testing results as described in subsection 7.2 below.

3. Specification of general market risk factors

3.1 General

3.1.1 The risk factors contained in a market risk measurement system, i.e. the market rates and prices that affect the value of an AI's trading positions, should be sufficient to capture the risks inherent in both the on- and off-balance sheet trading positions of the AI. Although AIs will have some discretion in specifying the risk factors for their internal models, the following should be met.

3.2 For interest rates

3.2.1 There should be a set of risk factors corresponding to interest rates in each currency in which the AI has significant interest rate sensitive on- or off-balance sheet positions[3].

3.2.2 The risk measurement system should model the yield curve using one of a number of generally accepted approaches, e.g. by estimating the forward rates of zero coupon yields. The yield curve should be divided into various maturity segments in order to capture variations in the volatility of rates along the yield curve. There will typically be one risk factor corresponding to each maturity segment (e.g. one month, three months, six months, one year, etc).

3.2.3 For material exposures to interest rate movements in the major currencies and markets, AIs should model the yield curve using a minimum of six risk factors. The number of risk factors used, however, should ultimately be driven by the nature of the AI's trading strategies. For instance, if an AI engages in complex arbitrage strategies or if its portfolio comprises various types of securities across many points of the yield curve, a greater number of risk factors would be required to capture interest rate risk accurately.

3.2.4 The risk measurement system should incorporate separate risk factors to capture spread risk (e.g. between bonds and swaps). A variety of approaches may be used to capture the spread risk arising from less than perfectly correlated movements between government and other fixed-income interest rates, such as specifying a completely separate yield curve for non-government fixed-income instruments (e.g. swaps or municipal securities) or estimating the spread over government rates at various points along the yield curve.

[3] AIs should have a set of risk factors for each currency accounting for 5% or more of their trading book exposures.

3.3 For exchange rates (including gold)

3.3.1 Since the VAR figure calculated by the risk measurement system will be expressed in Hong Kong dollars, any net position denominated in a foreign currency will give rise to foreign exchange risk. The risk measurement system should thus incorporate risk factors corresponding to the exchange rate between Hong Kong dollar and each foreign currency in which the AI has a significant exposure.

3.4 For equity prices

3.4.1 There should be risk factors corresponding to each of the equity markets in which the AI holds significant positions.

3.4.2 At a minimum, there should be a risk factor that is designed to capture market-wide movements in equity prices (e.g. a market index). Positions in individual securities or in sector indices can be expressed in "beta equivalents"[4] relative to this market-wide index.

3.4.3 A more detailed approach would be to have risk factors corresponding to various sectors of the overall equity market (for instance, industry sectors or cyclical and non-cyclical sectors). As above, positions in individual stocks within each sector can be expressed in beta equivalents relative to the sector index.

3.4.4 The most thorough approach would be to have risk factors corresponding to the volatility of individual equity issues.

3.4.5 The sophistication and nature of the modelling technique for a given market should correspond to the AI's exposure to the overall market as well as its concentration on individual equity issues in that market.

3.5 For commodity prices

3.5.1 There should be risk factors corresponding to each of the commodity markets in which the AI holds significant positions.

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[4] A "beta equivalent" position would be calculated from a market model of equity price returns (such as the CAPM model) by regressing the return on the individual stock or sector index on the risk-free rate of return and the return on the market index.

3.5.2 For relatively limited positions in commodity-based instruments, a straightforward specification of risk factors would be acceptable. Such a specification would probably entail one risk factor for each commodity price. In cases where the aggregate positions are quite small, it might be acceptable to use a single risk factor for a relatively broad sub-category of commodities (e.g. a single risk factor for all types of oil).

3.5.3 For more active trading the model should encompass:

- directional risk to capture the exposure from changes in spot prices arising from net open positions;
- forward gap and interest rate risk to capture the exposure to changes in forward prices arising from maturity mismatches; and
- basis risk to capture the exposure to changes in the price relationships between two similar but not identical commodities.

3.5.4 For more active trading, the model should also take account of variation in the "convenience yield"[5] between derivative positions such as forwards and swaps and cash positions in the commodity.

4. Quantitative standards

4.1 General

4.1.1 AIs have flexibility in devising the precise nature of their models but the following minimum standards will apply for the purpose of calculating their capital charges using the VAR approach.

4.2 Minimum standards

4.2.1 VAR should be computed on a daily basis.

4.2.2 In calculating VAR, a 99th percentile, one-tailed confidence interval is to be used.

[5] The convenience yield reflects the benefits from direct ownership of the physical commodity (for example, the ability to profit from temporary market shortages) and is affected both by market conditions and by factors such as physical costs.

4.2.3 In calculating VAR, an instantaneous price shock equivalent to a ten-day movement in prices is to be used, i.e. the minimum holding period will be ten trading days. AIs may use VAR numbers calculated according to shorter holding periods scaled up to ten days by the square root of time (for the treatment of options, see also para. 4.2.8 below).

4.2.4 The choice of historical observation period (sample period) for calculating VAR will be constrained to a minimum length of one year. For AIs that use a weighting scheme or other methods for the historical observation period, the effective observation period should be at least one year, i.e. the weighted average time lag of the individual observations cannot be less than six months. The HKMA may also require an AI to calculate its VAR using a shorter observation period if, in the judgement of the HKMA, this is justified by a significant upsurge in price volatility.

4.2.5 AIs should update their data sets at least once every three months and should also reassess them whenever market prices are subject to material changes.

4.2.6 No particular type of model is prescribed. AIs will be free to use models based, for example, on variance-covariance matrices, historical simulations or Monte Carlo simulations as long as the models capture all material risks run by the AIs.

4.2.7 AIs will have discretion to recognise empirical correlations within broad risk categories, e.g. interest rates, exchange rates, equity prices and commodity prices, including related options volatilities in each risk factor category, provided that the HKMA is satisfied that the AI's system for measuring correlations is sound and implemented with integrity.

4.2.8 AIs' models should capture accurately the unique risks associated with options within each of the broad risk categories. The following criteria apply to the measurement of options risk:

- AIs' models should capture the non-linear price characteristics of options positions, e.g. volatility risk and gamma risk;
- AIs are expected to move ultimately towards the application of a full ten-day price shock to options

positions or positions that display option-like characteristics. In the interim, the HKMA may require AIs to adjust their capital measure for options risk through other methods, e.g. periodic simulations or stress-testing; and

- each AI's risk measurement system should have a set of risk factors that captures the volatilities of the rates and prices underlying option positions, i.e. vega risk. AIs with relatively large or complex options portfolios should have detailed specifications of the relevant volatilities. This means that AIs should measure the volatilities of options positions broken down by different maturities.

4.3 Daily capital requirement

4.3.1 Each AI should meet, on a daily basis, a capital requirement expressed as the higher of:

- an average of the daily VAR measures on each of the preceding 60 business days, multiplied by a multiplication factor; and
- its previous day's VAR number measured according to the parameters specified in this section.

4.4 Multiplication factor

4.4.1 The multiplication factor will be set by the HKMA on the basis of its assessment of the quality of the AI's risk management system (see section 2 above), subject to an absolute minimum of three. In addition, AIs will be required to add to this factor a "plus factor" directly related to the ex-post performance of the model. The plus factor will range from zero to one based on the outcome of back-testing. If the back-testing results are satisfactory and the AI meets all of the qualitative standards set out in section 2 above, the plus factor could be zero. Sections 7 and 8 present in detail the approach to be applied for back-testing and the plus factor. There is a separate multiplication factor for the modelling of specific risk, the requirements of which are set out in section 5 below.

5. Treatment of specific risk

5.1 General

5.1.1 This section explains the manner in which the specific risk capital charge is to be calculated under the internal models approach.

5.1.2 AIs using internal models will be permitted to base their specific risk capital charge on modelled estimates if they meet all of the qualitative and quantitative requirements for general risk models as well as the additional criteria set out below.

5.1.3 AIs which are unable to meet these additional criteria will be required to base their specific risk capital charge on the full amount of such charge calculated under the standardised approach.

5.2 Criteria

5.2.1 The criteria for applying modelled estimates of specific risk require that an AI's model:

- explains the historical price variation in the portfolio[6];
- demonstrably captures concentration (magnitude and changes in composition)[7];
- be robust to an adverse environment[8]; and

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[6] The key ex-ante measures of model quality are "goodness-of-fit" measures which address the question of how much of the historical variation in price value is explained by the model. One measure of this type which can often be used is an R-squared measure from regression methodology. If this measure is to be used, the AI's model would be expected to be able to explain a high percentage, such as 90%, of the historical price variation or to include explicitly estimates of the residual variability not captured in the factors included in this regression. For some types of models, it may not be feasible to calculate a goodness-of-fit measure. In such cases the AI is expected to work with the HKMA to define an acceptable alternative measure which would meet this regulatory objective.

[7] The AI would be expected to demonstrate that the model is sensitive to changes in portfolio construction and that higher capital charges are required for portfolios that have increasing concentrations.

[8] The AI should be able to demonstrate that the model will signal rising risk in an adverse environment. This could be achieved by incorporating in the historical estimation period of the model at least one full credit cycle and ensuring that the model would not have been inaccurate in the downward portion of the cycle. Another approach for demonstrating this is through simulation of historical or plausible worst-case environments.

- be validated through back-testing aimed at assessing whether specific risk is being captured accurately.

5.2.2 In addition, the AI should be able to demonstrate that it has methodologies in place which allow it to capture event and default risk adequately for its traded debt and equity positions.

5.3 Surcharge

5.3.1 AIs which meet the criteria set out above for models but do not have methodologies in place to capture event and default risk adequately will be required to calculate their specific risk capital charge based on the internal model measurements plus an additional prudential surcharge as defined in the following paragraph.

5.3.2 For AIs applying the surcharge, the total market risk capital requirement will equal a minimum of three times the internal model's general and specific risk measure plus a surcharge of either:

- the specific risk portion of the VAR measure which should be isolated according to supervisory guidelines[9]; or, at the AI's option,

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[9] Techniques for separating general market risk and specific risk would include the following:

Equities

- The market should be identified with a single factor that is representative of the market as a whole, for example, a widely-accepted, broadly-based stock index for the country concerned.
- AIs that use factor models may assign one factor of their model, or a single linear combination of factors, as their general market risk factor.

Bonds

- The market should be identified with a reference curve for the currency concerned. For example, the curve might be a government bond yield curve or a swap curve; in any case, the curve should be based on a well-established and liquid underlying market and should be accepted by the market as a reference curve for the currency concerned.
- AIs may select their own technique for identifying the specific risk component of the VAR measure for purposes of applying the multiplier of four. Techniques would include:
  - using the incremental increase in VAR arising from the modelling of specific risk factors;
  - using the difference between the VAR measure and a measure calculated by substituting each individual equity position by a representative index; or
  - using an analytic separation between general market risk and specific risk implied by a particular model.

- the VAR measures of sub-portfolios of debt and equity positions that contain specific risk[10].

5.3.3 AIs using the second option under para. 5.3.2 above are required to identify their sub-portfolio structure ahead of time and should not change it without the HKMA's consent.

5.3.4 The surcharge is designed to treat the modelling of specific risk on the same basis as a general market risk model that has proven deficient during back-testing. That is, the equivalent of a multiplication factor of four would apply to the estimate of specific risk until such time as an AI can demonstrate that the methodologies it uses capture event and default risk adequately. Once an AI is able to demonstrate this, the minimum multiplication factor of three can be applied. However, a higher multiplication factor of four on the modelling of specific risk would remain possible, if future back-testing results were to indicate a serious deficiency within the model.

5.4 Back-testing requirement

5.4.1 AIs which apply modelled estimates of specific risk are required to conduct back-testing aimed at assessing whether specific risk is being captured accurately.

5.4.2 The methodology an AI should use for validating its specific risk estimates is to perform separate back tests on sub-portfolios using daily data on sub-portfolios subject to specific risk. The key sub-portfolios for this purpose are traded debt and equity positions. If, however, an AI itself separates its trading portfolio into finer categories (e.g. emerging markets, traded corporate debt), it is appropriate to keep these distinctions for sub-portfolio back-testing purposes.

5.4.3 An AI is required to commit to a sub-portfolio structure and to use it consistently unless it demonstrates to the HKMA that there is good reason to change the structure.

5.5 Exception analysis

5.5.1 AIs are required to have in place a process to analyse exceptions identified through the back-testing of specific

[10] This would apply to sub-portfolios containing positions that would be subject to specific risk under the standardised approach.

risk. This process is intended to serve as the fundamental way in which AIs correct their models of specific risk in the event they become inaccurate.

5.5.2 There will be a presumption that models which incorporate specific risk are "unacceptable" if the results at the sub-portfolio level produce a number of exceptions commensurate with the "red zone" as defined in section 8 below. AIs with "unacceptable" specific risk models are expected to take prompt action to correct the problem in the model and to ensure that there is a sufficient capital buffer to absorb the risk that the specific risk models could not adequately capture.

6. Model review

6.1 Acceptance criteria

6.1.1 In reviewing an AI's internal model, the HKMA will require assurance that:

- the internal validation process described in subsection 2.6 above is operating in a satisfactory manner;
- the formulae used in the calculation process as well as for the pricing of options and other complex instruments are validated by a qualified unit, which should be independent from the trading area;
- the structure of the internal model is appropriate with regard to the AI's portfolio;
- the model provides a reliable measure of potential losses over time by reviewing the results of the AI's back tests, i.e. comparing VAR measures with actual profits and losses of the AI's portfolio; and
- data flows and processes associated with the model are transparent and accessible. In particular, it is essential that the HKMA should have easy access, whenever it considers it necessary, to the model's specifications and parameters.

6.2 Portfolio testing

6.2.1 From time to time the HKMA may require AIs to participate in a portfolio testing exercise. Such an exercise may typically involve AIs using internal models to calculate the capital charge on test portfolios determined by the HKMA.

6.2.2 The purpose of the exercise is to determine the degree of consistency between AIs.

6.2.3 The results of such exercises may be taken into account in determining the reliability of an internal model used for measuring potential losses.

6.3 Recognition of models

6.3.1 The model review process will entail an on-site visit before a model is recognised as acceptable for calculating the market risk capital charge.

6.3.2 After the initial recognition of models by the HKMA, AIs should inform the HKMA of any subsequent material change to their models, including any material change in methodology or scope to cover new products and instruments. The HKMA will determine whether the models remain acceptable for calculating the market risk capital charge.

7. The use of back-testing

7.1 General

7.1.1 This section presents the framework for incorporating back-testing into the internal models approach to market risk capital requirements, while section 8 relates to the supervisory interpretation of the back-testing results and sets out the HKMA's standards in this regard.

7.1.2 The process whereby daily profits and losses are compared with model-generated risk measures to gauge the quality and accuracy of a risk measurement system is known as back-testing. As a technique for evaluating the quality of an AI's risk measurement model, back-testing continues to evolve. New approaches to back-testing are still being developed and discussed within the risk management community. At present, different AIs perform different types of back-testing comparisons and

the standards of interpretation also differ somewhat across AIs.

7.1.3 The essence of back-testing is the comparison of actual trading results with model-generated risk measures. If this comparison reveals limited differences, the back test raises no issue regarding the quality of the risk measurement model. In some cases, however, the comparison may uncover a great number of or significant differences, indicating likely problems with the model or with the assumptions of the back test. Between these two cases is a grey area where the test results are, on their own, inconclusive.

7.1.4 In considering how to incorporate back-testing more closely into the internal models approach to market risk capital requirements, the HKMA acknowledges both the fact that the industry has not yet settled on a single back-testing methodology and that there are concerns over the imperfect nature of the signal generated by back-testing.

7.2 Description of the back-testing framework

7.2.1 Back-testing programmes consist of a periodic comparison of an AI's daily VAR measures with the subsequent daily profit or loss ("trading outcome"). The VAR measures are intended to be larger than all but a certain fraction of the trading outcomes, where that fraction is determined by the confidence level of the VAR measure. Comparing the risk measures with the trading outcomes means that the AI counts the number of times the risk measures were larger than the trading outcome. The fraction actually covered can then be compared with the intended level of coverage to gauge the performance of the AI's risk model.

7.2.2 The back tests to be applied for capital adequacy purposes will compare whether the observed percentage of outcomes covered by the risk measure is consistent with a 99% level of confidence. That is, they attempt to determine if an AI's 99th percentile risk measures truly cover 99% of the AI's trading outcomes.

7.2.3 The back-testing framework requires the comparison of daily trading outcomes with a VAR measure based on a one-day holding period. This differs from the requirement set out in subsection 4.3 above. This

requirement reduces the contamination arising from changes in portfolio composition during the holding period which is reflected in actual profit and loss outcomes but not in VAR measures, which assume a static portfolio.

7.2.4 The same concerns about contamination of the trading outcomes continue to be relevant, however, even for one-day trading outcomes. A more sophisticated approach would involve a detailed attribution of profit and loss outcomes by source, including fees, spreads, market movements and intra-day trading results. In such a case the VAR measures can then be compared with the outcomes arising from market movements alone.

7.2.5 To the extent that the back-testing programme is viewed purely as a statistical test of the integrity of the calculation of the VAR measure, it is more appropriate to employ a definition of daily trading outcome that allows for an uncontaminated test. To meet this standard, AIs should develop the capability to perform back tests based on the hypothetical changes in portfolio value that would occur assuming that end-of-day positions remain unchanged during the holding period (say one day).

7.2.6 The HKMA encourages AIs to develop the capability to perform back tests using both hypothetical and actual trading outcomes. Each approach has its own value. In combination, the two approaches are likely to provide a strong understanding of the relation between calculated risk measures and trading outcomes.

7.2.7 The back-testing framework to be applied entails formal testing and accounting of exceptions on a quarterly basis using the most recent 12 months of data. The framework adopted by the HKMA is to count the number of times that the trading outcomes are not covered by the risk measures ("exceptions"). For example, over 200 trading days, a 99% daily risk measure should cover, on average, 198 of the 200 trading outcomes, leaving two exceptions. Using the most recent 12 months of data yields approximately 250 daily observations for the purposes of back-testing. The HKMA will use the number of exceptions (out of a sample of 250) generated by an AI's model as the basis for a supervisory response, which in serious cases means that the HKMA will consider imposing an increase in the AI's capital

requirement or disallowing use of the model (see sections 8 and 9 for more details).

7.2.8 The formal implementation of the back-testing programme should begin on the date that the internal models for measuring market risk became effective. This implies that the first formal accounting of exceptions under the back-testing programme would occur a year later. This does not preclude the HKMA from requesting back-testing results prior to that date and in particular does not preclude their usage as part of the approval process for internal models.

7.2.9 After a model is recognised for use by an AI, the HKMA will monitor its back-testing results on a continuing basis through information provided in the quarterly "Return of Market Risk Exposures – MA(BS)3A" ("Market Risk Return").

8. The interpretation of back-testing results

8.1 Three zone approach

8.1.1 With the statistical limitations of back-testing in mind the HKMA has established a framework for the supervisory interpretation of back-testing results that encompasses a range of possible responses, depending on the strength of the signal generated from the back test. These responses are classified into three zones, distinguished by colours into a hierarchy of responses.

8.1.2 The green zone corresponds to back-testing results that do not suggest a problem with the quality or accuracy of an AI's model.

8.1.3 The yellow zone encompasses results that raise questions in this regard but where such a conclusion is not definitive. The back-testing results could be consistent with either accurate or inaccurate models. In such cases the HKMA will require the AI to present additional information about its models.

8.1.4 The red zone indicates a back-testing result that almost certainly indicates a problem with an AI's risk model and the HKMA will require some actions to be initiated.

8.1.5 The table in subsection 8.5 below sets out the boundaries for these zones and the presumptive

supervisory response for each back-testing outcome, based on a sample of 250 observations. Where back-testing indicates weaknesses in an AI's model the minimum multiplication factor (see subsection 4.4 above) of three will be increased. This increment is referred to below as the "plus factor".

8.2 Green zone

8.2.1 This comprises the range of zero to four exceptions.

8.2.2 Since a model that truly provides 99% coverage would be quite likely to produce as many as four exceptions in a sample of 250 outcomes, there is little reason for concern raised by back-testing results that fall in this range.

8.2.3 In such a case, the minimum multiplication factor of three will be applied to the VAR outcome, provided that the AI has met all the qualitative criteria.

8.3 Yellow zone

8.3.1 The range from five to nine exceptions constitutes the yellow zone.

8.3.2 Outcomes in this range are plausible for both accurate and inaccurate models, although they are generally more likely for inaccurate models than for accurate models. Moreover, the presumption that the model is inaccurate should grow as the number of exceptions increases in the range from five to nine.

8.3.3 Within the yellow zone, the number of exceptions should generally guide the size of potential supervisory increases in an AI's capital requirement.

8.3.4 The table in subsection 8.5 below sets out the guidelines for increases in the multiplication factor applicable to the internal models capital requirement resulting from back-testing results falling in the yellow zone.

8.3.5 It should be stressed, however, that these increases are not meant to be purely automatic. Results in the yellow zone do not always imply an inaccurate model and the HKMA will not penalise AIs solely for bad luck. Nevertheless, to keep the incentives aligned properly, it can generally be presumed that back-testing results in the yellow zone would attract an increase in the

multiplication factor unless the AI can demonstrate that such an increase is not warranted. This means the burden of proof that the model is fundamentally sound rests with the AI concerned.

8.3.6 In such a situation, there are many different types of additional information that might be relevant to an assessment of the AI's model. For example, it would then be particularly valuable to see the results of back tests covering disaggregated sub-sets of the positions. AIs that engage in regular back-testing programmes may break up their trading activities into units organised around risk factors or product categories. Disaggregating in this way could allow the tracking of a problem that surfaced at the aggregate level back to its source at the level of a specific trading unit or risk model.

8.3.7 AIs should document all of the exceptions generated from their continuing back-testing programme, including an explanation for the exceptions. This documentation is important for determining an appropriate supervisory response to back-testing results falling in the yellow zone. AIs may also implement back-testing for confidence intervals other than the 99th percentile or may perform other statistical tests not considered here. This information could also prove very helpful in assessing their model.

8.3.8 In practice, there are several possible explanations for a back-testing exception:

- the basic integrity of the model;
- an under-specified or low quality model;
- poor intra-day trading results; or
- pure bad luck.

Classifying the exceptions generated by an AI's model into these categories can be a very useful exercise, as discussed in section 9 below.

8.4 Red zone

8.4.1 The red zone encompasses ten or more exceptions.

8.4.2 In contrast to the yellow zone, where the HKMA may exercise judgement in interpreting the back-testing results, outcomes in the red zone should generally lead

to a presumption that a problem exists with an AI's model. It is extremely unlikely that an accurate model would independently generate ten or more exceptions from a sample of 250 trading outcomes.

8.4.3 In general, therefore, if an AI's model falls into the red zone, the HKMA will increase the multiplication factor applicable to its model by one from three to four.

8.4.4 The HKMA will also investigate through on-site examination why the AI's model produced such a large number of exceptions and require the AI to begin work on improving its model immediately. In the case of a severe problem with the basic integrity of the model, the HKMA may disallow the use of the model for capital purposes.

8.4.5 Although ten exceptions is a very high number for 250 observations, there will on very rare occasions be a valid reason for an accurate model to produce so many exceptions. In particular, when financial markets are subject to a major regime shift, many volatilities and correlations can be expected to shift as well, perhaps substantially. An AI is expected to update its volatility and correlation estimates very promptly in this situation, otherwise such a regime shift could generate a number of exceptions in a short period of time. In essence, however, these exceptions would all be occurring for the same reason and therefore the appropriate supervisory reaction might not be the same as when there were ten exceptions but each from a separate incident. One possible supervisory response in this instance would be simply to require the AI's model to take account of the regime shift as quickly as it can while maintaining the integrity of its procedures for updating the model.

8.4.6 It should be stressed, however, that this exception should be allowed only under the most extraordinary circumstances. The HKMA will generally increase an AI's capital requirement for back-testing results that fall into the red zone.

8.5 Plus factor for back-testing exceptions

Zone	Number of exceptions	Plus Factor
Green zone	0	0.00
	1	0.00
	2	0.00
	3	0.00
	4	0.00
Yellow zone	5	0.40
	6	0.50
	7	0.65
	8	0.75
	9	0.85
Red zone	10 or more	1.00

9. Classification of exceptions

9.1 Reasons for exceptions

9.1.1 Exceptions will normally fall into the following categories:

- the basic integrity of the model is flawed;
- its accuracy needs improving;
- markets have moved in a fashion unanticipated by the model;
- intra-day trading.

9.1.2 Samples of exceptions arising from flawed integrity of the model could be that:

- the AI's systems are not capturing the risk of the positions, e.g. the positions are being reported incorrectly; or
- model volatilities or correlations are calculated incorrectly, e.g. the computer erroneously calculates daily model volatilities on a 280-day basis when it should be on a 250-day basis.

9.1.3 An example of an inaccuracy in a model that could cause exceptions would be that the risk measurement model is not assessing the risk of some instruments with sufficient precision, e.g. too few maturity buckets or a spread omitted.

9.1.4 Sample reasons for exceptions resulting from unanticipated market movements could be:

- markets moved by more than the model predicted was likely, i.e. volatility was significantly higher than expected;
- markets did not move together as expected, i.e. correlations were significantly different than was assumed by the model; or
- a very low probability event occurred.

9.1.5 Intra-day trading can cause exceptions, e.g. there was a large (and money losing) change in the positions or some other income events between the end of the first day, when the risk estimate was calculated, and the end of the second day, when trading results were tabulated.

9.2 Discussion of categories

9.2.1 In general, problems relating to the basic integrity of the risk measurement model are potentially the most serious. If exceptions are attributable to this category for a particular trading unit, the plus factor should apply. In addition, the model may be in need of substantial review or adjustment. The HKMA may disallow the use of internal models altogether until appropriate corrections are undertaken by the AI.

9.2.2 The second category of problem, lack of model precision, can be expected to occur at least part of the time with most risk measurement models. No model can hope to achieve infinite precision as all models involve some amount of approximation. If, however, a particular AI's model appears more prone to this type of problem than others, the HKMA will impose the plus factor and will also consider other incentives to encourage improvement.

9.2.3 The third category of problem, unanticipated market movements, should also be expected to occur at least some of the time with VAR models. Even an accurate

model cannot be expected to cover 100% of trading outcomes. Some exceptions will be the random 1% that the model can be expected not to cover. In other cases, the behaviour of the markets may shift so that previous estimates of volatility and correlation are no longer reliable. No VAR model will be immune from this type of problem; it is inherent in the reliance on past market behaviour as a means of gauging the risk of future market movements. Exceptions for such reasons do not suggest a problem. If, however, the shifts in volatilities and correlations are deemed to be permanent, the HKMA may require the AI to recalculate its VAR using volatilities and correlations based on a shorter observation period.

9.2.4 Depending on the definition of trading outcomes employed for the purpose of back-testing, exceptions could also be generated by intra-day trading results or an unusual event in trading income other than from the trading outcomes of the AI's positions. Although exceptions arising from these reasons may not necessarily suggest a problem with the VAR model, they could still be causes for concern. The imposition of the plus factor would be considered.

9.2.5 Another consideration is the extent to which a trading outcome exceeds the risk measure. With all other things being equal, exceptions generated by trading outcomes far in excess of the risk measure are of greater concern than those outcomes which are only slightly larger than the risk measure.

9.3 Consideration of factors by the HKMA

9.3.1 In deciding whether to apply increases in an AI's capital requirement, the HKMA will weigh these factors in addition to an appraisal of the AI's compliance with applicable qualitative standards of risk management. Based on the additional information provided by the AI, the HKMA will decide on the appropriate course of action.

9.3.2 In general, the imposition of a higher capital requirement for outcomes in the yellow zone is an appropriate response if the HKMA believes the reason for being in the yellow zone is a problem in an AI's model which can be corrected. This can be contrasted with the case of an

unexpected bout of high market volatility, which nearly all models may fail to predict. Exceptions due to extremely high market volatility do not necessarily indicate that an AI's risk model is in need of redesign.

9.3.3 In the case of severe problems with the basic integrity of the model, the HKMA will consider whether to disallow the use of the model for capital purposes altogether.

10. Stress-testing

10.1 General

10.1.1 AIs that use the internal models approach for calculating market risk capital requirements should have in place a rigorous and comprehensive stress-testing programme. Stress-testing is to identify events or influences that could greatly impact an AI and is a key component of the assessment of the adequacy of an AI's capital position. This module should be read in conjunction with IC-5 "Stress-testing"[11] that provides guidance on the use of stress tests for risk management purposes.

10.1.2 AIs' stress scenarios need to cover a range of factors that can create extraordinary losses or gains in trading portfolios, or make the control of risk in those portfolios very difficult. These factors include low-probability events in all major types of risks, including the various components of market, credit, and operational risks. Stress scenarios need to shed light on the impact of such events on positions that display both linear and non-linear price characteristics (i.e. options and instruments that have options-like characteristics).

10.1.3 AIs' stress tests should be both of a quantitative and qualitative nature. Quantitative criteria should identify plausible stress scenarios to which AIs could be exposed. Qualitative criteria should emphasise that two major goals of stress-testing are to evaluate the capacity of the AI's capital to absorb potential large losses and to identify steps the AI can take to reduce its risk and conserve capital. This assessment is integral to setting and evaluating the AI's management strategy. The results of stress-testing should therefore be routinely

[11] Module under industry consultation.

communicated to senior management and, periodically, to the Board of Directors.

10.1.4 In addition, the stress tests should incorporate both market risk and liquidity aspects of market disturbances. For example, AIs may not be able to unwind some positions quickly during a crisis situation and the values of these positions may be very volatile. Such considerations are particularly important for positions in emerging markets.

10.1.5 AIs should combine the use of supervisory stress scenarios with stress tests developed by AIs themselves to reflect their specific risk characteristics. Specifically, the HKMA may ask AIs to provide information on stress-testing in the three broad areas as discussed below.

10.2 Supervisory scenarios requiring no simulation by the AI

10.2.1 AIs should provide the HKMA with information on the five largest daily losses experienced during each quarter. The results are reported in the Market Risk Return.

10.2.2 This loss information can be compared to the level of capital and the corresponding VAR measures that result from the AI's internal measurement system. This information will help provide the HKMA with a picture of how many days of peak day losses would have been covered by the corresponding VAR measures.

10.3 Supervisory scenarios requiring simulation by the AI

10.3.1 AIs should subject their portfolios to a series of simulated stress scenarios and provide the HKMA with the results quarterly. These scenarios could include testing the current portfolio against past periods of significant disturbance, such as the 1987 equity crash, the ERM crises of 1992 and 1993, the fall in bond markets in the first quarter of 1994, the Mexican crisis at the end of 1994, or the Asian crisis of 1997 and 1998, incorporating both the large price movements and the sharp reduction in liquidity associated with these events.

10.3.2 A second type of scenario would evaluate the sensitivity of the AI's market risk exposure to changes in the assumptions about volatilities and correlations. Applying this test would require an evaluation of the historical

range of variation for volatilities and correlations and evaluation of the AI's current positions against the extreme values of the historical range. Due consideration should be given to the sharp variation that at times occurs in a matter of days in periods of significant market disturbance (e.g. like those mentioned in para. 10.3.1 above).

10.4 Scenarios developed by the AI

10.4.1 An AI should also develop its own stress tests which it identifies as exceptional but plausible events based on the characteristics of its portfolio (e.g. problems in a key region of the world combined with a sharp move in oil prices). AIs should provide the HKMA with a description of the methodology used to determine the scenarios as well as a summary of the results derived from these scenarios.

10.4.2 The results should be reviewed periodically by senior management and should be reflected in the policies set by senior management and the Board of Directors. Moreover, if the testing reveals particular vulnerability to a given set of circumstances, the HKMA would expect the AI to take prompt action to manage those risks appropriately (e.g. by hedging against that outcome or reducing the size of its exposures).