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Robert C. Merton and the Science of Finance

From his pioneering work on optimal portfolio selection to options pricing and retirement security, the Nobel laureate continues to seek remedies for complex financial problems.

► By **Zvi Bodie**, Professor Emeritus, Finance, Boston University

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From his pioneering work on optimal portfolio selection to options pricing and retirement security, the Nobel laureate continues to seek innovative solutions for complex financial problems.



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ROBERT C. MERTON
Nobel laureate, 1997
Professor, MIT

*Adapted from "Robert C. Merton and the Science of Finance" by Zvi Bodie,
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Paul Samuelson, the first American to receive the Nobel Prize in Economic Sciences, once compared Robert C. Merton's influence on finance to Isaac Newton's impact on physics. Put another way, starting with his 1970 doctoral dissertation and continuing today, **Merton has revolutionized the theory and practice of finance.**

Many people in the defined contribution (DC) industry probably know about Merton's theoretical and applied work, which includes an effort to improve the design of DC plans. The professor himself describes this work as a means to address the primary question asked by people saving for retirement: "Will I have sufficient income in retirement to live comfortably?"

Most plan sponsors would like to provide a sufficient answer to that question for their plan participants, and thanks to Merton, the DC industry is now more focused than ever on the importance of retirement income. Yet, to fully understand and appreciate Merton's contributions to DC—and finance more broadly—requires a careful review of his accomplishments.

For many years I have worked with Merton on a variety of research initiatives. Here, I offer a detailed look at selected highlights of his career and the overarching body of work that I refer to as "The Mertonian Revolution in Finance."

Paul Samuelson's Research Assistant

Merton attended the Columbia University School of Engineering and Applied Science, receiving a BS in engineering mathematics in 1966. It was there that he encountered Samuelson—who in 1970 would become the first American Nobel laureate in economics—in the form of his famous introductory textbook on economics. Merton then went to the California Institute of Technology to pursue a PhD in applied mathematics. But he soon decided to leave Caltech (and mathematics) to study economics, applying to a half-dozen good departments. Only one—the Massachusetts Institute of Technology (MIT)—accepted him and gave him a full fellowship.

When he arrived at MIT in the fall of 1967, Merton took Samuelson's mathematical economics course and loved it. Samuelson offered him a job as a research assistant. "I did not get particularly good grades in my courses in

the department," Merton recalls, "mainly because I spent much of my time 'playing with' research ideas and working on joint research with Paul."

In the course of his work for Samuelson, Merton discovered shared interests and some common knowledge about the stock market, warrants, and convertible securities. In the summer of 1968, they began a joint effort to advance Samuelson's 1965 theory of warrant pricing, subsequently published in 1969.

That summer Merton also made his first major contribution to the theory of finance: He attacked, on his own, the lifetime dynamic consumption-portfolio selection problem in "continuous time." (Lifetime dynamic consumption refers to how individuals' spending varies over time. The portfolio selection problem refers, in simple terms, to the best way to diversify a portfolio and balance its expected return against its risks. Continuous time refers to the idea that these decisions are made continuously, not just at one point in time.) There was a long tradition of lifecycle consumption models in economics but none that incorporated uncertainty and included the portfolio selection decision.¹ Merton addressed this problem, and his paper became Chapter 2 in his doctoral dissertation.²

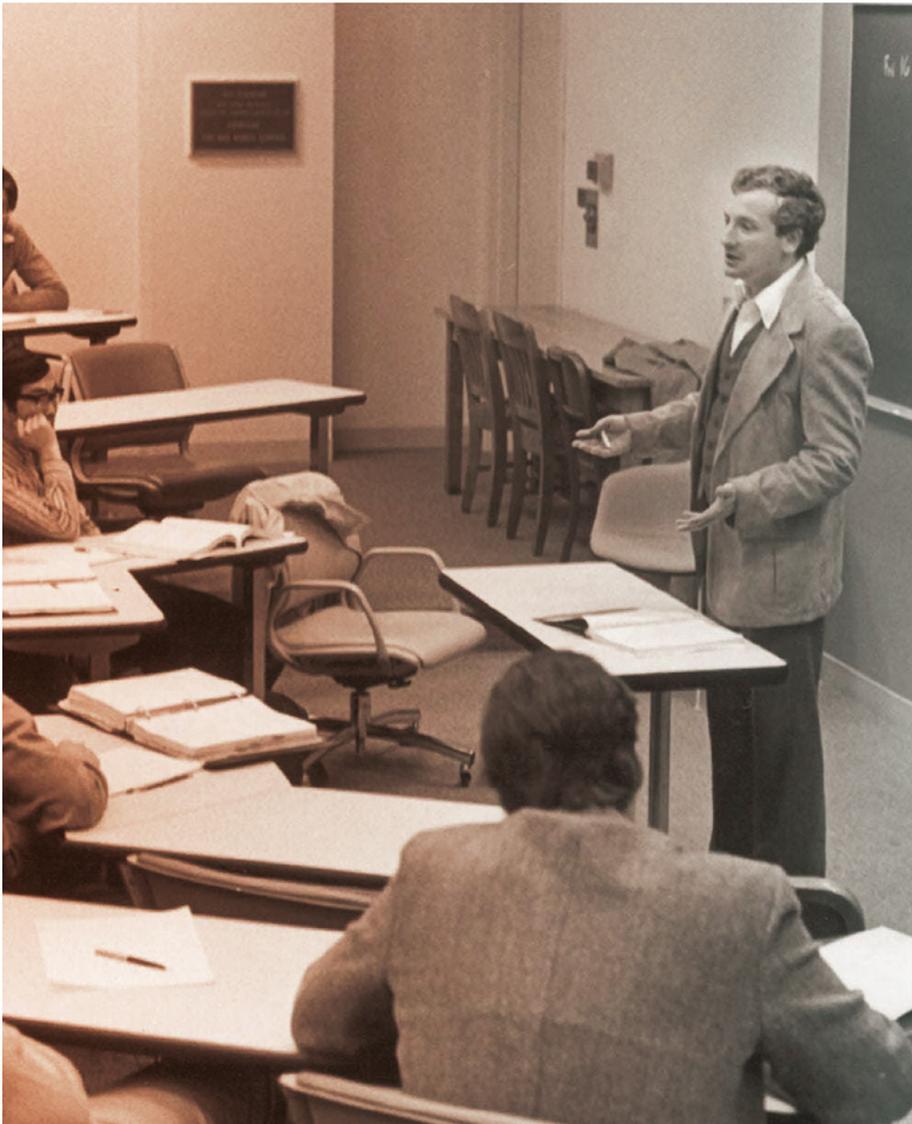
1970 MIT Working Paper

Thanks to a job offer arranged by Franco Modigliani, an MIT professor at the time, Merton was hired and started teaching at MIT's Sloan School of Management in the fall of 1970. His work on "A Dynamic General Equilibrium Model of the Asset Market and Its Application to the Pricing of the Capital Structure of the Firm"³ appeared as the MIT No. 497-70 working paper in December 1970. It contained early versions of at least three groundbreaking papers on key aspects of finance theory: the Intertemporal Capital Asset Pricing Model or ICAPM (1973), Rational Option Pricing (1973), and Risky Corporate Debt (1974).⁴ In over 45 years of studying and teaching finance, never have I seen one paper so rich in its academic ideas, theories, and future contributions to the science of finance.



▲ EDUCATOR

Merton began his teaching career in the fall of 1970.



ICAPM

In Merton's model of consumption and portfolio selection, the desire to *hedge* against a risk gives rise to a demand for securities correlated with that risk. For example, a desire to hedge against adverse changes in short-term interest rates induces a demand for long-term bonds. In equilibrium a security's risk premium will reflect not only its volatility relative to the market but also its volatility relative to commonly shared hedging portfolios. The result of these hedging demands is Merton's multifactor ICAPM. Instead of the single market risk premium of the Capital Asset Pricing Model (CAPM)—a theory developed in the 1960s by William Sharpe, Jack Treynor, John Lintner, and Jan Mossin—there are several factors in the ICAPM, each of which corresponds to the correlation of a security's return with a hedging portfolio.⁵

Merton's ICAPM provides a theoretical rationale for investment firms to offer a family of hedging portfolios that could be combined to suit the needs of different types of clients as well as a theoretical justification for a multifactor investment strategy.⁶

The ICAPM and Merton's continuous-time technology were foundational for the development of consumption-based asset pricing models (CCAPM), which researchers have used widely to price risky securities in the subsequent four decades.⁷

Options Pricing

The research that Merton is most known for—and the discovery that led to his Nobel Prize two decades later—is the model for options pricing.⁸

The Chicago Board Options Exchange (CBOE) began trading the first listed options in the US in April 1973—a month before the official publication of “The Pricing of Options and Corporate Liabilities,” the famous paper penned by Fischer Black and Myron Scholes, in the *Journal of Political Economy*.⁹ Simultaneously, Merton published his “Theory of Rational Option Pricing” in the *Bell Journal of Economics and Management Science*.¹⁰ By 1975, traders on the CBOE were using the model to both price and hedge their options positions. Indeed, Texas Instruments created a hand-held calculator that was specially programmed to produce Black-Scholes/Merton options prices and hedge ratios.



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COLLEAGUES

Merton and Zvi Bodie have worked together on a variety of research initiatives focused on pensions and retirement.

Merton's work in this area also set the foundation for a new branch of finance called Contingent Claims Analysis (CCA), a technique for determining the price of a security whose payoffs depend on the prices of one or more other securities.¹¹ The applications of CCA range from the pricing of complex financial securities to the evaluation of corporate capital budgeting and strategic decisions. The theory and mathematical modeling of CCA for such applications have become even more important to the practice of finance than the original options applications.

Financial Engineering

Another development in the 1970s was the application of options-pricing theory to analyzing real investment opportunities and making capital-budgeting decisions involving drug discovery, oil fields leases, mineral rights, alternative production processes, multiple-fuel power plants, patents, and the option to commence, delay, or abandon a project. "Financial engineering" is the term used to describe these activities, and the investment opportunities are called "real options."

Black, Scholes, and Merton did not fully appreciate the breadth with which options-pricing theory could and would be applied in the 45 years following the publication of their papers. The term financial engineering has come to mean the practical application of modern financial science to solve economic challenges faced by individuals, businesses, financial institutions, or governments.¹²

Theory of Financial Intermediation

In 1990, Merton published *Continuous-Time Finance*, a synthesis of his earlier work. Chapter 14, on intermediation and institutions, represented a bridge to a new direction in his research. From that time until the present, he has focused on understanding the financial system while putting a special emphasis on the dynamics of institutional change.

In particular, he is studying how financial technology and innovation drive changes in the design of financial institutions and markets and the management of financial services firms, as well as the role of regulatory and accounting systems in supporting these changes. The role of fintech (and other new ways of engaging investors and plan participants) is of special interest. His thoughts and consultations with regulators and service providers are helping to shape how we interact with the stewards of our financial dreams.

A Functional Perspective

Today, decision makers around the world face many issues that concern institutional change. In China, for example, decentralization and privatization of large parts of the economy during the past decade produced remarkable improvements in standards of living.¹³ Public officials and business leaders now see an urgent need to create a financial infrastructure that

Merton has focused on understanding the financial system and has put a special emphasis on the dynamics of institutional change.

supports continued economic development. Japan is considering fundamental changes to the structure of its banking system in an effort to overcome economic stagnation.¹⁴ And in Europe and the US, pension, social security, and defined contribution reform has become a top priority. A critical issue everywhere is controlling the risk of default by financial institutions.

For a variety of reasons—including differences in size, complexity, and available technology, as well as differences in political, cultural, and historical backgrounds—financial institutions generally differ across borders. They also change over time. To analyze how and why financial institutions differ across borders and change over time, Merton adopted a framework he called the

Selected Books by Robert Merton



Continuous-Time Finance

Completed in 1990, revised in 1992, and translated into Chinese, this is Merton's best-known and most scientifically important book. It develops the continuous-time mathematical modeling of finance, provides an overview and synthesis of finance theory from the perspective of continuous-time analysis, and covers individual finance choice, corporate finance, financial intermediation, capital markets, and selected topics on the interface between private and public finance. (New Jersey: Wiley-Blackwell, 1992.)



Financial Economics

First published in 1997 and revised in 2009, this textbook on basic finance is featured in the curriculum of top US and international business schools. It presents the subject as a set of principles much like first courses in economics and the physical sciences and was intended for use in its current form anywhere in the world; the book is written so that its concepts are as relevant and understandable to a student in Argentina, France, Japan, or China as they are to a student in the United States. The international aspects of finance are integrated throughout the book, not confined to separate "international" chapters. It has been translated into eight foreign languages: Chinese, French, Japanese, Korean, Polish, Portuguese, Russian, and Spanish. (Out of print; will be revised and expanded.)



The Global Financial System: A Functional Perspective

Merton and other leading financial scholars offer a framework to enhance the success of individual financial firms and the efficiency of the financial system as a whole. They look at the system's functions rather than its ever-changing institutions, an outlook that anticipates the financial system's future developments. Those functions include clearing and settling payments, pooling resources, transferring economic resources across time and space, managing risk, providing information, and dealing with incentive problems. (Boston: Harvard Business Review Press, 1995.)



Cases in Financial Engineering: Applied Studies of Financial Innovation

Authored by Robert Merton, Scott Mason, Andre Perold, and Peter Tufano, this collection of 35-plus cases examines how major companies took bold steps to ensure their financial strength and superiority. The cases address real products, real financial innovations, and real-world applications. Merton provides a conceptual overview in Chapter 1, "Financial Innovation and the Financial System." (New Jersey: Prentice Hall, 1995.)

"functional perspective."¹⁵ Its key element is a focus on functions rather than institutions as the conceptual "anchor."¹⁶ The functional perspective rests on two basic premises:

- **Financial functions are more stable than financial institutions—that is, functions change less over time and vary less across borders.**
- **Institutional form follows function—that is, innovation and competition among institutions ultimately result in greater efficiency in the performance of financial system functions.**

Global Financial System Project

Merton refined and applied his functional perspective in a series of working papers, published articles, and book chapters. In 1992, he and Carliss Baldwin, his Harvard Business School (HBS) colleague and a former MIT student, led the creation of the Global Financial System Project¹⁷ at HBS. This initiative, which involved several finance colleagues working together with senior management from 15 global financial services firms, expanded the research effort devoted to applying the functional approach to the financial system and the management of financial institutions. The main result was a volume published in 1995 that discussed how the financial system had performed in the past and was likely to perform in the future.¹⁸

The final chapter considered the changes in financial infrastructure necessary to support welfare-improving financial innovation,¹⁹ warning that financial crises were liable to occur in the future because the pace of financial product innovation exceeds the rate of change in infrastructure needed to accommodate it. Although no explicit forecasts were made, the authors were implicitly anticipating a global financial crisis.

Systemic Risk

In the wake of the 2007–2008 financial crisis, Merton, his MIT colleague Andrew Lo, and Amir Khandani initiated a joint research effort to understand the causes in order to avoid a repeat. They found that a combination of rising home prices, declining interest rates, and near-frictionless refinancing opportunities created unintentional synchronization of homeowner leverage, leading to a “ratchet” effect on leverage because homes are indivisible and owner-occupants cannot raise equity to reduce leverage when home prices fall.²⁰ Their simulation of the US housing market yielded potential losses of \$1.7 trillion from June 2006 to December 2008 with cash-out refinancing vs. only \$330 billion in the absence of cash-out refinancing. They concluded that the refinancing ratchet effect is a new type of systemic risk in the financial system and does not rely on any dysfunctional behaviors.

Global Retirement System Reform

Among the most pressing policy issues around the world is pension, social security, and defined contribution reform. Merton has long been concerned with the efficient design of retirement income systems.²¹ For over four decades, he has been contemplating, researching, and speaking about this topic around the world. In his early papers, he envisioned a reformed Social Security system in which benefits would be linked to national per capita consumption. In his recent published work, he is concerned with improving the design of defined contribution retirement plans.²² In addition to his scholarly activities as a professor at MIT Sloan,²³ he is engaged in putting his theory into practice as



▲ INNOVATOR

Merton is known for his contributions to the beneficial relationship between finance theory and practice.

Resident Scientist at Dimensional Holdings Inc., where he is the creator of Target Retirement Solution, a global integrated retirement-funding solution system.

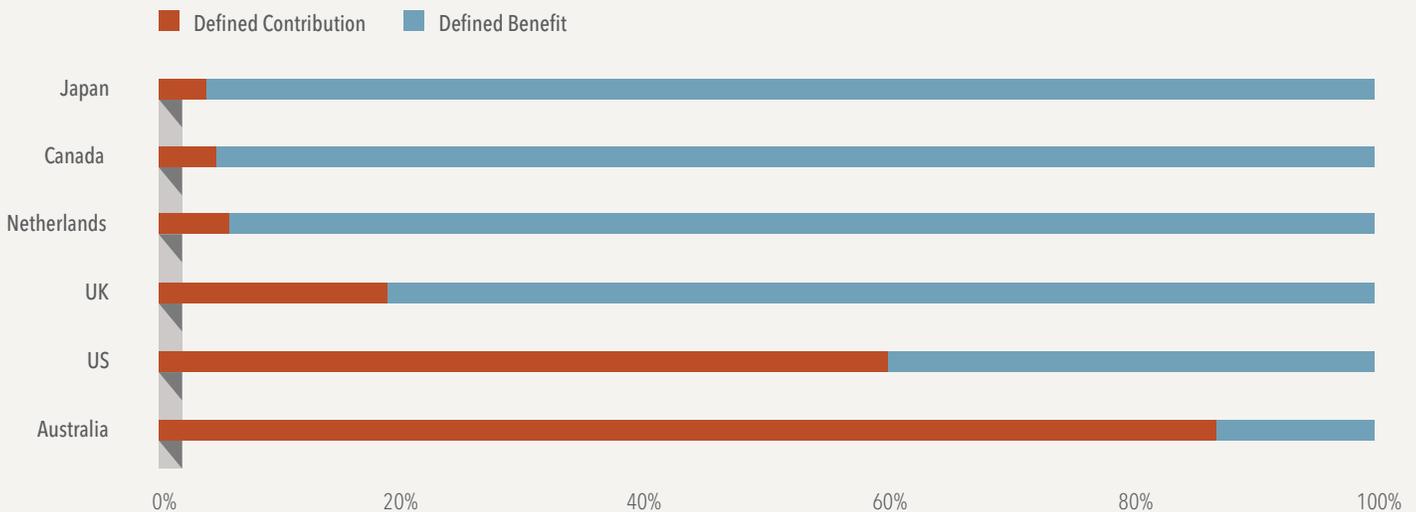
“Insofar as addressing the retirement income shortfall is a problem, it is one of engineering, not science,” Merton says. “We already have the tools to fix this issue. We know how to make the system sustainable and increase people’s chances of a good retirement. Essentially, this new system comes down to making smarter products rather than trying to make consumers smarter about finance.”

The answer, in Merton’s view, is to adopt a liability-driven investment (LDI) strategy that is equivalent to how an insurer hedges an annuity contract or how pension funds hedge their liabilities for future retirement payments to members.

Several companies in Europe started implementing Merton’s retirement solution in the mid-2000s, and the idea continues to gain traction around the globe.

EXHIBIT 1

Assets in Defined Contribution vs. Defined Benefit



Source: "Global pension assets study 2018," Thinking Ahead Institute, Willis Towers Watson, February 2018. © 2019 Willis Towers Watson. Used with permission.

The goal is to grow the savings of plan participants during their accumulation phase and manage income uncertainty by using long-term inflation-linked bonds as the lowest-risk hedge leading up to and during their decumulation phase. This approach gives participants a clearer view of the income that a portfolio may provide in retirement.

"Most target date or risk-based DC solutions tend to put employees nearing retirement in shorter-maturity bonds. But short-term bonds are more risky than almost any other asset if the goal is retirement income," Merton explains. "A better way to manage income risk is to use inflation-protected instruments, such as Treasury Inflation-Protected Securities (TIPS), that can match the duration of the retirement income need (the liability). This approach isn't new. In fact, defined benefit (DB) plans have

long regarded income risk as the most important risk to manage." (See **Exhibit 1**, above, for a snapshot of the DB/DC split among countries that account for most of the world's pension money. Global pension systems, not unlike the US system, face funding and sustainability challenges as they move from more DB-oriented to more DC-oriented systems. Merton has been at the forefront of addressing this trend—and its implications for participants—with regulators, central banks, and academics alike.)

Several companies in Europe started implementing Merton's solution in the mid-2000s, and the idea continues to gain traction around the globe, including the US and also South Africa and Canada. "It's built on financial science," Merton says, "and these principles work everywhere independent of culture or the design of the financial system."

Postscript

In my view, no individual has contributed more to the beneficial relationship between finance theory and practice than Robert C. Merton. Today, he still teaches at MIT and often lectures around the world. Not only has "The Mertonian Revolution in Finance" helped shape modern finance, it has also provided us with insights, theories, and models for our collective future. The title of one of Merton's recent lectures to an audience in China describes his central theme: "Solving Global Challenges Using Finance Science."²⁴ To that I say, amen! ◀



Robert C. Merton

Robert C. Merton is the School of Management Distinguished Professor of Finance at the MIT Sloan School of Management and University Professor Emeritus at Harvard University. He was the George Fisher Baker Professor of Business Administration (1988 to 1998) and the John and Natty McArthur University Professor (1998 to 2010) at Harvard Business School. After receiving a PhD in economics from MIT in 1970, Merton served on the finance faculty of MIT's Sloan School of Management until 1988, at which time he was J.C. Penney Professor of Management. He served as an independent director of the Dimensional US Mutual Funds board from 2003 to 2009. He then became Resident Scientist at Dimensional Holdings Inc., where he is the creator of the Target Retirement Solution, a global integrated retirement-funding solution system.

Merton received the Alfred Nobel Memorial Prize in Economic Sciences in 1997 for a new method to determine the value of derivatives. He is past president of the American Finance Association, a member of the National Academy of Sciences, and a Fellow of the American Academy of Arts and Sciences. Merton received the inaugural Financial Engineer of the Year Award from the International Association of Financial Engineers, which also elected him a Senior Fellow. A Distinguished Fellow of the Institute for Quantitative Research in Finance ('Q Group') and a Fellow of the Financial Management Association, he received the Nicholas Molodovsky Award from the CFA Institute. He received the 2011 CME Group Fred Arditti Innovation Award and the 2013 World Federation of Exchanges Award for Excellence.

Merton's research focuses on finance theory, including lifecycle and retirement finance, optimal portfolio selection, capital asset pricing, pricing of options, credit risk, loan guarantees and improving the methods of measuring and managing macro-financial risk.

Merton received a BS in engineering mathematics from Columbia University and a MS in applied mathematics from California Institute of Technology.

Zvi Bodie

Zvi Bodie is the Norman and Adele Barron Professor of Management, Emeritus, at Boston University. He holds a PhD in economics from the Massachusetts Institute of Technology, MA in economics from the Hebrew University, and BA with honors in philosophy from Brooklyn College. A thought leader in lifecycle finance, Bodie was recognized in 2007 by the Retirement Income Industry Association with their Lifetime Achievement Award for applied research.

Bodie's most prominent books include *Investments*, widely used in the programs offered by the CFA Institute and the Society of Actuaries, and *Financial Economics*, a textbook coauthored with Robert C. Merton and David Cleeton. Bodie also authored two mass-market books, *Worry-Free Investing: A Safe Approach to Achieving Your Lifetime Financial Goals and Risk Less and Prosper: Your Guide to Safer Investing*.

1. Franco Modigliani and Milton Friedman each received Nobel Prizes for their work on lifetime consumption behavior.
2. Robert C. Merton, "Lifetime Portfolio Selection under Uncertainty: The Continuous-Time Case," *The Review of Economics and Statistics* 51 no. 3 (August 1969): 239–246 (Chapter 4 in *Continuous-Time Finance*); Paul A. Samuelson, "Lifetime Portfolio Selection by Dynamic Stochastic Programming," *The Review of Economics and Statistics* 51, no. 3, (August 1969): 247–257; Robert C. Merton, *Continuous-Time Finance*. (Oxford, UK: Basil Blackwell, 1990; Rev. ed., 1992.)
3. Robert C. Merton, "A Dynamic General Equilibrium Model of the Asset Market and Its Application to the Pricing of the Capital Structure of the Firm." The paper was not officially published until Merton made it Chapter 11 in *Continuous-Time Finance* in 1990.
4. Robert C. Merton, "An Intertemporal Capital Asset Pricing Model," *Econometrica* 41 (1973): 867–887 (Chapter 15 in *Continuous-Time Finance*); "Theory of Rational Option Pricing," *Bell Journal of Economics and Management Science* 4, no. 1 (Spring 1973): 141–183 (Chapter 8 in *Continuous-Time Finance*); "On the Pricing of Corporate Debt: The Risk Structure of Interest Rates," *Journal of Finance* 29, no. 2 (May 1974): 449–470 (Chapter 12 in *Continuous-Time Finance*).
5. Robert C. Merton, "An Intertemporal Capital Asset Pricing Model," *Econometrica* 41, no. 5 (September 1973): 867–887 (Chapter 8 in *Continuous-Time Finance*).
6. Eugene F. Fama, a professor at the University of Chicago Booth School of Business and a consultant to Dimensional, has cited Merton's ICAPM as a possible theoretical rationale for the Fama-French multifactor empirical findings.
7. The CCAPM was the work of Merton's student, Douglas Breeden, "An intertemporal asset pricing model with stochastic consumption and investment opportunities," *Journal of Financial Economics* 7, no. 3 (1979): 265–296.
8. Merton shared the Nobel with Myron Scholes. For the story of how Merton, Scholes, and Fischer Black developed their model, see Peter L. Bernstein, *Capital Ideas: The Improbable Origins of Modern Wall Street* (Wiley, 1991); Fischer Black, "How We Came Up with the Option Formula," *Journal of Portfolio Management* 15, no. 2 (1989): 4–8; and Myron S. Scholes, "Derivatives in a Dynamic Environment," *American Economic Review* 88, no. 3, (June 1998): 350–370.
9. Fischer Black and Myron Scholes, "The Pricing of Options and Corporate Liabilities," *Journal of Political Economy* 81, no. 3 (1973): 637–654.
10. Robert C. Merton, "Theory of Rational Option Pricing," *Bell Journal of Economics and Management Science* 4, no. 1 (Spring, 1973): 141–183. Merton deliberately delayed the publication date of "Theory of Rational Option Pricing" until the paper by Black and Scholes was published in spring 1973.
11. Robert C. Merton, "On the Pricing of Contingent Claims and the Modigliani-Miller Theorem," *Journal of Financial Economics* 5 (November 1977): 241–249 (Chapter 13 in *Continuous-Time Finance*).
12. See Robert C. Merton, "Future Possibilities in Finance Theory and Finance Practice," *Mathematical Finance—Bachelier Congress 2000* (2002).
13. "China's Economic Rise: History, Trends, Challenges, and Implications for the United States," Congressional Research Service, February 2018.
14. "Japan Financial System Stability Assessment," IMF Country Report No. 17/244, July 2017.
15. Merton's functional perspective is likely a legacy from his father, the famous sociologist, Robert K. Merton. Robert C. Merton uses concepts and terminology coined by his father: manifest and latent functions, theory of the middle range, self-fulfilling prophecy, and many more.
16. See Robert C. Merton, "A Functional Perspective of Financial Intermediation," *Financial Management* 24, no. 2, (1995): 23–41; Peter L. Bernstein, *Capital Ideas Evolving*, Chapter 4: (Wiley 2007).
17. The project is described in detail in Robert C. Merton and Peter Tufano, *Intellectual Venture Capital: Essays in Honor of Dean John H. McArthur* (HBS Press, 1998).
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21. Robert C. Merton, "The Crisis in Retirement Planning," *Harvard Business Review*, July–August 2014.
22. Robert C. Merton, "The Future of Retirement Planning," *The Future of Life-Cycle Saving and Investing*, edited by Zvi Bodie, Dennis McLeavey, and Laurence B. Siegel, Research Foundation of CFA Institute, (2007); Robert C. Merton and Arun Muralidhar, "Time for Retirement 'SeLFIES'?", *Investments & Pensions Europe*, April 2017.
23. Merton retired from Harvard and returned to MIT in 2010.
24. Delivered at 2018 China International Conference in Finance, July 11, 2018, Tianjin, China.

Zvi Bodie is an occasional speaker at Dimensional Fund Advisors LP events and receives honoraria for his services. Robert C. Merton provides consulting services to Dimensional Fund Advisors LP.

A liability-driven investment (LDI) strategy is designed to focus on assets that match future liabilities. LDI strategies contain certain risks that prospective investors should evaluate and understand prior to making a decision to invest. These risks may include, but are not limited to, interest rate risk, counterparty risk, liquidity risk, and leverage risk.

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