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Fischer Black

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Fischer Black

WE HAVE LOST A MAJESTIC colleague and a dear friend in the untimely death of Fischer Black on August 30, 1995. He was only 57 years old. He loved the mixing of basic and applied research. He was often heard to say that the best pure research grows from efforts to solve applied problems—and that the best applied research to solve problems grows from intellectual curiosity. He surely best exemplified this dictum, both in applying the principles of financial economics to produce first-rate practice and in modeling practice to generate first-rate theory. Some academics have successfully moved to practice and even a few practitioners have successfully become academics. But Fischer was truly the rare case. He was facile at moving back and forth between the academic and business communities, often succeeding in both settings simultaneously. Few have matched in even one dimension Fischer's extraordinary curiosity, originality, dedication to scholarship, and intellectual courage to challenge the status quo of economic thought.

Fischer graduated from Harvard College with an A.B. in Physics in 1959 and went on to achieve a Ph.D. in Applied Mathematics at Harvard University in 1964. Typical of Fischer's marriage of theory with the application of theory, his thesis combined the fundamentals of logic with computer design. His first position was in computer science at Bolt Beranek & Newman, where he applied his thesis research to work on the theory of handling information for libraries and hospitals of the 21st century. He left to join Arthur D. Little, Inc. in 1965. There he consulted on a broad range of assignments, with primary emphasis on financial issues. Fischer described his motivation for the move as a desire to work on more applied problems that had a more immediate payoff. At Arthur D. Little, he met and was influenced by colleague consultants working on institutional and theoretical problems in finance; in particular, Fischer credited Jack Treynor, an innovative financial mind in his own right, with shaping his way of thinking about markets and risk and return.

It was during a consulting project to measure mutual fund performance in 1966 that Fischer first met Michael Jensen, then a graduate student at the University of Chicago. Later in 1968, knowing that his former Chicago classmate, Myron Scholes, was joining the faculty of MIT, Jensen, in turn, suggested that he contact "this interesting fellow" when he got to Boston. And so began a quarter-century collaboration that inexorably linked Black and Scholes. After a number of stimulating meetings, Scholes introduced Fischer to the MIT-finance workshop that was generally held on Tuesday evenings. It was there that Fischer first engaged finance academics, visitors as well as those associated with MIT giving papers there. As anyone who knew Fischer can imagine, the mix of personalities and the discussions led to lively debates on the merits of the ideas that were being presented. Fischer's involvement with academic researchers developed further when, in 1969, Jensen organized the first Wells Fargo conference of financial economists in Rochester, which

was to be followed in 1970 by a second conference organized by Scholes at MIT. About this time, Scholes introduced his new MIT colleague, Robert Merton, to Fischer.

The Wells Fargo conferences were the major vehicles through which Fischer met other financial economists and became integrated into the main line of academic research in financial economics. From the outset, Fischer was bubbling with new ideas. His self-professed poor memory led him to the practice of always writing those ideas down immediately, no matter what else was going on. This practice would later become a part of the Fischer Black lore in which he would interrupt his own lectures with periods of silence while he stopped to make notations as ideas were generated. Fischer circulated his working papers in the sincere hope of drawing constructive criticism. In turn, he generously devoted much time to giving detailed comments on the papers of those who interacted with him, a practice we all greatly appreciated and one that became another defining Fischer Black characteristic.

In 1969, Fischer left Arthur D. Little to form his own consulting firm, Associates in Finance. This move allowed him to devote systematically at least one day a week to pure research, a practice he continued throughout his career. About this time, Scholes was proposing a strategy to Wells Fargo that they abandon active pension-fund-money management for passive-fund management: Wells Fargo responded by proposing that a major research project be undertaken to explore its feasibility. Fischer, who was also exploring such an approach to money management, was a natural to join in the consulting project. Because Fischer was on his own with no research institutional affiliation, this consulting project was the essential funding vehicle for many of his important early papers on risk and return.

It was evident by 1971 that Fischer Black was making a significant intellectual contribution to the profession. Merton Miller at the University of Chicago invited Fischer to become the Ford Foundation Visiting Professor of Finance for 1971–1972. Miller, however, had longer-run ambitions. During Fischer's visit, a famous professor from a famous West Coast university called Miller and asked whether he thought that Fischer would be interested in accepting a position as an *assistant* professor at that university. Miller and his colleagues were already preparing to offer Fischer a *full* professorship. In the spirit of friendly academic competition, however, Miller did not attempt to dissuade the competition from going forward with *their* offer. In 1972, Fischer was appointed to a full professorship at the Graduate School of Business, University of Chicago. He enjoyed the experience immensely. With his strong beliefs in markets and rational behavior, he out-Chicagoed Chicago. However, because Fischer's wife and family had returned to Boston, Robert Merton and his colleagues saw an opportunity to entice Fischer to leave Chicago and come to MIT. They succeeded and Fischer returned to Boston in 1975 to become a Professor of Finance at the Sloan School of Management. From then until he left MIT in 1984, he fascinated his MIT colleagues and myriad graduate students with insights and questions. More than a decade later, former MIT Ph.D. students still regale colleagues with Fischer Black teaching and re-

search stories. For instance, Fischer offered a popular course built around a list of 50 questions. Although the list changed little from year to year, the students would return multiple times because, as they put it, "the questions are the same, but each year the answers change."

In 1984, Fischer was drawn back to the practitioner world seemingly full time when he joined Goldman Sachs & Company. He became one of the most successful "rocket scientists" on Wall Street and later became a Goldman partner. He nevertheless remained active in pure research, applying his knowledge to practice throughout the rest of his life. He also continued to publish his research findings in scientific journals while at Goldman. In fact, he was fond of pointing out that the puzzles he confronted as a practitioner did more to stimulate his pure research than those he encountered as an academic. At Goldman, Fischer worked on the application of quantitative methods to client problems in portfolio management, security design, and hedging. He developed models to value securities such as warrants, convertibles, high-yield bonds, and other instruments that clients issued. He developed models to value bond and interest-rate options. But most importantly, he was the intellectual leader of an enormously talented and successful applied research group at Goldman Sachs.

Even after leaving academe, Fischer continued to give extensive and critical research comments on the working papers and published papers of scholars in finance and economics. He would send letters, telephone, or more recently use e-mail to convey great excitement or disagreement with major points in a paper, explain why, and point out ways to make the paper stronger. Rather remarkably, these comments were often sent unsolicited to researchers he did not otherwise know. Furthermore, they were generally right on target. Although many disagreed with his suggestions and criticisms, none disputed his collegial generosity, his intellectual honesty and his purity of scholarship.

As we know, Fischer Black's best known and most important contribution to finance and economic science is the Black-Scholes Option Pricing model. It stands as one of the intellectual pillars supporting 25 years of remarkable development in finance theory. It also played a foundational role in the development of the option and derivative-security markets that are at the center of the extraordinary innovations in the global financial system during this same period. The magnitude of its immediate and combined impact on financial economic theory and practice is without parallel. Happily, the influence of this research is widely documented in a variety of trade and academic works, and the detailed story of how the formula was created is presented in "The Universal Financial Device," a chapter in Bernstein (1992).¹ It is, therefore, enough to note here that the fundamental Black and Scholes theoretical paper "The Pricing of Options and Corporate Liabilities," published in *The Journal of Political Economy* in May 1973 is among the most-cited papers ever in finance.² It is thus especially ironic that they had so much difficulty in getting

¹ Bernstein, Peter L., 1992, *Capital Ideas*, Free Press (New York).

² A complete list of Fischer Black's publications is included in the Appendix.

it accepted for publication in a refereed journal. Indeed, because of this difficulty, the empirical tests of their option pricing model appeared in print a full year earlier in the *unrefereed* annual sessions volume of *The Journal of Finance*.

Fischer published other significant papers on options and derivative contracts. These include "The Pricing of Commodity Contracts" (1976); "Valuing Corporate Securities: Some Effects of Bond Indenture Provisions." (with John Cox, 1976); "Simplifying Portfolio Insurance" (with Robert Jones, 1987); "Constant Proportion Portfolio Insurance and the Synthetic Put Option" (with Ramine Rouhani, 1989); "Theory of Constant Proportion Portfolio Insurance" (with André Perold, 1992); "A One-Factor Model of Interest Rates and Its Application to Treasury Bond Options" (with Emanuel Derman and William Toy, 1990); "Bond and Option Pricing When Short Rates Are Lognormal" (with Piotr Karasinski, 1991); and "Interest Rates as Options" (1995). In addition to these mathematically sophisticated works, Fischer wrote several nonquantitative papers explaining the substance and limitations of derivative contracts for practitioners and students. One was entitled "Fact and Fantasy in the Use of Options" (1975); others include "The Holes in Black-Scholes" (1988); "How We Came Up with the Option Formula" (1989); "How to Use the Holes in Black-Scholes" (1989); and "Living up to the Model" (1990).

As rightly recognized by financial academics and practitioners, the Black-Scholes Option Pricing model is the greatest jewel in the Fischer Black crown. But, we of the guild should also take note that whole tiers of Fischer's contributions qualify in their own right as research of the very first class. These can be partitioned into five substantive areas: 1) asset pricing, 2) design of financial markets and institutions, 3) portfolio management, 4) taxes and economic behavior, and 5) business cycles and monetary theory.

In the asset pricing area, Fischer was among the first to test the capital asset pricing model. His paper "The Capital Asset Pricing Model: Some Empirical Tests" (with Jensen and Scholes, 1972) provided a methodological standard that was widely emulated in subsequent empirical tests and extensions of the capital asset pricing model. Its substantive findings that low beta stocks outperformed high beta stocks led Fischer to expand the capital asset pricing theory to allow for the effects of restrictions on borrowing as a possible explanation of the empirical rejection of the standard model. His model was published in the paper "Capital Market Equilibrium with Restricted Borrowing" (1972). Other asset pricing papers include "Equilibrium in the Creation of Investment Goods Under Uncertainty" (1972); "Yes, Virginia, There Is Hope: Tests of the Value Line Ranking System" (1973), in which he found that the ranking system did have predictive power; "International Capital Market Equilibrium with Investment Barriers" (1974); "Studies of Stock Price Volatility Changes" (1976), in which Fischer showed that the volatility of the stock depended on the level of the stock's price; "Individual Investment and Consumption Under Uncertainty" (1988); "Mean Reversion and Consumption Smoothing" (1990); and "Beta and Return" (1993).

In the design of financial markets and institutions that includes the market microstructure area, Fischer wrote extensively about the markets in which securities were exchanged and the interaction of individual behavior with market mechanisms. One of his first papers in this area focused on the feasibility of a completely automated exchange in his paper "Toward a Fully Automated Exchange" (1971). This was followed with papers "An Approach to the Regulation of Bank Holding Companies" (with Miller and Posner, 1978); "What Should We Do About the Fools and Gamblers?" (1978) which was a forerunner to his presidential address at the American Finance Association annual meeting in 1985 entitled "Noise"; "The Future of Financial Services" (1985); "An Equilibrium Model of the Crash" (1988); "Does Technology Matter" (1989); "Estimating Expected Return" (1993); and most recently "Hedging, Speculation and Systemic Risk" (1995) and "Equilibrium Exchanges" (1995). Fischer was at the forefront of using theory to predict the institutions that should arise, if they do not already exist. A number of his predictions have come true, or are on the verge of coming true.

In portfolio management, Fischer had wide-ranging views. His early work with Jack Treynor on how to combine security analyst inputs with passive portfolios is currently used extensively in financial applications and in student instruction. Those two papers are "How to Use Security Analysis to Improve Portfolio Selection" (1973) and "Portfolio Selection Using Special Information, Under the Assumptions of the Diagonal Model, with Mean-Variance Portfolio Objectives and Without Constraints" (1972). Those views were expanded in a paper on asset allocation: "Asset Allocation: Combining Investor Views with Market Equilibrium" (with Robert Litterman, 1991). He wrote extensively on the implications of market efficiency for portfolio management and for accounting rules in the papers "Implications of the Random Walk Hypothesis for Portfolio Management" (1971); "Can Portfolio Managers Outrun the Random Walkers?" (1974); "The Accountants Job" (1976); "The Magic in Earnings" (1980); "A Simple Discounting Rule" (1988); and "Choosing Accounting Rules" (1993). His research in this area includes modeling of the portfolio allocation decision of portfolio managers. He wrote a paper describing the real-world structural difficulties in getting institutions and other investors to implement passive investment strategies entitled "From Theory to a New Financial Product" (with Myron Scholes, 1974). He followed this with "The Investment Policy Spectrum: Individuals, Endowment Funds and Pension Funds" (1976); "A New Investment Strategy for Pension Funds" (with Moray P. Dewhurst, 1981); "Should You Use Stocks to Hedge Your Pension Liability" (1989); "Global Portfolio Optimization" (with Robert Litterman, 1992), and most recently "The Plan Sponsor's Goal" (forthcoming in *Financial Analysts Journal*). Fischer applied the same theoretical reasoning in "Corporate Investment Decisions" (with Jack Treynor, 1976) and "The Ins and Outs of Foreign Investment" (1978). He became interested in international investing and addressed the key issue of the extent that investors should hedge foreign currency exposures in making international investments. This culminated in papers on universal hedging: "Universal Hedging: Optimizing Currency Risk and Reward in Inter-

national Equity Portfolios" (1989); "How I Discovered Universal Hedging" (1990); "Equilibrium Exchange Rate Hedging" (1990); and "Global Reach" (1992).

Fischer was deeply interested in and puzzled by the effects of taxes on individual and corporate decision-making. This he expressed in his papers on dividend policy: "The Effects of Dividend Yield and Dividend Policy on Common Stock Prices and Returns" (with Myron Scholes, 1974); "The Dividend Puzzle" (1976); and "Why Firms Pay Dividends" (1990). He developed the rather counter-mainstream view that for tax reasons it was inefficient for pension funds to hold assets other than bonds in "The Tax Consequences of Long-Run Pension Policy" (1980).

Fischer believed that finance was a special branch of economics. He held that the concept of general equilibrium was a deep and fundamental tool of analysis for finance. He also believed that the finance paradigm and its mathematical technology had much to offer for the better understanding of general economics. Nowhere is this more apparent than in his research on business cycles and monetary policy. Here, the themes of the capital asset pricing model, efficient markets, hedging, and dynamic equilibrium appear and reappear. Fischer believed that his contributions in this area would be seen, in the long run, as perhaps his most important, and he was truly excited about the implications of his work even though it was generally not accepted by mainstream macro-economists. The theories of those macro-economists relied more on market frictions to constrain and explain behavior of economic agents. But, in his dynamic macro models, Fischer showed that there would be economic incentives for agents to reduce the import of those frictions that constrained their behavior. Fischer took care to report that his earliest interest in the area arose from myriad discussions on macro-economic policies with Jack Treynor. His first paper was "Banking and Interest Rates in a World Without Money: The Effects of Uncontrolled Banking" (1970). This was followed by "Active and Passive Monetary Policy in a Neoclassical Model" (1972); "Uniqueness of the Price Level in Monetary Growth Models with Rational Expectations" (1974); "Global Monetarism in a World of National Currencies" (1978); and "The ABCs of Business Cycles" (1981). Fischer artfully discusses the difficulties in testing macro-economic models in his paper "The Trouble with Econometric Models" (1982). Fischer was very proud of his books on business cycles and macro theory, the first having been published in 1987 by Basil Blackwell: *Business Cycles and Equilibrium*. Even during his illness, he had the courage and tenacity to finish his second book *Exploring General Equilibrium*, published in 1995 by MIT Press.

This brief summary of Fischer Black's research cannot hope to capture the breadth and depth of honor and respect accorded him by the practitioner and academic communities. President of the American Finance Association in 1985 and selected Financial Engineer of the Year in 1994, Fischer received the Graham and Dodd Award for the best published paper in *The Financial Analysts Journal* four times, causing some to suggest that the Award be retired in his name. By way of further illustration, here are selected quotations from memorials to Fischer in trade publications around the world:

Fischer Black, financial economist and intellectual godfather of modern derivatives markets, died. . . . He was one of the most productive economic minds of his century and, had he lived, would surely have won a Nobel prize. . . . [He] provided, in effect, tools for calculating financial risk to a precise degree without having to make a guess about the likely direction of markets. . . . Softly spoken, and economical with words, those he used were rarely wasted. The Economist, (September 9, 1995).

Dr. Black, who was a Senior Fellow of the IAFE and the recipient of the 1994 IAFE/SunGard Financial Engineer of the Year Award, played a central role in the transformation of finance from a descriptive to an analytical science. IAFE Fall '95 Newsletter.

Eventually they hit on a formula. As a piece of engineering work emanating from MIT, it rivaled in importance the contributions of chemical engineering in the 1920s and 1930s or of electrical engineering of the 1930s and 1940s. Regarded as certain to share in a Nobel Prize in economics had he lived, Mr Black kept working virtually until the last. The Boston Globe (September 4, 1995).

A prince of finance is dead at 57. . . . Fischer Black . . . was the world's single most remarkable advertisement for business education—a man who, like Louis Pasteur, combined deep thoughts with practical applications. The Boston Globe (September 5, 1995).

That solution helped lay the cornerstone for today's vast global options market, a marketplace that touches almost everyone with a stake in the capital markets. . . . New York Times (August 31, 1995).

Fischer made very significant contributions across many areas at Goldman Sachs. For his creativity and original thinking, his thoughtfulness and dry wit, we shall miss him. Goldman Sachs & Co.

Repeatedly refined, the Black-Scholes valuation model has touched broad areas of corporate finance, from executive compensation to market risk management. . . . Black moved easily between the worlds of business and academia. . . . Although he had few academic credentials, "we knew genius when we saw it," said [Merton] Miller. . . . Mr William Floresh, vice chairman of the CBOE describes the impact of the Black and Scholes work as "staggering." "Without a mathematical model that could predict comfortably where options prices could fall, we would not have had the participation of big investors that we have seen." he said. [He] also pioneered the use of indexed, or "passive" management for mutual funds, a strategy now employed by some 30 percent of US retirement funds." The Financial Times (September 3, 1995).

[He was] among a cadre of "rocket scientists" whose work in the 1960s and 1970s moved finance beyond the realm of banking and elevated risk

management to a science. . . . Fischer Black thrived on the practical applications of his work, and easily bridged the business and university communities. . . . Although frail from his fight with cancer, the last year of his life, Black continued to write and share comments and criticism with colleagues and academic associates. Futures Industry (October/November, 1995).

Seminal contributor to theoretical, empirical, applied, and practical finance, Fischer Black was universally respected and liked. So it was that in July, about six weeks before his death, Fischer's friends, colleagues, and admirers arranged a collective tribute, which was presented to him in a letter. Since Fischer responded to that letter with great emotion and outright joy, we include it in excerpted form:

Dear Fischer:

Your many friends, colleagues, and admirers want to honor you and to celebrate your seminal contributions to finance and economic science. They have decided to do so in three parts: a chair, a prize and a collection of your scientific papers.

They will establish a chair in the Sloan School of Management: The Fischer Black Visiting Professor of Financial Economics at the Massachusetts Institute of Technology. The holders will be first-rate minds whose contributions are either in finance directly or in the applications of finance principles to the analysis of general economics. Holders of the Chair should exemplify the research qualities of its eponym: originality, curiosity, dedication to scholarship, intellectual honesty, and the courage to challenge the status quo. The holder's work should demonstrate a commitment to the fundamental thesis that good research influences good practice. Reflecting your own career, successive holders of the Chair are expected to come from both the academic and practitioner communities.

The choice of a visiting instead of a permanent professorship is intended to encourage the development and exchange of new ideas and perspectives in finance. It will also help MIT specifically, and the profession more generally, to avoid intellectual in-breeding and stagnation. The Chair-holders will have no regular teaching responsibilities. Instead they will be expected to give a series of lectures on topics of special interest and be a general intellectual resource for the MIT faculty. As you have done for so many of us, Chair-holders should offer detailed and critical comments on the finance faculty's research.

The Fischer Black Prize is being created to honor individual financial research. It will be awarded biennially for a body of work that best exemplifies the Fischer Black hallmark of developing original theoretical research concepts that have a direct and significant impact on finance practice. The Prize will be supported by an endowment and administered by the Board of Directors of the American Finance Association.

The collected scientific papers of Fischer Black must be published. Happily, we understand that just such a volume is already underway at MIT Press. As a complement to that volume, extensive review of the collected works will be written that trace the intellectual development of the ideas, identify patterns of continuity, both across subject matter and through time, pointing out instances of fundamental changes in thought. They will include reflections on the self-integrated perspective provided by your two books. The authors of the reviews will be contemporaries of yours who can offer first-hand descriptions of the initial impact of your research on academics and finance practice. . . .

The three parts are conceived as an integrated whole to recognize your contributions and to thank you on behalf of all—past, present, and future—who benefit from them. The Chair will be the most physically enduring of the three since MIT will always be there. The Prize will have the most immediate and dynamic significance with its direct linkage to ongoing research and current practice. And the volume will be the most intellectually enduring because it provides a permanent record of your important collective contributions to economic thought.

We . . . a large group of colleagues, support this initiative and pledge to realize it. We all count you as a friend. All of our minds have been broadened by your work. All have enjoyed disagreeing with you from time to time. All hope that this celebration of you and your work will bring you great satisfaction.

With sincere thanks and deep admiration.

On receiving this tribute, Fischer, in his typically modest way, expressed “stunned” surprise that his friends and colleagues chose to honor his contributions. He was clearly overjoyed at the tribute. Fischer was especially touched that the details of the three parts—the visiting professorship, the prize, and the commentaries on his contributions—so closely captured his values about science. As he put it, “Someone out there seems to know me! . . . I hope it helps to spread my enthusiasm for finding useful truths.” He saw the award as unique. This is the way he wanted to be remembered.

We have known Fischer for nearly 30 years. To some, with his tall, thin figure and his quiet speech, he might have appeared aloof. He was not. He was charming, quick to laugh, and known to use wit when appropriate. He loved his children and was proud of their accomplishments. He was truly excited about discovery and truth. He loved finance. We miss Fischer Black. He enjoyed sharing his ideas and his life’s experiences with us. We learned from him and he learned from us. Many times now we find ourselves asking, What would Fischer say about that idea? Only Fischer truly knows. There are many in the guild who lay claim to him as we do. We say good-bye to a great friend and colleague.

Robert C. Merton

Harvard University and Long-Term Capital Management, L.P.

Myron S. Scholes

Stanford University and Long-Term Capital Management, L.P.

Appendix

Publications of Fischer Black

Books

Exploring General Equilibrium. (Cambridge, MA: MIT Press, 1995).

Business Cycles and Equilibrium. (New York and Oxford: Basil Blackwell, 1987).

Papers

"Neutral Technical Change." unpublished memorandum.

"The Plan Sponsor's Goal." forthcoming in *Financial Analysts Journal*.

"Interest Rates as Options." *Journal of Finance* 50, 1411–1416.

"Hedging, Speculation, and Systemic Risk." *Journal of Derivatives* 2 (Summer, 1995), 6–8.

"Equilibrium Exchanges." *Financial Analysts Journal* 51 (May/June, 1995), 23–29.

"Using a One-Factor Model to Value Interest Rate-Sensitive Securities: With an Application to Treasury Bond Options." (with Emanuel Derman, William Toy and Jack C. Francis). In Jack Clark Francis and Avner Wolf, eds. *The Handbook of Interest Rate Risk Management* (Burr Ridge, IL: Irwin Professional Publishing, 1994), 302–320.

"Choosing Accounting Rules." *Accounting Horizons* 7 (December, 1993), 1–17.

"Estimating Expected Return." *Financial Analysts Journal* 49 (September/October, 1993), 36–38 (Graham and Dodd award winner).

"Beta and Return." *Journal of Portfolio Management* 20 (Fall, 1993), 8–18.

"Global Reach." *Risk Magazine* 5 (December, 1992), 27–32.

"Global Portfolio Optimization." (with Robert Litterman). *Financial Analysts Journal* 48 (September/October, 1992), 28–43.

"Theory of Constant Proportion Portfolio Insurance." (with André F. Perold). *Journal of Economic Dynamics and Control* 16 (1992), 403–426.

"Asset Allocation: Combining Investor Views with Market Equilibrium." (with Robert Litterman). *Journal of Fixed Income* 1 (September, 1991), 7–18.

"Bond and Option Pricing When Short Rates Are Lognormal." (with Piotr Karasinski). *Financial Analysts Journal* 47 (July/August, 1991), 52–59.

"Equilibrium Exchange Rate Hedging." *Journal of Finance* 45 (July, 1990), 899–907.

"Why Firms Pay Dividends." *Financial Analysts Journal* 46 (May/June, 1990), 5.

"Mean Reversion and Consumption Smoothing." *Review of Financial Studies* 3 (1990), 107–114.

"Living Up To the Model." *Risk Magazine* 3 (March, 1990), 11–13.

"How I Discovered Universal Hedging." *Investing* 4 (Winter, 1990), 60–64.

"A One-Factor Model of Interest Rates and its Application to Treasury Bond Options." (with Emanuel Derman and William Toy). *Financial Analysts Journal* 46 (January/February, 1990), 33–39.

"Universal Hedging: Optimizing Currency Risk and Reward in International Equity Portfolios." *Financial Analysts Journal* 45 (July/August, 1989), 16–22 (Graham and Dodd award winner).

"Does Technology Matter?" In Henry C. Lucas, Jr. and Robert A. Schwartz, eds. *Information Technology for the Securities Markets*. (Homewood, IL: Dow Jones-Irwin, 1989), 151–152.

"Should You Use Stocks to Hedge Your Pension Liability?" *Financial Analysts Journal* 45 (January/February, 1989), 10–12.

"How To Use the Holes in Black-Scholes." *Journal of Applied Corporate Finance* 4 (Winter, 1989), 67–73.

- "How We Came Up with the Option Formula." *Journal of Portfolio Management* 15 (Winter, 1989), 4–8.
- "Constant Proportion Portfolio Insurance and the Synthetic Put Option: A Comparison." (with Ramine Rouhani). In Frank J. Fabozzi, ed. *Investment Management*. (Cambridge, MA: Ballinger, 1989), 695–708.
- "Simplifying Portfolio Insurance for the Seller." (with Erol Hakanoglu). In Frank J. Fabozzi, ed. *Investment Management*. (Cambridge, MA: Ballinger, 1989), 709–726.
- "An Equilibrium Model of the Crash." In Stanley Fischer, ed. *NBER Macroeconomics Annual* 1988. (Cambridge, MA: MIT Press), 269–275.
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- "Noise." *Journal of Finance* 41 (July, 1986), 529–543.
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- "Bank Funds Management in an Efficient Market." *Journal of Financial Economics* 2 (December, 1975), 323–339.
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