IS VALUE-AT-RISK (VAR) A FAIR PROXY FOR MARKET RISK UNDER CONDITIONS OF MARKET LEVERAGE?

Ex-Post Intraday Market Risk Extrema vs. Ex-Ante RiskMetrics™ VaR Limits For the British Pound, Japanese Yen, and Swiss Franc Futures Markets From September 1972 to September 2000:

Implications for the Internal Models Approach to Risk-Based Capital Allocation Requirements and Portfolio Risk Management and Performance Assessment

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(ABSTRACT)

Ex-post intraday market-risk extrema are compared with ex-ante standard RiskMetrics parametric Value-at-Risk (VaR) limits for three foreign currency futures markets (British Pound, Japanese Yen, Swiss Frank) to determine whether forecasted volatility of market returns based on settlement price data provides a valid proxy for short-term market risk independent of market leverage.

Intraday violations of ex-ante one-day VaR limits at the 95% confidence level should occur for less than 5% of market days. Violation frequencies for each of the markets tested are shown to occur well in excess of this 5% tolerance level: 9.54% for the British Pound, 7.09% for the Japanese Yen, and 7.79% for the Swiss Franc futures markets.

Thus, it is empirically demonstrated that VaR is a poor proxy for short-term market risk under conditions of market leverage.

Implications for managing (measuring, monitoring, controlling), reporting, and regulating financial market risk are discussed.

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I thank Dr. Thomas Lutton for his support and encouragement throughout the course of this thesis; his guidance and comments not only helped to motivate my interest in the statistical foundations of econometric time-series forecasting, but also helped to clarify my understanding of the gap between the conventionally accepted Value-at-Risk model (VaR) and actual market risk exposure under conditions of leverage.

I thank Dr. Nancy Wentzler for providing invaluable references to the regulatory literature, specifically that regarding the regulation of financial markets and the role of internal-models based approaches to risk management and capital adequacy standards.

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Finally, I thank Elaine W. Lang, my wife, and Abigail W. Lang, my daughter, for their abundant love and patience. The joy they bring to my life has contributed greatly to my ability and motivation to complete this work.

DEDICATION

This thesis is dedicated to my parents:

To my late father,
Grover William Lang,
the greatest man I have known.

And

To my mother,
Beverly Morgan Lang,
a model of courage, love, and wisdom.

TABLE OF CONTENTS

SECTION 1. INTRODUCTION

> *modern times and the past is mastery of risk: the notion that the future is more than a whim of the gods and that men and women are not passive before nature."* [1]
>
> Peter L. Bernstein

Financial market regulation strives to promote economic stability of the international and domestic financial architecture in a way that allows for future economic growth without stifling current financial innovation. Financial market regulators are, therefore, primarily concerned with macro-threats to the financial architecture, namely risks that pose a systemic threat and/or the potential for contagion.

Such risks are typically classified as market, credit, liquidity, legal, operational, or reputational. Although each is relevant to market stability, the use of highly-leveraged derivatives instruments and the globalization of financial markets have made market risk, in particular, a primary concern for regulators and market participants. This concern has led to globally accepted regulations, standards, and methodologies for measuring, monitoring, controlling, and reporting market risk.

The models or methodologies for measuring market risk fall into two basic categories: Value-at-Risk (VaR) models and stress testing or scenario analysis. Value-at-Risk models can be further classified as parametric and non-parametric. Parametric VaR, or more commonly VaR, is the most widely accepted and least complex implementation of VaR; it has also become synonymous with VaR in the literature. At present, J.P. Morgan's standard RiskMetrics™, a parametric VaR model, has become the pre-eminent international standard for measuring market risk.

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[1] Bernstein, Peter L. *Against the Gods: The Remarkable Story of Risk.* (New York: John Wiley & Sons, Inc., 1996), 1.

Standard VaR is defined as the maximum financial loss that a given market position can be expected to suffer over a one-day time horizon with a confidence level of ninety-five percent.

In its current form, VaR is linearly proportional to a forecast of volatility based on historical settlement prices. VaR is, therefore, implicitly assumed to be independent of intraday price extremes and, therefore, market leverage. This assumption may be fatally flawed since leveraged market positions are not immune to market risk extrema posed by intraday price excursions.

Individuals and institutions trading leveraged market positions (i.e. trading on margin) are subject to margin calls based on the instantaneous (mark-to-market) value of the leveraged market positions. If a margin call is given and not met, either voluntary or forced liquidation of position(s) is required by financial market regulations. Quite often such liquidation occurs at or near an intraday price extreme.

Thus, the conventionally accepted measure of market risk may not capture the actual market risk posed to leveraged market positions since settlement data may substantially underestimate the actual market risk posed to leveraged market positions by intraday price extrema. Therefore, the current standard of Value-at-Risk may not be a valid proxy for actual market risk under conditions of leverage and intraday violations of VaR limits would occur more frequently than expected.

Such an occurrence would have far-reaching implications:

- The very models proposed to limit market risk introduced by leveraged instruments may substantially understate the actual market risk involved and, thereby, diminish the effectiveness of market regulation, supervision, and transparency.
- Portfolio risk and performance assessment metrics may differ under conditions of active vs. passive investment strategies as well as conditions of market leverage.
- The Efficient Market Hypothesis (EMH) may not be valid for short-term time frames.

This thesis attempts to answer the question: "Is VaR a fair proxy for short-term market risk under conditions of market leverage?"

Section 2 gives a more detailed version of this introduction with appropriate references.

Section 3 provides a formal definition and derivation of the standard RiskMetrics^{TM} model for computing one-day VaR limits at the 95% confidence level. This section also highlights the assumptions underlying the standard RiskMetrics^{TM} model.

Section 4 discusses the procedure used to empirically backtest standard RiskMetrics on the British Pound, Japanese Yen, and Swiss Franc futures. This section further discusses the data used to backtest the model as well as the results obtained.

Section 5 offers conclusions and gives a summary of the implications of the results of this work.

Section 6 presents recommendations for further study.

SECTION 2. BACKGROUND

> *"'[O]ur knowledge of the way things work, in society or in nature, comes trailing clouds of vagueness. Vast ills have followed a belief in certainty.'"* [2]
>
> Kenneth Arrow

2.1 Risk

Risk and uncertainty lie at the heart of most human endeavors. Of several possible meanings attributed to "risk" by The American Heritage College Dictionary, the two most pertinent to this work are:[3]

- "The possibility of suffering harm or loss; danger."
- "The variability of returns from an investment."

The glossary of the well-known and respected textbook Investments (Bodie, Kane, and Marcus) defines risky- and risk-free assets as:[4]

- "Risky asset. An asset with an uncertain rate of return."
- "Risk-free asset. An asset with a certain rate of return; often

Risk represents uncertainty in the outcome of a random event, uncertainty in the exact value that a random variable will assume at some specific time in the future. Thus, risk is a byproduct of inherent uncertainty and is present even if a well-defined probability distribution for the random variable can be constructed.

As stated above risk is also defined as the potential for realizing a loss. Risk, therefore, represents a potential cost; a cost that must be weighed against the potential for realizing a gain. This idea of risk-adjusted return lies at the core of modern portfolio management and performance assessment.

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[2]Bernstein, 7.
[3] *The American Heritage College Dictionary, 3rd ed.* (Boston: Houghton Mifflin Company, 1997).
[4] Bodie, Zvi, Alex Kane, Alan J. Marcus. *Investments, 4th ed.* (Boston: McGraw-Hill, 1999). 939.

Although individuals, with different utilities for risk and reward may make different decisions when faced with the same probability distributions for potential risk and reward[5,6,7], institutional agents require preference-independent metrics in order to objectively manage (measure, monitor, control), report, and regulate risk.[8] These metrics must be as applicable to portfolios of investments as they are to the individual portfolio components.[9] The general methodology for developing such risk metrics is to define risk as linearly proportional to forecasted variability or dispersion (standard deviation) of investment returns about the expected return and the cost of risk as linearly proportional to the forecasted variance of returns.[10]

2.2 Financial Markets: Change and Crises[11,12]

In the last decade, revolutionary changes in financial markets (e.g. "the growing importance of capital markets in credit intermediation, the emergence of markets for intermediating risk, changes in the activities and risk profiles of financial institutions, and the increasingly global nature of financial intermediation"[13]) have taken place "spurred largely by a technological revolution that has reduced the costs of information gathering, processing and transmission."[14]

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[5] Arrow, Kenneth J. *Essays in the Theory of Risk-Bearing.* (Chicago: Markham Publishing Company, 1971).
[6] Raiffa, H. *Decision Analysis: Introductory Lectures on Choices under Uncertainty* (Reading, Massachussetts: Addison-Wesley, 1968).
[7] Borch, Karl H. *The Economics of Uncertainty.* (Princeton, NJ: Princeton University Press), 1972.
[8] Grinold, Richard C. and Ronald N. Kahn. *Active Portfolio Management, 2nd ed.* (New York: McGraw-Hill, 2000), 42.
[9] Grinold, 42
[10] Grinold, 41.
[11] "Causes, Effects and Regulatory Implications of Financial and Economic Turbulence in Emerging Markets." Emerging Markets Committee of the International Organization of Securities Commissions, November 1999.
[12] Jordan, Jerry. "Financial Crisis and Market Regulation." www.frb.org.
[13] Hoenig, Thomas M. "Rethinking Financial Regulation." (Federal Reserve Bank of Minneapolis: www.minneapolisfed.org/pubs/region/96-12/hoenig.html: December 1996), 2.
[14] Hoenig, 1.

These rapid changes combined with recent incidents in the banking and financial markets (e.g. the U.S. Savings and Loan crisis, the downfall of Barings, the intervention by the U.S. Federal Reserve in the Long-Term Capital Asset Management meltdown, the Asian Crisis, the Russian Ruble devaluation, the Sumitomo Copper scandal, etc.) have led to concerns regarding the adequacy of the current regulatory framework to prevent and/or reduce the probability and magnitude of, and to contain, financial crises. Questions have also arisen regarding the risk management practices and principles currently implemented by individual financial market participants.

2.3 Financial Market Regulation[15,16,17,18,19,20]

One of the primary goals of financial market regulation is to promote financial market stability[21] without sacrificing market efficiency or stifling financial innovation.[22]

> "In an operational sense, this means that financial market disruptions should not have a significant impact on aggregate real economic activity. This definition suggests that the failure of an individual financial institution, even a large institution, should not be a concern unless it is allowed to propagate or become systemic. By itself, the failure of a single, large institution is unlikely to have a great effect on aggregate output because the total assets of even the largest financial firms account for only a small share of aggregate output. When Drexel, Burnham, Lambert failed in 1990, for example, there was no noticeable or lasting effect on economic activity. As we know from the banking panics of the late 1800s and early 1900s, however, failures that propagate through

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[15] Remarks by Laurence H. Meyer. (Cato Institute, Washington, D.C., 16th Annual Monetary Conference, Money in the New Millenium: The Global Financial Architecture, October 22, 1998.)
[16] "Strengthening the International Financial Architecture." (Cologne: Report of the G7 Finance Ministers to the Koln Economic Summit, June 18-20, 1999).
[17] "Objectives and Principles of Securities Regulation." International Organization of Securities Commissions, September 1998.
[18] "Hedge Funds and Other Highly Leveraged Institutions." Report of the Technical Committee of the International Organization of Securities Commissions, November 1999.
[19] "Supervisory Framework for Markets." Report of the Technical Committee of the International Organization of Securities Commissions, May 1999.
[20] "Core Principles Methodology." Basel Committee on Banking Supervision, October 1999.
[21] Hoenig, 4.
[22] See also Gibson, Rajna and Heinz Zimmermann. "The Benefits and Risks of Derivative Instruments: www.finance.wat.ch/GenevaPapers/paper1.htm)

> the financial system can have disastrous consequences for the real economy.
>
> The primary ingredients that make it possible for problems at a few institutions to spread to many are the use of extensive leverage by these institutions and their direct ties to the payment system. For example, the failure of a single bank could spread to other banks that have large credit exposures to the failing bank through clearinghouses and correspondent deposits. The failure of these banks, in turn, could spread to other institutions in a similar manner."[23]

At the most basic level, the regulatory framework required to foster market stability depends critically on the ability of financial market regulators, institutions, and participants to adequately measure, monitor, control, and report financial market risks. These risks traditionally include, but are not limited to, market or price risk, credit risk, liquidity risk, legal risk, operational risk, and reputational risk.[24]

2.4 Market Risk

> "The rise in proprietary trading, market-making, and active portfolio management has also dramatically altered the risk profiles of financial institutions. If used properly for portfolio management, new financial instruments can certainly reduce an institution's risk exposure and raise its profitability and viability in the financial marketplace. If used improperly, however, they expose the institution to sudden, extraordinary losses, raising the likelihood of failure. Moreover, the risks and opportunities for failure are often exacerbated by the leverage associated with the new activities and the larger numbers of players and greater degree of anonymity in financial markets. Increased trading activity, for example, has significantly increased the exposure of banks to market risk – the risk of loss due to changes in asset prices and the volatility of asset prices. Like traditional credit risk, market risk can lead to significant losses and ultimately to failure if not managed appropriately. In contrast to credit-related losses, which can take time to develop, losses due to market risk can occur quickly. The Barings failure is a prime example of how quickly a large exposure to market risk can cause an institution to fail

[23] Hoenig, 4.

[24] "Recommendations for Public Disclosure of Trading and Derivatives Activities of Banks and Securities Firms." (Transparency Group of the Basel Committee on Banking Supervision and Technical Committee of the International Organization of Securities Commissions (IOSCO): October 1999), 14-15.

> – the bulk of its net losses occurred over a two-week period, with one-fourth of the losses occurring on a single day."[25]

Recent market events have shown that market risk, propagated through prices in particular markets, currently poses a much greater threat of systemic market risk "than the undercapitalisation of any particular group of banks as was the case in the mid 1980's." [26]

2.5 Market Risk: Regulatory Framework[27,28]

In July of 1988, the Basle[29] Committee on Banking Supervision released a document entitled "International Convergence of Capital Measurement and Capital Standards"[30] which set forth an "agreement among the G-10 central banks to apply common minimum capital standards to their banking industries, to be achieved by end-year 1992."[31]

An "Amendment to the Capital Accord to Incorporate Market Risks," released in January 1996 and updated in April 1998, states that:

> "As from the end of 1997, or earlier if their supervisory authority so prescribes, banks will be required to measure and apply capital charges in respect of their market risks in addition to their credit risks. Market risk is defined as the risk of losses in on and off-balance-sheet positions arising from movements in market prices. The risks subject to this requirement are:

[25] Hoenig, 3.
[26] "Equity at Risk." (Executive Summary: www.bis.org).
[27] "Recognizing a Firm's Internal Market Risk Model for the Purposes of Calculating Required Regulatory Capital: Guidance to Supervisors." Report by the Technical Committee of the International Organization of Securities Commissions, May 1999.
[28] "Methodologies for Determining Minimum Capital Standards for Internationally Active Securities Firms Which Permit the Use of Models Under Prescribed Conditions." A Report by the Technical Committee of the International Organization of Securities Commissions, May 1998.
[29] Spelled "Basle" and "Basel" by equally reputable sources. In each case, I shall use the spelling I find most immediately appropriate.
[30] "International Convergence of Capital Measurement and Capital Standards." (Basle: Basle Committee on Banking Supervision, www.bis.org/publ/bcbs04a.htm July 1988).
[31] "International Convergence of Capital Measurement and Capital Standards." cover sheet.

- the risks pertaining to *interest rate-related instruments* and *equities* in the trading book*;*
- *foreign exchange risk* and *commodities risk* throughout the bank."[32]

The Amendment states further that capital charges must be based on the current (mark-to-market) value[33] of the items in the trading book and that banks would have a choice between two alternative methods for measuring market risk: a standard method based on a shorthand calculation or an internal models method based on a Value-at-Risk (VaR) calculation.[34]

The "Overview of the Amendment to the Capital Accord to Incorporate Market Risks"[35] states:

> "The objective in introducing this significant amendment to the Capital Accord is to provide an explicit capital cushion for the price risks to which banks are exposed, particularly those arising from their trading activities. Introducing the discipline that capital requirements impose is seen as an important further step in strengthening the soundness and stability of the international banking system and of financial markets generally. Also part of the Amendment and underpinning this is a set of strict qualitative standards for the risk management process which apply to banks basing their capital requirements on the results of internal models. The Committee sees these qualitative standards as reinforcing the continued efforts within the supervisory community to achieve improvements in risk management techniques across the full range of financial market participants."[36]

The "Core Principles Methodology," issued by the Basel Committee in October 1999, outlines recommendations for the effective implementation of the Core Principles of Effective Banking Supervision and reiterates the need for enhanced supervision of

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[32] "Amendment to the Capital Accord to Incorporate Market Risks." (Basle Committee on Banking Supervision, www.bis.org, January 1996, updated to April 1998), 1.
[33] "Amendment to the Capital Accord to Incorporate Market Risks.", 2.
[34] "Amendment to the Capital Accord to Incorporate Market Risks.", 3.
[35] "Overview of the Amendment to the Capital Accord to Incorporate Market Risks." (Basle Committee on Banking Supervision, www.bis.org, January 1996).
[36] "Overview of the Amendment to the Capital Accord to Incorporate Market Risks, 1.

banks, stressing the necessity for effectively measuring, monitoring, reporting, and controlling market-based risk.[37]

Also released in October 1999 by the Basle Committee on Banking Supervision and the Technical Committee of the International Organization of Securities Commissions (IOSCO) was the paper entitled "Recommendation for Public Disclosure of Trading and Derivatives Activities of Banks and Securities Firms"[38] which "presents recommendations for public disclosures of trading and derivatives activities of banks and securities firms."[39]

In addition, the Global Derivatives Study Group in "Derivatives: Practices and Principles," [40] states that "Market risk is best measured as 'value at risk' ".[41]

As a result of these regulatory publications and guidelines, Market Risk is increasingly being measured by financial market participants using a Value-at-Risk approach. Thus, tests of the validity of standard VaR models and the assumptions upon which they are based is important to both market participants and regulators.

2.6 Value-at-Risk (VaR)

> "Value at Risk (VaR) is that dollar amount such that the likelihood of experiencing a loss in the market value of a financial instrument or a portfolio of instruments in excess of that amount, due to an 'adverse change' in market risk factors over a specified 'risk horizon' is less than a specified 'tolerance level.'"[42]

Within the framework of these documents lies a potential contradiction. Standard parametric Value-at-Risk (VaR) models are based on a 1-day forecast of market volatility

[37] "Core Principles Methodology." (Basel: Basel Committee on Banking Supervision, www.bis.org, October 1999).
[38] "Recommendations for Public Disclosure of Trading and Derivatives Activities of Banks and Securities

[39] "Recommendations for Public Disclosure of Trading and Derivatives Activities of Banks and Securities

[40] "Derivatives: Practices and Principles." (Washington, D.C.: Group of Thirty, July 1993).
[41] "Derivatives: Practices and Principles.", 10.
[42] Schwartz, Robert J. and Clifford W. Smith, Jr., editors. Derivatives Handbook: Risk Management and Control. (New York: John Wiley & Sons)

computed from daily market settlement prices. On the other hand, individuals and institutions trading leveraged market positions (i.e. trading on margin) are subject to margin calls based on the instantaneous (mark-to-market) value of the leveraged market positions. If a margin call is given and not met, either voluntary or forced liquidation of position(s) is required by financial market regulations. Quite often such liquidation occurs at or near an intraday price extreme.

Thus, the conventionally accepted measure of market risk may not capture the actual market risk posed to leveraged market positions since settlement data may substantially underestimate the actual market risk posed to leveraged market positions by intraday price extrema. Therefore, the current standard of Value-at-Risk may not be a valid proxy for actual market risk under conditions of leverage and intraday violations of VaR limits would occur more frequently than expected.

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- Portfolio risk and performance assessment metrics may differ under conditions of active vs. passive investment strategies as well as conditions of market leverage.
- The Efficient Market Hypothesis (EMH) may not be valid for short-term time frames.

2.7 RiskMetrics VaR

In 1994, J. P. Morgan released "RiskMetrics™, a set of techniques and data to measure market risks in portfolios of fixed income instruments, equities, foreign exchange, commodities, and their derivatives issued in over 30 countries."[43] In 1998, RiskMetrics was spun off from J. P. Morgan. Since the release of RiskMetrics™ in 1994

[43] RiskMetrics Technical Document description, www.RiskMetrics.com.

and in tandem with sweeping regulatory changes (mentioned above), standard RiskMetrics^{TM}, or parametric VaR has become an internationally-accepted standard for measuring VaR.

Since RiskMetrics^{TM} represents a cornerstone of risk management theory and practice, it is important to test the assumptions upon which it is built in order to assess the applicability of RiskMetrics^{TM} in various situations. In the following sections, the standard RiskMetrics model and methodology for a single financial instrument will be defined, derived, and backtested on foreign currency futures historical data.

In what follows, RiskMetrics^{TM} and RiskMetrics will be used interchangeably.

SECTION 3. STANDARD RISKMETRICS (PARAMETRIC VAR)

"[R]isk is a choice rather than a fate."[44]

Peter L. Bernstein

3.1 Definition

"The standard RiskMetrics model assumes that returns follow a conditional normal distribution – conditional on the standard deviation – where the variance of returns is a function of the previous day's variance forecast and squared return."[45]

The standard RiskMetrics model, an econometric model for continuously-compounded financial-instrument returns, can be expressed mathematically as:

$$r_t = \sigma_t \cdot \varepsilon_t$$

$$\sigma_t^2 = \lambda \cdot \sigma_{t-1}^2 + (1 - \lambda) \cdot r_{t-1}^{\ 2}$$

Where:

r_t is the one-day return at time t

σ_t is the standard deviation of returns at time t

σ_t^2 is the variance of returns at time t

ε_t is a normally distributed random variable with mean = 0 and variance = 1

λ is the decay factor (set equal to 0.94 for 1-day time horizons).

3.2 Derivation

The following derivation is a condensed version of that found in the RiskMetrics Technical Document and uses the same mathematical notation found therein. Since this

[44] Bernstein, 8.
[45] RiskMetrics Technical Document, 236.

thesis is concerned with the methodology for determining VaR for a single financial instrument only, the following derivation ignores material concerning the temporal correlations between financial instruments within a portfolio.

3.2.1 Financial Returns

"RiskMetrics measures change in value of a portfolio (often referred to as the adverse price move) in terms of log price changes also known as continuously-compounded returns." [46]

Let P_t be the market settlement (closing) price of a given financial instrument for date t. Thus, P_{t-1} is the closing price for the same financial instrument on day t-1, one day prior to day t. The one-day percent return R_t, also called the one-day price change relative, is defined as:

$$R_t \equiv (P_t - P_{t-1}) / P_{t-1}$$

Thus:

$$P_t = (1 + R_t)\cdot P_{t-1}$$

Or:

$$P_t / P_{t-1} = 1 + R_t$$

Where $1 + R_t$ is the one-day gross return which can be converted to a continuously-compounded return as follows:

$$\exp(r_t) = 1 + R_t$$

[46] RiskMetrics Technical Document, 45.

Or:

$$
\begin{aligned}
r_t &= \ln(1 + R_t) \\
&= \ln(P_t / P_{t-1}) \\
&= \ln(P_t) - \ln(P_{t-1})
\end{aligned}
$$

Thus:

$$r_t = p_t - p_{t-1}$$

Where:

$$p_t = \ln(P_t)$$

Note: one of the primary reasons for working with returns rather than prices is their statistical properties; continuously-compounded returns are temporally additive. For example, the continuously-compounded return for a k-day period can be written as the sum of the k one-day returns:

$$
\begin{aligned}
r_t(k) &= \ln(P_t / P_{t-k}) \\
&= \ln[(P_t / P_{t-1})\cdot(P_{t-1} / P_{t-2})\cdot\ldots\cdot(P_{t-[k-1]} / P_{t-k})] \\
&= \ln(P_t / P_{t-1}) + \ln(P_{t-1} / P_{t-2}) + \ldots + \ln(P_{t-[k-1]} / P_{t-k}) \\
&= r_t + r_{t-1} + \ldots + r_{t-[k-1]}
\end{aligned}
$$

Or:

$$r_t(k) = \Sigma(r_{t-i})$$

where the summation over i runs from 0 to k-1.

Thus, “when 1-day returns are computed using r_t, then a model describing the distribution of 1-day returns extends straightforwardly to returns greater than one day.”[47]

3.2.2 Econometric Modeling: Financial Prices and Returns

> “A risk measurement model attempts to characterize the future change in a portfolio’s value. Often, it does so by making forecasts of each of a portfolio’s underlying instrument’s future price changes, using only past changes to construct these forecasts. This task of describing future price changes requires that we model the following; (1) the temporal dynamics of returns; i.e., model the evolution of returns over time, and (2) the distribution of returns at any point in time.”[48]

The derivation of the standard RiskMetrics econometric model starts with a random walk model of asset price dynamics. This model “applies naturally to assets such as foreign exchange rates, commodities, and equities where only one price exists per asset."[49]

The random walk model with drift is written mathematically as:

$$P_t = P_{t-1} + \mu + \sigma \cdot \varepsilon_t$$

$$\varepsilon_t \sim \mathit{IID}\ N(0,1)$$

Where:

μ = constant drift or change in prices over 1 time period

σ = standard deviation of the error term (scalar).

[47] RiskMetrics Technical Document, 49.
[48] RiskMetrics Technical Document, 49.
[49] RiskMetrics Technical Document, 50.

IID means identically and independently distributed and N(0,1) is a normal distribution with mean = 0 and variance = 1. Thus, "[t]he conditional distribution of P_t, given P_{t-1}, is normally distributed."[50]

The random-walk model in this form permits negative (nonsensical) prices. If, however, the random-walk model is applied to log prices, this problem disappears:

$$p_t = p_{t-1} + \mu + \sigma \cdot \varepsilon_t$$
$$\varepsilon_t \sim \textit{IID}\ \mathrm{N}(0,1)$$

Or in terms of returns:

$$r_t = p_t - p_{t-1} = \mu + \sigma \cdot \varepsilon_t$$
$$\varepsilon_t \sim \textit{IID}\ \mathrm{N}(0,1)$$

Thus, the new model for prices is:

$$\begin{aligned} r_t &= p_t - p_{t-1} \\ &= \ln(P_t) - \ln(P_{t-1}) \\ &= \ln(P_t / P_{t-1}) \\ &= \mu + \sigma \cdot \varepsilon_t \end{aligned}$$

So:

$$P_t / P_{t-1} = \exp(\mu + \sigma \cdot \varepsilon_t)$$

Or:

$$P_t = P_{t-1} \cdot \exp(\mu + \sigma \cdot \varepsilon_t)$$

---

[50] RiskMetrics Technical Document, 50

Where again:

$$\varepsilon_t \sim \mathit{IID}\ N(0,1)$$

Thus, "when ε_t is normally distributed, P_t follows a lognormal distribution."[51]

3.2.3 *Empirically-Motivated Modifications*

Historical price series for real world financial instruments exhibit volatility clustering, evidence of time-dependence of the variance of returns, also known as heteroscedasticity. The model is easily modified with the substitution:

$$\sigma \rightarrow \sigma_t$$

And the model becomes:

$$r_t = \mu + \sigma_t \cdot \varepsilon_t$$

$$\varepsilon_t \sim \mathit{IID}\ N(0,1)$$

RiskMetrics further assumes that $\mu = 0$ and the model simplifies to:

$$r_t = \sigma_t \cdot \varepsilon_t$$

$$\varepsilon_t \sim \mathit{IID}\ N(0,1)$$

Applying the Box-Ljung test statistic to the first order autocorrelation coefficient, RiskMetrics also finds that "while returns are not autocorrelated, their squares are [52] This, of course, implies autocorrelation of variances:

[51] RiskMetrics Technical Document, 50.
[52] RiskMetrics Technical Document, 59.

$$\sigma_t = E\{[r_t - E(r_t)]^2\}$$
$$= E[r_t^2 - 2 \cdot r_t \cdot E(r_t) + (E(r_t))^2]$$
$$= E(r_t^2) - 2 \cdot E(r_t) \cdot E(r_t) + (E(r_t))^2$$
$$= E(r_t^2) - (E(r_t))^2$$

According to Jorian[53], expected squared returns dominate squared expected returns by a factor of 700 to one on average. Therefore, expected returns are set equal to zero in the above formula:

$$\mu = E(r_t) = 0$$

Thus:

$$\sigma_t^2 = E(r_t^2)$$

Thus, RiskMetrics assumes that returns are distributed according to a conditional (time-dependent) normal distribution. Returns are not independently distributed because squared returns are autocorrelated and returns are not identically distributed because of the time-dependence of the variance.

So far, the RiskMetrics model can be written:

$$r_t = \sigma_t \cdot \varepsilon_t$$
$$\varepsilon_t \sim N(0,1)$$

Two other empirical observations are worth noting:

1) Distributions of financial returns display fat tails which means that extreme price movements occur more often than predicted by a normal distribution model.

[53] Jorion, Phillipe. "Predicting Volatility in the Foreign Exchange Market." Journal of Finance, 2, (June 1995), pp. 507-528.

2) The peak of the return distribution is higher and the distribution narrower than a normal distribution and is, therefore, a leptokurtotic distribution rather than a perfectly normal distribution.

These points aside, RiskMetrics assumes a normal distribution for returns.

3.2.4 Value-at-Risk (VaR)

Now since the distribution of returns is described by a time dependent normal distribution, it is possible to define a standardized variable (return) as:

$$z_t = (r_t - \mu_t) / \sigma_t$$

Which follows a standard normal distribution, N(0,1).

Thus,

$$\text{Probability}[z_t < -1.65] = 5\%$$

Or:

$$\text{Probability}[(r_t - \mu_t) / \sigma_t < -1.65] = 5\%$$

When $\mu_t = 0$, this becomes:

$$\text{Probability}[r_t < -1.65 \cdot \sigma_t] = 5\%$$

Which is the one-day (short-term time horizon) VaR calculation. Losses greater than r_t should occur less than 5% of the time, less than 5 out of every 100 market days. The RiskMetrics model of financial returns can be fully described by a single parameter, the standard deviation of returns, σ_t, more commonly referred to as volatility.

3.2.5 Forecasting Volatility

To forecast VaR, it is first necessary to forecast volatility. RiskMetrics forecasts volatility based on historical price data rather than volatility implied by options prices for practical reasons:

1) Since most option valuation models consider volatility homoscedastic, interpretation of implied volatility is not straightforward and is highly sensitive to the option valuation model specification.
2) Implied volatility is restricted to a fixed forecast horizon.
3) Implied volatility requires an observable and liquid options market for any financial instrument under discussion; such a market may not exist.

Recalling that:

$$\sigma_t^2 = E(r_t^2)$$

RiskMetrics forecasts future variance of returns as an exponentially weighted moving average of past squared returns:

$$\sigma_{1,t+1|t}^2 = \Sigma(\lambda^i \cdot r_{1,t-1}^2) / \Sigma\lambda^i$$

Where $\sigma_{1,t+1|t}$ is the one-day volatility forecast for time t+1 given information up to and including time t and $0 < \lambda < 1$ and here, and in what follows, the index i ranges from 0 to infinity.

Thus:

$$\Sigma\lambda^i = 1 / (1 - \lambda)$$

And:

$$\sigma_{1,t+1|t}^2 = (1 - \lambda)\cdot\Sigma(\lambda^i \cdot r_{1,t-1}^2)$$

So:

$$\sigma_{1,t+1|t}^2 = (1 - \lambda)\cdot\Sigma(\lambda^i \cdot r_{1,t-1}^2)$$
$$= (1 - \lambda)\cdot(r_{1,t}^2 + \lambda\cdot r_{1,t-1}^2 + \lambda^2\cdot r_{1,t-2}^2 + \dots)$$
$$= (1 - \lambda)\cdot r_{1,t}^2 + [\lambda\cdot(1 - \lambda)\cdot(r_{1,t-1}^2 + \lambda\cdot r_{1,t-2}^2 + \dots)]$$
$$= (1 - \lambda)\cdot r_{1,t}^2 + \lambda\cdot\sigma_{1,t|t-1}^2$$

And finally,

$$\sigma_{1,t+1|t} = [\lambda\cdot\sigma_{1,t|t-1}^2 + (1 - \lambda)\cdot r_{1,t}^2]^{1/2}$$

Note: in practice, the first iteration of this calculation requires a seed value for volatility.

Extrapolation of this 1-day result to a T-day forecast is accomplished as[54,55]:

$$\sigma_{1,t+T|t}^2 = T \cdot \sigma_{1,t+1|t}^2$$
$$\sigma_{1,t+T|t} = [T]^{1/2} \cdot \sigma_{1,t+1|t}$$

3.2.6 The Decay Factor

RiskMetrics determines the decay factor for one-day time horizons to be 0.94 which is shown, at the 1% confidence level, to be equivalent to including approximately 74 days in the calculation.[56] This is accomplished by minimizing the root mean squared error (between forecasted variance and ex-post variance) as a function of the decay factor for the 480+ time series that RiskMetrics tracks and weighting the results to determine

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[54] Hull, John. *Options, Futures, and Other Derivative Securities. 2nd ed.* (Englewood Cliffs, NJ: Prentice Hall,1993), 209-210.
[55] RiskMetrics Technical Document, 86 - 87.
[56] RiskMetrics Technical Document, 94, 97.

optimal decay factor.[57] This decay factor is then assumed to be appropriate for all price data series, independent of the specific market.

3.2.7 Model Specification

The standard RiskMetrics model, or simply, standard RiskMetrics, for a one-day time horizon can now be written:

$$r_t = \sigma_t \cdot \varepsilon_t \qquad \varepsilon_t \sim N(0,1)$$

$$\sigma_t^2 = \lambda \cdot \sigma_{t-1}^2 + (1 - \lambda) \cdot r_{t-1}^{\ 2}$$

$$\lambda = 0.94$$

Thus, one-day VaR is given by:

$$\text{Probability}[r_t < -1.65 \cdot \sigma_t] = 5\%$$

3.2.8 Underlying Assumptions

There are several fundamental assumptions underlying standard RiskMetrics; the validity of the model depends critically on the validity of the following assumptions:

- Prices are assumed to be continuous, when in fact prices are discrete in the financial markets.
- Markets are assumed to continuously trade, when in fact most markets are open during a restricted trading session only and if multiple sessions exist, liquidity differences cause differences in the magnitude of intra-session price extrema.
- Price data is closing data only. This implies that market positions are entered and exited only on the close, a remnant of assuming the

[57] RiskMetrics Technical Document 98.

markets are totally efficient and that a buy-and-hold approach is the only valid approach. At a deeper level the implication is that intraday price extrema are irrelevant to risk measurement or, equivalently, that a volatility forecast based on historical settlement prices is a valid proxy for risk independent of market leverage and/or trading strategy. Extreme intraday events are assumed to be meaningless.

- Gross returns follow a lognormal distribution; thus, log gross-returns follow a normal distribution. This assumes that a single parameter, volatility, is sufficient to describe the distribution and, therefore, the VaR of both long and short market positions. Investigation of the effect of fitting higher order moments to the empirical distribution, namely skewness and kurtosis, are promising.[58]
- Long positions exclusively are implied. The VaR probability statement explicitly defines risk of loss to a long position.
- Autocorrelation of return variances is assumed to exist. The degree of autocorrelation is time-horizon dependent.
- Mean return is assumed to be zero. This is highly questionable on short-time scales. Mean reversion may be intuitively obvious from the RiskMetrics diagrams, but only on an exceptionally long time scale and even then, the mean return is highly sensitive to small changes in that time scale.
- Scaling is assumed to be appropriate. Scaling daily volatility to weekly time scales may be limited or even invalid.

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[58] Li, David X. "Value at Risk Based on the Volatility, Skewness and Kurtosis." (New York: RiskMetrics Group www.RiskMetrics.com, March 4, 1999).

SECTION 4. BACKTESTING RISKMETRICS

"There's many a slip twixt cup and lip."

Benjamin Franklin

4.1 Introduction

Empirically backtesting the standard RiskMetrics for ex-post (realized) intraday violations (particularly relevant under conditions of market leverage) of ex-ante VaR answers the question: Does VaR (standard RiskMetrics parametric VaR) underestimate the short-term market-risk exposure of leveraged market positions? This, in turns answers a more philosophical question: Is volatility a fair proxy for short-term market risk independent of trading strategy or market leverage?

4.2 Backtesting Procedure

The standard RiskMetrics model is used to produce ex-ante VaR limits for historical time-series data for the British Pound, Japanese Yen, and Swiss Franc futures markets from November 1973 to August 2000. These ex-ante VaR limits are then compared with computed ex-post intraday risk extrema to determine the validity of VaR under conditions of market leverage.

Since:

$$\text{Probability}[r_t < -1.65 \cdot \sigma_t] = 5\%$$

Ex-ante VaR limits are given by:

$$r_t = -1.65 \cdot \sigma_t$$

Where:

$$\sigma_t^2 = \lambda \cdot \sigma_{t-1}^2 + (1 - \lambda) \cdot r_{t-1}^{\ 2}$$
$$r_t = \ln(P_{t-1} / P_{t-2})$$
$$\lambda = 0.94$$

And the initial (seed value) for variance is given by the ex-post variance of returns for the most recent 74-day period[59]:

$$\sigma_{75}^2 = \Sigma(r_i - r_{avg})^2 / 74$$
$$r_{avg} = \Sigma r_i / 74$$

Where the summation over i runs from 1 to 74.

Now, for a long market position, the ex-post maximum intraday loss, assuming intraday mark-to-market valuation against the previous closing price, would occur at the lowest price of the day, L_t and would be given by:

$$r_{t,\ max\ intraday\ loss} = \ln(C_{t-1} / L_t)$$

Where C_{t-1} is the closing price of day t-1 and L_t is the low of day t.

Thus, an ex-post intraday violation of the ex-ante VaR limit occurs if and when:

$$r_{t,\ max\ intraday\ loss} < -1.65 \cdot \sigma_{t|t-1}$$

[59] To understand why 74 days are used to determine the seed variance for this calculation, see the description of time-series data below.

Microsoft™ Excel is used to calculate both ex-ante VaR limits and ex-post market risk extrema using the above formulas and historical price data (described below) to determine the frequency (percentage of market days) for which ex-post intraday violations of the ex-ante VaR limits occur. These results are compared with the expected maximum violation percentage of 5%.

4.3 Time-Series Data[60]

RiskMetrics forecasts volatility (variance of returns) using an exponentially-weighted moving average that effectively samples 74 days of past price data. Backtesting requires a series of such forecasts, the greater the number the greater the statistical significance of the backtesting results. In other words, it requires 174 days of historical data to generate 100 ex-post vs. ex-ante comparisons. This poses a minor problem. Futures contracts are expiring contracts, they have limited lifetimes often lasting 3 months or less (70 market days or less). In addition, multiple futures contracts may trade simultaneously at different market prices.

For example, in January of a given year, Swiss Franc futures contracts with expiration dates in March, June, and September may be trading simultaneously with most of the market liquidity confined to the nearest contract month, in this case the March contract. As the March contract nears expiration (mid-March), market liquidity shifts from the March contract to the next most liquid contract, in this case the June contract. And, on each market day, the March, June, and September contracts generally trade at differing prices due to carrying costs, convenience yields, etc.

Thus, in order to have sufficient time-series data to perform a statistically significant backtest, it is necessary to mathematically create what is called a continuous-futures contract, a long-term contract composed of a linked series of limited-lifetime futures contracts. Such a mathematically-derived data stream must take into account the fact that simultaneously-trading contracts (different contract expiration months) for the same futures market (e.g. Swiss Franc) trade at different prices as well as different levels

[60] For a glossary of futures terms and data types, consult Schwager.

of market liquidity. And, as noted above, liquidity moves from one contract to another as time passes.

Fortunately, Commodity Systems, Inc. (CSI), the most accurate data source for futures data, as rated by Futures Magazine[61], produces just such a contract, the Perpetual™ contract.

CSI distributes end-of-day data (date, open, high, low, close, contract volume, contract open interest, total market volume, total market open interest) for four types of futures contract data:

1) Individual futures contract data. This data represents daily historical price data for a given futures contract, a futures contract in a given market with a given expiration date. This data represents price data for futures contracts that actually trade on a futures exchange, raw price data.
2) Continuous (linked) near-month futures contract data. This data is created by splicing together data from the most liquid contract month for a given futures market at any given time. Although this data represents actual price data, it creates artificial gaps between closing prices from one day to the next when a rollover[62] occurs. Such a price gap does not actually occur for any single contract and represents an artificial price jump that would not occur for any given market position.
3) Continuous back-adjusted futures contract data. This data is created from the continuous near-month futures contract data by adjusting out contract rollover gaps. Thus, distant price data will not represent actual traded prices or price levels; in fact, distant prices can even be negative in strongly trending markets.

[61] Knight, Sheldon. "How Clean is Your End-of-Day Data." (Futures Magazine, September 1999), 64-69.
[62] A rollover is said to occur when a market position is transferred from one contract month to another contract month. This requires exiting the former position and establishing the latter position. This is typically done to maintain a market position in the contract with the most trading volume.

4) Perpetual™ contract data. This data represents a time-weighted average price of the two currently most liquid contract months that lie prior to and later than a date 3 months in the future. Thus, Perpetual™ Contract data represent liquidity-adjusted fixed-forward contract data. Perpetual contract data therefore, avoid extreme market volatility resulting from lack of market liquidity. Dr. Bob Pelletier, statistician and President of CSI, claims that Perpetual contract data have superior stationarity properties compared to other types of contract data.

For this work, CSI Perpetual™ Data for the British Pound, Japanese Yen, and Swiss Franc currency futures markets from September 1973 to September 2000 are used.

4.4 Backtest Results

Microsoft™ Excel and Perpetual™ Market Data for the British Pound, Japanese Yen, and Swiss Franc futures markets from September 6, 1973 to September 26, 2000 were used to backtest RiskMetrics. Intraday violations of ex-ante one-day VaR limits at the 95% confidence level should occur for less than 5% of market days. Violation frequencies for each of the markets tested occurred well in excess of this 5% tolerance level: 9.54% for the British Pound, 7.09% for the Japanese Yen, and 7.79% for the Swiss Franc futures markets. For comparison purposes, RiskMetrics was backtested in the conventional format for violations of the VaR risk limits ignoring intraday price extremes. Violation frequencies for this backtest were reasonably consistent with the 5% tolerance level set by RiskMetrics: 5.47% for the British Pound, 4.34% for the Japanese Yen, and 4.79% for the Swiss Franc futures markets. Only in the case of the British Pound is the conventional 5% limit violated. These results are listed in the table below:

Market	Intraday Violations	Conventional Violations	Trading Days
British Pound	**9.54%**	**5.47%**	**6825**
Japanese Yen	**7.09%**	**4.34%**	**7079**
Swiss Franc	**7.79%**	**4.79%**	**6825**

Intraday violations occur 74.41% more frequently than conventional violations for the British Pound, 63.36% more for the Japanese Yen, and 62.63% more for the Swiss Franc futures markets. In addition, these markets experience intraday violations in excess of the 5% level by 4.54% for the British Pound, 2.09% for the Japanese Yen, and 2.79% for the Swiss Franc.

The number of ex-post evaluations of ex-ante forecasts was 6825 for the British Pound, 7079 for the Japanese Yen, and 6825 for the Swiss Franc futures markets.[63]

[63] Note: the discrepancy between the frequency of intraday violations and that of conventional violations seems to correlate well with market liquidity with the magnitude of the discrepancy increasing with decreasing liquidity as measured by average daily volume. Average daily volume, number of futures contracts traded daily, on the International Monetary Market (IMM) at the Chicago Mercantile Exchange (CME) in Chicago, Illinois, in 1999 was 10,678 for the British Pound, 29,569 for the Japanese Yen, and 16342 for the Swiss Franc. No formal quantitative comparison has been made.

SECTION 5. CONCLUSIONS

For want of a nail, the shoe was lost;
For want of the shoe, the horse was lost;
For want of the horse, the rider was lost;
For want of the rider, the battle was lost;
For want of the battle, the kingdom was lost;
And all from the want of a horseshoe nail.

Nursery Rhyme

Conventional parametric VaR, the heart of risk-based capital allocation standards, for financial and non-financial firms alike, underestimates actual intraday market risk for leveraged market positions. Even leveraged positions held as a hedge in a margin account that is separate from the account in which the hedged instrument is held could pose a problem. Intraday violations of conventional VaR risk limits may result in liquidation of the hedge and, therefore, unanticipated risk spikes in the previously hedged portfolio, a very undesirable consequence.

These conclusions obviously have important implications for both regulators and market participants as well as much of the theory of finance. Some of these implications are:

- Regulations concerning capital-based allocation standards may require revision and or restatement.
- Parametric VaR methods may need to be revised. This may be as simple as using one of the available formulas for volatility that incorporates information about daily highs and lows, scaling the conventional daily volatility with respect to average daily price ranges or average true ranges, or perhaps something more complex like incorporating intraday path-dependence into the econometric forecast of future volatility. Modifications for the discreteness of prices and

parametric inclusion of higher order moments may be advantageous especially as regards more precise VaR limits of long vs. short positions in a cash (unleveraged) account. Revision to account for intraday price extremes may reduce dependence on stress testing models and scenario analysis that are currently required to supplement VaR based on empirical evidence of VaR limitations.

- Options valuation models, constructed from short-term arbitrage arguments, may require revision in the same vein.
- Portfolio manager performance metrics (e.g. Sharpe ratio) may require revision to incorporate a higher degree of short-term risk for active vs. passive investment strategies.
- Revision of the Capital Asset Pricing Model (CAPM) to account for active vs. passive investing based on different models of the cost of risk may be required.
- These results may have implications for the Standard Portfolio Analysis of Risk (SPAN) margining systems currently used to set margin for the U.S. futures and options markets.
- The efficient market hypothesis, even if it does hold, may be applicable to market noise based on conventional volatility only. Market noise in excess of conventional volatility, due to lumpiness in buying and selling (liquidity), even at market equilibrium, may offer more efficient entries and exits based on order flow and size. Certain participants (e.g. floor traders) with more immediate information concerning order flow and lower transaction costs may have a substantial edge over other market participants on certain time scales. Other violations of the efficient market hypothesis based on this idea may also exist. A measure of market inefficiency based on the magnitude of deviation of actual short-term risk from conventional VaR may be useful in trading.

- The discrepancy between the frequency of intraday VaR violations and conventional VaR violations may be useful in characterizing and measuring market liquidity and making liquidity comparisons between different markets (e.g. coffee futures vs. swiss franc futures).
- Conventional buy-and-hold strategies based on buying and selling on the close may have an advantage over strategies that try to time the market and which, thereby, gain exposure to enhanced short-term market risk. The new type of investing called folio investing (see www.foliofn.com) may serve a similar purpose for large investors and other professionals who may experience increased short-term risk based on their own influence on market prices. Crossed trades from folio accounts may not add liquidity to the marketplace, but they also will not contribute to high-frequency intraday noise due to order lumpiness in less-liquid markets or during less-liquid trading hours. Furthermore, this work provides support for this type of investing since conventional volatility seems to understate the true level of intraday market risk.
- Active portfolio managers may need to incorporate more dynamic risk management models to account for enhanced short-term risk in order to efficiently allocate portfolio capital and to match risk to expected return. Also, even active managers who seem to be "beating the index" may be found to be taking on more risk than is justified by excess returns. The risk-adjusted returns may be found to be less than the risk adjusted returns of the benchmark portfolio.
- It may be possible to draw a clear dividing line between trading and investing based on the ratio of total expected return over a given time frame to intraday risk measures. This work demonstrates why short-term (momentum) traders may actually be increasing their level of risk by placing stops based on conventional volatility measures. Actualization of losses may occur intraday that would not have

occurred if buy and sell orders were executed only at the market closing (settlement) price.

Finally, this work has demonstrated how standard RiskMetrics may be applied to those commodities markets for which RiskMetrics does not currently provide data and Commodity Systems, Inc. does. This includes all currently active futures markets.

SECTION 6. SUGGESTIONS FOR FURTHER STUDY

A few suggestions for further empirical research are:

1. Investigate the deviation of actual market returns from the assumed lognormal distribution. Determine values for the skewness and kurtosis of the actual distribution and formulate a parametric VaR model that incorporates higher order moments.

2. Investigate to what extent the assumption of zero mean return is valid. Incorporate this into a parametric model to account for the asymmetric effects of drift on long vs. short market positions under conditions of leverage.

3. Determine the extent of the validity of using the same decay factor for every market.

4. Investigate the validity of scaling 1-day VaR limits up to the 10-day time frame used by the Bank for International Settlements.

5. Determine whether intraday violations of VaR limits have information important to determining a market-liquidity metric.

6. Investigate the performance of RiskMetrics VaR if conventional volatility is replaced with volatility measures from the literature that incorporate the high and the low of each trading day.

7. Develop a more precise model that looks at the average expected loss over the given time horizon and models the volatility of losses about the average loss and then determines a value at risk based on the mean loss and the estimated standard deviation of the loss distribution.

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Relevant Internet Links

Bank for International Settlements: www.bis.org

Commodity Futures Trading Commission: www.cftc.gov

Federal Reserve: www.federalreserve.org

Gloria Mundi's website: www.gloriamundi.org

Group of Thirty, The: www.group30.org

International Finance and Commodities Institute: www.iafe.org

International Organization of Securities Commissions: www.iosco.org

Office of the Comptroller of the Currency: www.occ.treas.gov

RiskMetrics: www.riskmetric.org

U.S. Treasury: www.ustreas.gov

VITA

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In late 1994, Mr. Lang decided to pursue his intense interest in finance and markets. He joined Field Financial Group in McLean, Virginia as a Commodities Broker and by 1995 was a principal and half-owner of the company.

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