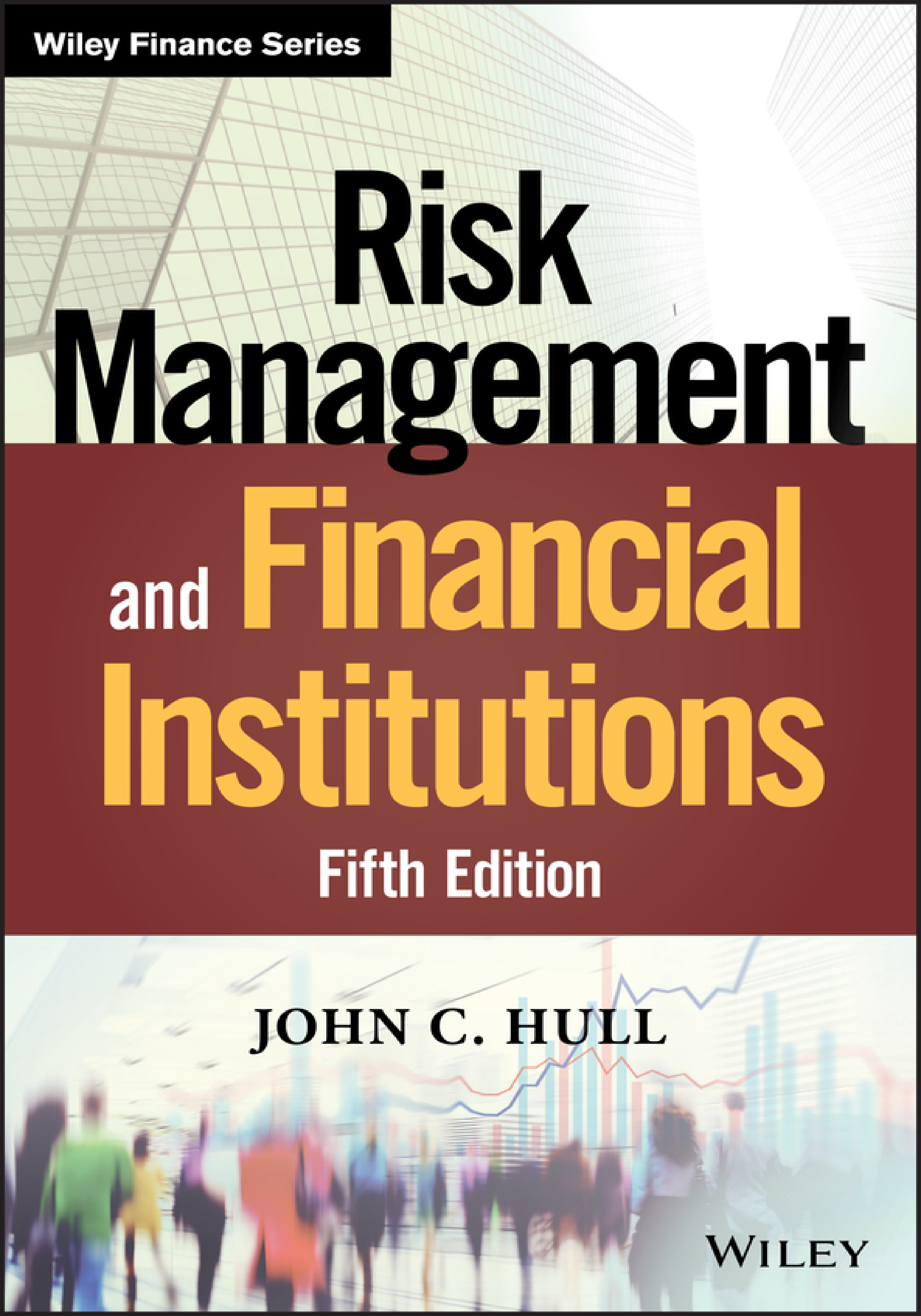

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Risk Management and Financial Institutions

Fifth Edition

JOHN C. HULL

WILEY

Risk Management and Financial Institutions

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To Michelle, Peter, and David

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Business Snapshots

Preface

Risk management practices and the regulation of financial institutions have continued to evolve in the past three years. *Risk Management and Financial Institutions* has been expanded and updated to reflect this. Like my other popular text *Options, Futures, and Other Derivatives*, the book is designed to be suitable for practicing managers as well as university students. Those studying for FMA and PRM qualifications will also find the book useful.

The book is appropriate for university courses in either risk management or financial institutions. It is not necessary for students to take a course on options and futures markets prior to taking a course based on this book. But if they have taken such a course, some of the material in the first nine chapters does not need to be covered.

The level of mathematical sophistication and the way material is presented have been managed carefully so that the book is accessible to as wide an audience as possible. For example, when covering copulas in Chapter 11, I present the intuition followed by a detailed numerical example; when covering maximum likelihood methods in Chapter 10 and extreme value theory in Chapter 13, I provide numerical examples and enough details for readers to develop their own spreadsheets. I have also provided Excel spreadsheets for many applications on my website:

www-2.rotman.utoronto.ca/~hull

This is a book about risk management, so there is very little material on the valuation of derivatives. (That is the main focus of my other two books, *Options, Futures, and Other Derivatives* and *Fundamentals of Futures and Options Markets*.) The appendices at the end of the book include material that summarizes valuation and other results that are important in risk management. The RMFI Software (version 1.00) is designed for this book and can be downloaded from my website.

New Material

The fifth edition has been fully updated and contains much new material. In particular:

1. A new chapter on financial innovation has been included (Chapter 28).
2. A new chapter on the regulation of OTC derivatives markets has been included (Chapter 17). This covers both cleared and uncleared transactions and explains the Standard Initial Margin Model (SIMM).
3. The chapter on the Fundamental Review of the Trading Book (FRTB) has been rewritten to provide a fuller description and reflect recent changes (Chapter 18).
4. The chapter on the model-building approach to estimating value at risk and expected shortfall (Chapter 14) has been rewritten to better reflect the way the market handles interest rates and the way the model-building approach is used for SIMM and FRTB.
5. The chapter on operational risk (Chapter 23) has been rewritten to reflect regulatory developments in this area.
6. The chapter on model risk management (Chapter 25) has been rewritten to cover more than just valuation models and to reflect regulatory requirements such as SR 11-7.
7. At various points in the book, recent developments such as IFRS 9 and SA-CCR are covered.

Slides

Several hundred PowerPoint slides can be downloaded from my website or from the Wiley Higher Education website. Adopting instructors are welcome to adapt the slides to meet their own needs.

Questions and Problems

End-of-chapter problems are divided into two groups: “Practice Questions and Problems” and “Further Questions.” Solutions to the former are at the end of the book. Solutions to the latter and accompanying worksheets are available to adopting instructors from the Wiley Higher Education website.

Instructor Material

The instructor’s manual is made available to adopting instructors on the Wiley Higher Education website. It contains solutions to “Further Questions” (with Excel worksheets), notes on the teaching of each chapter, and some suggestions on course organization.

Acknowledgments

Many people have played a part in the production of this book. I have benefited from interactions with many academics and practicing risk managers. I would like to thank the students in my MBA, Master of Finance, and Master of Financial Risk Management courses at the University of Toronto, many of whom have made suggestions as to how the material could be improved.

Alan White, a colleague at the University of Toronto, deserves a special acknowledgment. Alan and I have been carrying out joint research and consulting in the area of derivatives and risk management for about 30 years. During that time we have spent countless hours discussing key issues. Many of the new ideas in this book, and many of the new ways used to explain old ideas, are as much Alan's as mine. Alan has done most of the development work on the RMFI software.

Special thanks are due to many people at Wiley, particularly Bill Falloon, Mike Henton, Kimberly Monroe-Hill, Judy Howarth, and Steven Kyritz, for their enthusiasm, advice, and encouragement.

I welcome comments on the book from readers. My e-mail address is:

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Joseph L. Rotman School of Management
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Chapter 1

Introduction

Imagine you are the Chief Risk Officer (CRO) of a major corporation. The Chief Executive Officer (CEO) wants your views on a major new venture. You have been inundated with reports showing that the new venture has a positive net present value and will enhance shareholder value. What sort of analysis and ideas is the CEO looking for from you?

As CRO it is your job to consider how the new venture fits into the company's portfolio. What is the correlation of the performance of the new venture with the rest of the company's business? When the rest of the business is experiencing difficulties, will the new venture also provide poor returns, or will it have the effect of dampening the ups and downs in the rest of the business?

Companies must take risks if they are to survive and prosper. The risk management function's primary responsibility is to understand the portfolio of risks that the company is currently taking and the risks it plans to take in the future. It must decide whether the risks are acceptable and, if they are not acceptable, what action should be taken.

Most of this book is concerned with the ways risks are managed by banks and other financial institutions, but many of the ideas and approaches we will discuss are equally applicable to nonfinancial corporations. Risk management has become progressively more important for all corporations in the last few decades. Financial institutions in particular are finding they have to increase the resources they devote to risk management. Large "rogue trader" losses such as those at Barings Bank in 1995, Allied Irish Bank in 2002, Société Générale in 2007, and UBS in 2011 would have been avoided if procedures used by the banks for collecting data on trading positions had been more

Table 1.1 One-Year Return from Investing $100,000 in a Stock

Probability	Return
0.05	+50%
0.25	+30%
0.40	+10%
0.25	−10%
0.05	−30%

carefully developed. Huge subprime losses at banks such as Citigroup, UBS, and Merrill Lynch would have been less severe if risk management groups had been able to convince senior management that unacceptable risks were being taken.

This chapter sets the scene. It starts by reviewing the classical arguments concerning the risk-return trade-offs faced by an investor who is choosing a portfolio of stocks and bonds. It then considers whether the same arguments can be used by a company in choosing new projects and managing its risk exposure. The chapter concludes that there are reasons why companies—particularly financial institutions—should be concerned with the total risk they face, not just with the risk from the viewpoint of a well-diversified shareholder.

1.1 Risk vs. Return for Investors

As all fund managers know, there is a trade-off between risk and return when money is invested. The greater the risks taken, the higher the return that can be realized. The trade-off is actually between risk and *expected return*, not between risk and actual return. The term "expected return" sometimes causes confusion. In everyday language an outcome that is "expected" is considered highly likely to occur. However, statisticians define the expected value of a variable as its average (or mean) value. Expected return is therefore a weighted average of the possible returns, where the weight applied to a particular return equals the probability of that return occurring. The possible returns and their probabilities can be either estimated from historical data or assessed subjectively.

Suppose, for example, that you have $100,000 to invest for one year. Suppose further that Treasury bills yield 5%.[1] One alternative is to buy Treasury bills. There is then no risk and the expected return is 5%. Another alternative is to invest the $100,000 in a stock. To simplify things, we suppose that the possible outcomes from this investment are as shown in Table 1.1. There is a 0.05 probability that the return will be +50%; there

---

[1] This is close to the historical average, but quite a bit higher than the Treasury yields seen in the years following 2008 in many countries.

is a 0.25 probability that the return will be +30%; and so on. Expressing the returns in decimal form, the expected return per year is:

$$0.05 \times 0.50 + 0.25 \times 0.30 + 0.40 \times 0.10 + 0.25 \times (-0.10) + 0.05 \times (-0.30) = 0.10$$

This shows that, in return for taking some risk, you are able to increase your expected return per annum from the 5% offered by Treasury bills to 10%. If things work out well, your return per annum could be as high as 50%. But the worst-case outcome is a −30% return or a loss of $30,000.

One of the first attempts to understand the trade-off between risk and expected return was by Markowitz (1952). Later, Sharpe (1964) and others carried the Markowitz analysis a stage further by developing what is known as the capital asset pricing model. This is a relationship between expected return and what is termed "systematic risk." In 1976, Ross developed arbitrage pricing theory, which can be viewed as an extension of the capital asset pricing model to the situation where there are several sources of systematic risk. The key insights of these researchers have had a profound effect on the way portfolio managers think about and analyze the risk-return trade-offs they face. In this section we review these insights.

1.1.1 Quantifying Risk

How do you quantify the risk you are taking when you choose an investment? A convenient measure that is often used is the standard deviation of the return over one year. This is

$$\sqrt{E(R^2) - [E(R)]^2}$$

where R is the return per annum. The symbol E denotes expected value so that $E(R)$ is the expected return per annum. In Table 1.1, as we have shown, $E(R) = 0.10$. To calculate $E(R^2)$ we must weight the alternative squared returns by their probabilities:

$$\begin{aligned} E(R^2) &= 0.05 \times 0.50^2 + 0.25 \times 0.30^2 + 0.40 \times 0.10^2 + 0.25 \times (-0.10)^2 \\ &\quad + 0.05 \times (-0.30)^2 = 0.046 \end{aligned}$$

The standard deviation of the annual return is therefore $\sqrt{0.046 - 0.1^2} = 0.1897$ or 18.97%.

1.1.2 Investment Opportunities

Suppose we choose to characterize every investment opportunity by its expected return and standard deviation of return. We can plot available risky investments on a chart such as Figure 1.1, where the horizontal axis is the standard deviation of the return and the vertical axis is the expected return.

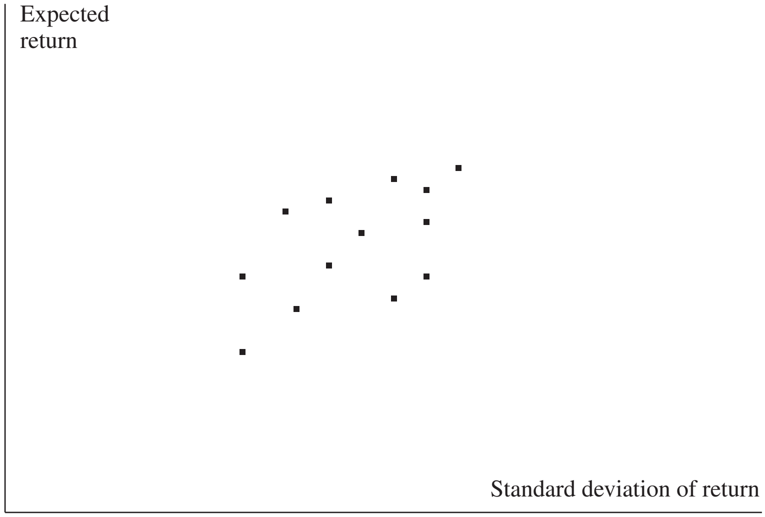

Figure 1.1 Alternative Risky Investments

Once we have identified the expected return and the standard deviation of the return for individual investments, it is natural to think about what happens when we combine investments to form a portfolio. Consider two investments with returns R_1 and R_2. The return from putting a proportion w_1 of our money in the first investment and a proportion $w_2 = 1 - w_1$ in the second investment is

$$w_1R_1 + w_2R_2$$

The portfolio expected return is

$$\mu_P = w_1\mu_1 + w_2\mu_2 \tag{1.1}$$

where μ_1 is the expected return from the first investment and μ_2 is the expected return from the second investment. The standard deviation of the portfolio return is given by

$$\sigma_P = \sqrt{w_1^2\sigma_1^2 + w_2^2\sigma_2^2 + 2\rho w_1w_2\sigma_1\sigma_2} \tag{1.2}$$

where σ_1 and σ_2 are the standard deviations of R_1 and R_2 and ρ is the coefficient of correlation between the two.

Suppose that μ_1 is 10% per annum and σ_1 is 16% per annum, while μ_2 is 15% per annum and σ_2 is 24% per annum. Suppose also that the coefficient of correlation, ρ, between the returns is 0.2 or 20%. Table 1.2 shows the values of μ_P and σ_P for a number of different values of w_1 and w_2. The calculations show that by putting part of your money in the first investment and part in the second investment a wide range of risk-return combinations can be achieved. These are plotted in Figure 1.2.

Table 1.2 Expected Return, μ_P, and Standard Deviation of Return, σ_P, from a Portfolio Consisting of Two Investments

w_1	w_2	μ_P	σ_P
0.0	1.0	15%	24.00%
0.2	0.8	14%	20.09%
0.4	0.6	13%	16.89%
0.6	0.4	12%	14.87%
0.8	0.2	11%	14.54%
1.0	0.0	10%	16.00%

The expected returns from the investments are 10% and 15%; the standard deviations of the returns are 16% and 24%; and the correlation between returns is 0.2.

Most investors are risk-averse. They want to increase expected return while reducing the standard deviation of return. This means that they want to move as far as they can in a "northwest" direction in Figures 1.1 and 1.2. Figure 1.2 shows that forming a portfolio of the two investments we have been considering helps them do this. For example, by putting 60% in the first investment and 40% in the second, a portfolio with an expected return of 12% and a standard deviation of return equal to 14.87% is obtained. This is an improvement over the risk-return trade-off for the first investment. (The expected return is 2% higher and the standard deviation of the return is 1.13% lower.)

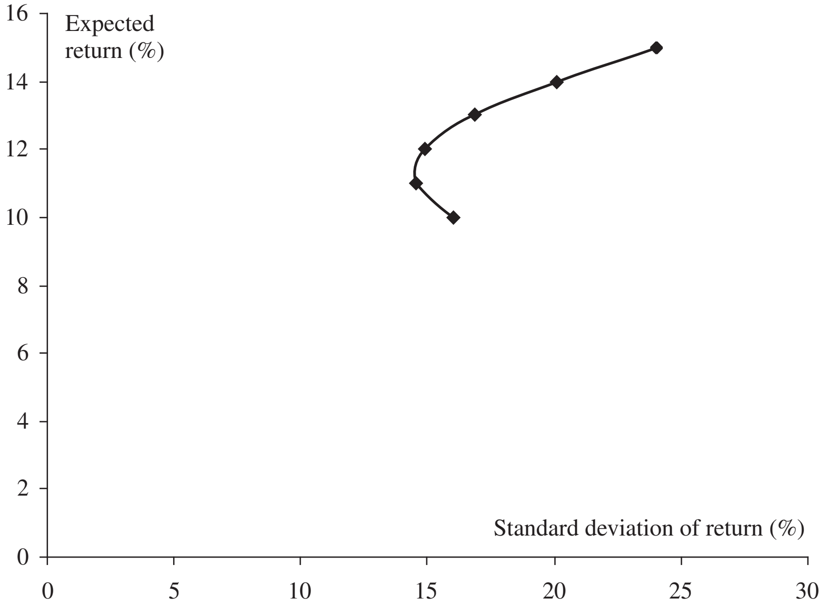

Figure 1.2 Alternative Risk-Return Combinations from Two Investments (as Calculated in Table 1.2)

1.2 The Efficient Frontier

Let us now bring a third investment into our analysis. The third investment can be combined with any combination of the first two investments to produce new risk-return combinations. This enables us to move further in the northwest direction. We can then add a fourth investment. This can be combined with any combination of the first three investments to produce yet more investment opportunities. As we continue this process, considering every possible portfolio of the available risky investments, we obtain what is known as an *efficient frontier*. This represents the limit of how far we can move in a northwest direction and is illustrated in Figure 1.3. There is no investment that dominates a point on the efficient frontier in the sense that it has both a higher expected return and a lower standard deviation of return. The area southeast of the efficient frontier represents the set of all investments that are possible. For any point in this area that is not on the efficient frontier, there is a point on the efficient frontier that has a higher expected return and lower standard deviation of return.

In Figure 1.3 we have considered only risky investments. What does the efficient frontier of all possible investments look like? Specifically, what happens when we include the risk-free investment? Suppose that the risk-free investment yields a return of R_F. In Figure 1.4 we have denoted the risk-free investment by point F and drawn a tangent from point F to the efficient frontier of risky investments that was developed in Figure 1.3. M is the point of tangency. As we will now show, the line FJ is our new efficient frontier.

Consider what happens when we form an investment I by putting β_I of the funds we have available for investment in the risky portfolio, M, and $1 - \beta_I$ in the risk-free investment F ($0 < \beta_I < 1$). From equation (1.1) the expected return from the investment, $E(R_I)$, is given by

$$E(R_I) = (1 - \beta_I)R_F + \beta_I E(R_M)$$

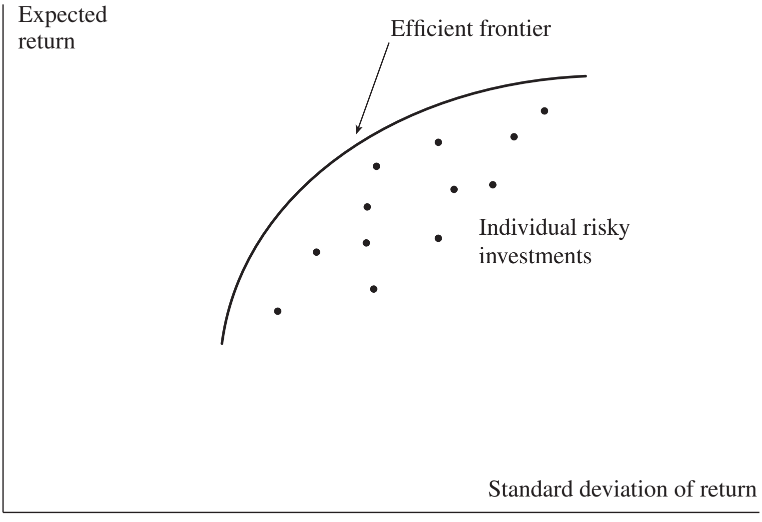

Figure 1.3 Efficient Frontier Obtainable from Risky Investments

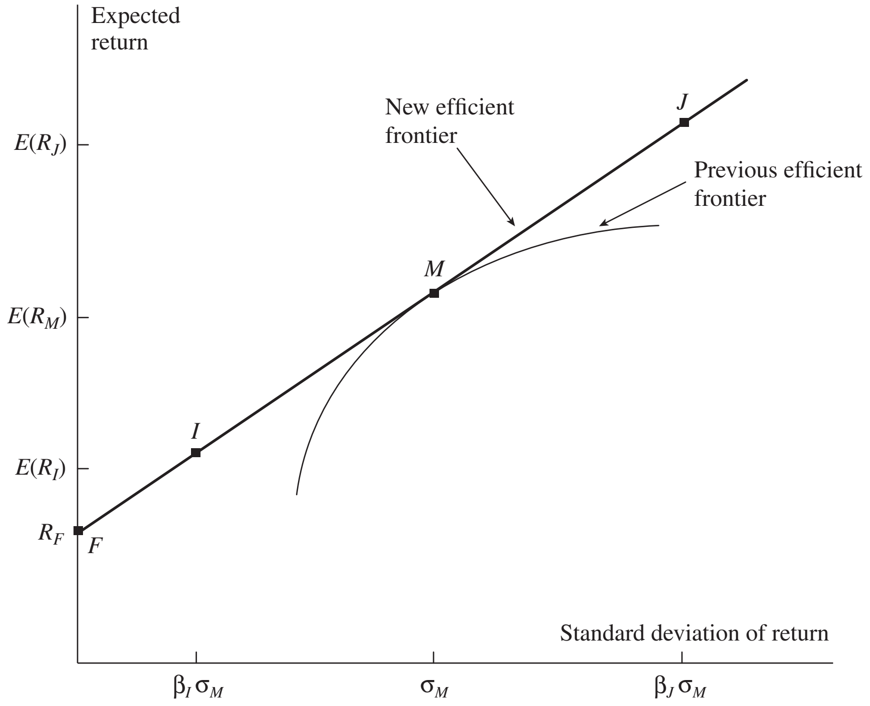

Figure 1.4 The Efficient Frontier of All Investments
Point I is achieved by investing a percentage β_I of available funds in portfolio M and the rest in a risk-free investment. Point J is achieved by borrowing $\beta_J - 1$ of available funds at the risk-free rate and investing everything in portfolio M.

and from equation (1.2), because the risk-free investment has zero standard deviation, the return R_I has standard deviation

$$\beta_I \sigma_M$$

where σ_M is the standard deviation of return for portfolio M. This risk-return combination corresponds to the point labeled I in Figure 1.4. From the perspective of both expected return and standard deviation of return, point I is β_I of the way from F to M.

All points on the line FM can be obtained by choosing a suitable combination of the investment represented by point F and the investment represented by point M. The points on this line dominate all the points on the previous efficient frontier because they give a better risk-return combination. The straight line FM is therefore part of the new efficient frontier.

If we make the simplifying assumption that we can borrow at the risk-free rate of R_F as well as invest at that rate, we can create investments that are on the continuation of FM beyond M. Suppose, for example, that we want to create the investment represented by the point J in Figure 1.4 where the distance of J from F is β_J times the distance of M from F ($\beta_J > 1$). We borrow $\beta_J - 1$ of the amount that we have available for investment at rate R_F and then invest everything (the original funds and the borrowed funds) in the investment represented by point M. After allowing for the interest paid, the new investment has an expected return, $E(R_J)$, given by

$$E(R_J) = \beta_J E(R_M) - (\beta_J - 1)R_F = (1 - \beta_J)R_F + \beta_J E(R_M)$$

and the standard deviation of the return is

$$\beta_J \sigma_M$$

This shows that the risk and expected return combination corresponds to point J. (Note that the formulas for the expected return and standard deviation of return in terms of beta are the same whether beta is greater than or less than 1.)

The argument that we have presented shows that, when the risk-free investment is considered, the efficient frontier must be a straight line. To put this another way, there should be a linear trade-off between the expected return and the standard deviation of returns, as indicated in Figure 1.4. All investors should choose the same portfolio of risky assets. This is the portfolio represented by M. They should then reflect their appetite for risk by combining this risky investment with borrowing or lending at the risk-free rate.

It is a short step from here to argue that the portfolio of risky investments represented by M must be the portfolio of all risky investments. Suppose a particular investment is not in the portfolio. No investors would hold it and its price would have to go down so that its expected return increased and it became part of portfolio M. In fact, we can go further than this. To ensure a balance between the supply and demand for each investment, the price of each risky investment must adjust so that the amount of that investment in portfolio M is proportional to the amount of that investment available in the economy. The investment represented by point M is therefore usually referred to as the *market portfolio*.

1.3 The Capital Asset Pricing Model

How do investors decide on the expected returns they require for individual investments? Based on the analysis we have presented, the market portfolio should play a key role. The expected return required on an investment should reflect the extent to which the investment contributes to the risks of the market portfolio.

A common procedure is to use historical data and regression analysis to determine a best-fit linear relationship between returns from an investment and returns from the market portfolio. This relationship has the form:

$$R = a + \beta R_M + \epsilon \tag{1.3}$$

where R is the return from the investment, R_M is the return from the market portfolio, a and β are constants, and ϵ is a random variable equal to the regression error.

Equation (1.3) shows that there are two uncertain components to the risk in the investment's return:

1. A component βR_M, which is a multiple of the return from the market portfolio.
2. A component ϵ, which is unrelated to the return from the market portfolio.

The first component is referred to as *systematic risk*. The second component is referred to as *nonsystematic risk*.

Consider first the nonsystematic risk. If we assume that the ϵ variables for different investments are independent of each other, the nonsystematic risk is almost completely diversified away in a large portfolio. An investor should not therefore be concerned about nonsystematic risk and should not require an extra return above the risk-free rate for bearing nonsystematic risk.

The systematic risk component is what should matter to an investor. When a large well-diversified portfolio is held, the systematic risk represented by βR_M does not disappear. An investor should require an expected return to compensate for this systematic risk.

We know how investors trade off systematic risk and expected return from Figure 1.4. When $\beta = 0$ there is no systematic risk and the expected return is R_F. When $\beta = 1$, we have the same systematic risk as the market portfolio, which is represented by point M, and the expected return should be $E(R_M)$. In general

$$E(R) = R_F + \beta[E(R_M) - R_F] \tag{1.4}$$

This is the *capital asset pricing model*. The excess expected return over the risk-free rate required on the investment is β times the excess expected return on the market portfolio. This relationship is plotted in Figure 1.5. The parameter β is the *beta* of the investment.

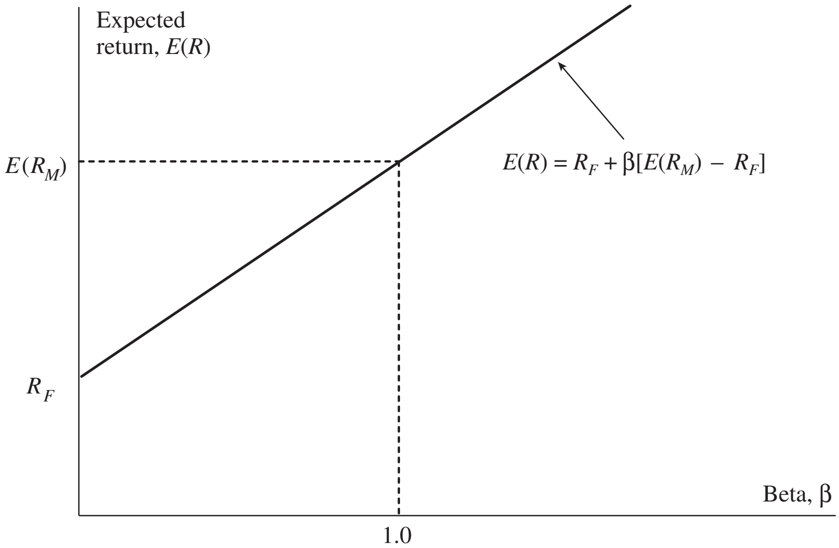

Figure 1.5 The Capital Asset Pricing Model