CAPITAL IDEAS

The Improbable Origins of Modern Wall Street

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Chapter
11

The Universal Financial Device

We did not make money but we did learn some more truth.

In Book I of *Politics,* Aristotle conducts a lengthy analysis of the accumulation of wealth. He takes a dim view of the whole thing. Although he considers such matters "not unworthy of philosophy," he adds that "to be engaged in them practically is illiberal and irksome." He refers in particular to earnings from interest—the Greek word for which, "tokos," literally means "offspring." He then observes: " . . . interest, which means the birth of money from money, is applied to the breeding of money because the offspring resembles the parent. Wherefore, of all modes of getting wealth this is the most unnatural."

Aristotle goes on to tell the story of the philosopher Thales the Milesian, who developed a "financial device which involves a principle of universal application." People had chided Thales because he was a poor man, taking his poverty as proof that philosophy is of no practical use. Thales knew what he was about, however, and set out to demonstrate the foolishness of this reproach.

Thales had exceptional skill in reading the stars. One winter he foresaw that the autumn olive harvest would be much larger than normal. He took the little money he had saved up and paid quiet visits to all the owners of olive presses in the area, placing small deposits with each of them to guarantee him first claim on the use of their presses when fall arrived. He was able to negotiate low prices, for the harvest was still nine months off, and, anyway,

who could know whether the harvest would be large or small. The story ends as you may have guessed: "When the harvest-time came, and many [presses] were wanted all at once and of a sudden, he let them out at any rate he pleased, and made a quantity of money. Thus he showed the world that philosophers can easily be rich if they like, but that their ambition is of another sort."

Aristotle's anecdote about Thales and his financial device is the first recorded mention of the instrument that has come to be known as an option. An option is essentially a contract that gives the owner the right to take a stipulated action under conditions specified and agreed to in advance.

Option contracts do not oblige the owner to act unless he wishes to do so. If the olive crop had turned out to be disappointing, Thales would have let his options lapse; he would have exercised them only if the crop had turned out to be great enough to overwhelm the olive-pressing capacity of the community.

A 1688 treatise on the workings of the Amsterdam stock exchange by Joseph de la Vega reveals that options and similar types of securities in common use today were already dominating trading activities at the time. This is significant, as Amsterdam was the most sophisticated and important financial center of the seventeenth century, even more important than London. And we have seen that Louis Bachelier, in the course of writing his thesis in Paris in 1900, was attracted to the problem of valuing options.

Options are everywhere around us. The father who tells his little boy to stop watching television and go to bed "or else" is giving his son an interesting option. The boy has no obligation to turn off the TV and go to bed, but his father has given him the right to take up the option of keeping the set on and accepting his punishment. A direct command to abandon the living room for the bedroom would not have been an option.

Thales won out on his options because, as it turned out, he had a better idea than the press owners of how big the harvest was going to be. Still, his arrangement would have made sense even if he had been less prescient. The owner of an olive grove might simply have wanted to hedge against the risk that, come harvest time, no presses would be available for his crop. He could buy an option on the use of the presses, taking it up if the crop turned out to be large, letting it lapse if the crop was small. It would cost him something, but, as with any hedging scheme, it would protect him against catastrophe.

Options perform an almost endless variety of functions. Some people seek a high return; others hope to hedge their risks. Each group accommodates the other. People like Thales, who believe they know what the future holds, use options to speculate on the future; they are willing to run the risk of losing a small amount in return for the hope of making a much larger gain. People like the olive growers, who have no knowledge of the future, will pay a small amount to hedge against risks and to limit losses that might otherwise ruin them; those options will also provide some revenue for the owners of the presses that will come in handy if the crop turns out to be poor.

The primary function of options is to give investors some control over how changes in the market will affect their portfolios. For a cost, buyers of options can limit losses without placing any limits on their profits. They can also use options to give them time to see how the market moves before committing their full capital. Sellers of options who expect little change in market prices can pocket an extra premium. In short, options satisfy the needs of both hedgers and speculators.

In the world of business and finance, there are markets in options on thousands of individual stocks and on the major indexes of the stock market as a whole, both in the United States and in foreign financial centers as well. There are options on bonds, commodities, foreign currencies, and on so-called futures and forward contracts that obligate the holder to deliver these assets to another party before a specified date.

There are also less visible options that are even more pervasive. Bonds that the holder can convert into common stock at will and bonds whose issuer has the right to prepay them are known as implicit options.

Anyone who has ever taken out a home mortgage with a prepayment privilege has purchased an option from the bank. The cost of that option is included in the interest rate on the mortgage, which will be higher than it would be without the prepayment privilege.

When you insure your car against collision, you are buying an option from the insurance company. That option will be worthless if you never have an accident—you pay the premium and collect nothing. But if your car is totaled, you have the right to leave what remains of it with the insurance company and collect a check for the insured amount.

An option that gives the holder the right to acquire an asset is known as a call option. Thales bought a call option on the olive presses. A homeowner with a prepayment privilege on the family mortgage also has a call option, because the family has the right to repurchase the mortgage from the bank if interest rates decline. An option that gives the holder the right to require another party to buy an asset at the will of its owner is known as a put option. You buy a put option when you insure your car against collision. Put options cover situations in which asset values are likely to fall; call options cover situations in which asset values are likely to appreciate.

My investment counseling firm began using options markets in the mid-1960s when we set up a small speculative mutual fund for our clients. In those days, nobody thought very much about how to value options in any systematic manner. Rules of thumb sufficed.

Options on a small number of big stocks traded over-the-counter at that time, with prices set largely by seat-of-the-pants negotiations. We sold calls on the stocks owned by our fund—that is, we gave others the right to buy those stocks from us at prices specified ahead of time—because the belief among professionals was that the speculators who bought calls were characteristically overoptimistic and tended to pay too much for them. In selling calls, we were betting that the greed of the buyers would give us a built-in advantage.

As we were winging it in the over-the-counter options market, we had little theoretical basis for the prices at which we made our transactions. The only considerations we explicitly factored in were time and the rate of interest. The longer the owner of the call enjoyed the right to buy a stock from us, the higher the price we charged. Because the call could be exercised at any moment during that time, we had to be ready to provide the shares to the option-owner when the call came. This tied up our money and cost us interest income, while the option-owner kept earning interest on his money right up to the moment he decided to exercise the option. The premium we received had to compensate us for that lost interest.

One other matter seemed too obvious to require much attention. The call options stipulated a price—called the exercise price—at which the owner could buy the stocks from us during the life of the option. At an exercise price of $50, the option

would be worth more when the stock was selling at $60 than when it was selling at $40. At $60, the option was worth at least $10, and more on the chance that the stock might go even higher (unless the option was about to expire). In such a situation the option is said to be in-the-money. The option would be out-of-the-money when the stock was selling below the exercise price; the option would have no intrinsic value under those conditions. The world of out-of-the-money options was murky, and the bargaining between us and the buyer was less systematic.

We were happy skimming a nice return from speculators who were as unsophisticated but hungrier than we. What we did not know was that a theory to establish the scientific principles for valuing options was just then becoming a hot topic among the finance and economics faculty at MIT. This was heady business for mathematically inclined economists, because it called for a harmonized response, on the one hand, to the uncertainty of how the price of the stock would move and, on the other hand, to the factors we were already taking into account:—time, interest rates, the current price of the stock, and the exercise price specified in the option contract.

I saw Paul Samuelson once in a while on social occasions, but I was unaware that he, as usual, had started another ball rolling with a paper published in 1965, "Rational Theory of Warrant Pricing." Warrants are essentially the same as options. They give the owner the right to buy a specified number of shares of stock at a specified price during a specified period of time; as with options, the owner is under no obligation to exercise that right. There are two minor differences. Warrants are issued by corporations and sold by them to investors, while investors create and sell options to one another. And warrants typically run a much longer time than options before they expire.

Samuelson's paper was the culmination of some ten years of work, inspired in part by his first looking into Bachelier and in part by the simple desire to make some money for himself—the desire that had led him originally to subscribe to the "RHM Warrant and Low-Price Stock Survey." Kruizenga, the student who had been sent back to the drawing boards in 1956 by the discovery of Bachelier's work, was writing his doctoral thesis on this very subject at Samuelson's suggestion.

Samuelson's paper almost succeeded in solving the valuation problem, but—uncharacteristically—he did not quite get there on

this particular occasion. Although his solution was on the mark, it was not sufficiently generalized to be applicable in all instances. Samuelson himself has noted that "the results of the paper were not obvious. . . . [I] was not sure how they would come out until the work was done." Although his younger colleagues would build on his work later on, Samuelson's frustration at his inability to develop a formula for all seasons once led him to complain that "Too little is written about the 'near misses' in science."[1]

Samuelson was not alone in his search. In addition to the two papers by Kruizenga in the late 1950s, Paul Cootner's book, *The Random Character of Stock Market Prices,* included a paper on warrant prices by Case Sprenkle dated 1960, based on a Ph.D. thesis at Yale and acknowledging an intellectual debt to James Tobin. Cootner's book also contained papers on the subject by A. James Boness and Herbert Ayres, both of whom had done the underlying work while studying at MIT. MIT must have been a hotbed of curiosity about options and warrants.

The prime movers in bringing the theory of option pricing to fruition were Fischer Black, a young mathematician in Boston who would end up on the MIT faculty, and Myron Scholes, a fledgling member of the MIT faculty.

At the time Black began his study of options, he had little awareness of Samuelson or his work, had not yet arrived at MIT, had never taken a course in either economics or finance, and had no idea that he would ever be associated with Samuelson or MIT. Black had graduated from Harvard in 1959 with a degree in physics and with considerable exposure to mathematics and psychology. He received his Ph.D. at Harvard in 1964 in applied mathematics, with an emphasis on operations research, logic, computer design, and artificial intelligence. His main interests were in applying these subjects to methods for processing information.

A year after receiving his doctorate, Black decided his studies had been too abstract. Seeking a spot in the world of business, he took a job at Arthur D. Little. There he met Jack Treynor and the two became fast friends. Treynor, who was still deep in ruminations about the Capital Asset Pricing Model, found Black a stimulating intellectual companion. Black became so fascinated by CAPM that he gradually gave up his work with computers and information processing and shifted to finance.

Black's decision to switch career paths is another example of

how the study of financial markets seems to pull scientists into its orbit. Bachelier was lured from mathematics, Sharpe from medicine, Osborne from astronomy, Working and Kendall from statistical theory, and Treynor from physics and math.

Black decided that the Capital Asset Pricing Model was right up his alley—"the notion of equilibrium in the market for risky assets had great beauty for me. . . . I worked on the Capital Asset Pricing Model because I wanted to discover the truth."[2] He was especially attracted by what he calls the "cruel truth" of the model: "To get higher expected gain, you must take more risk. If you wish to climb a tall mountain, you must be prepared to suffer some pain."[3]

The linkage between gain and pain is what propels the market toward the equilibrium that Modigliani and Miller had described and in which Black believes passionately. Although Black recognizes that "noise traders" frequently drive asset prices away from their intrinsic values, he rejects the notion that chaos plays any role in the financial marketplace: "When people are seeking profits, equilibrium will prevail."[4]

By happenstance, Black learned how to fit this concept into the structure of financial theory by serving as intermediary in a debate on the issues between Treynor at ADL and John Lintner at Harvard Business School. Each would tell Black, "This is the way it is in finance." Treynor refers to this exchange as a "strange dialogue," but, in view of Black's subsequent career, his education as intermediary must have been very good.[5]

A short time after Treynor left Arthur D. Little and Boston to work for Donald Regan at Merrill Lynch in New York, Black inherited some of the work that Treynor had been doing at ADL in analyzing and designing portfolio management systems. Inspired by what Treynor had done, Black set out to apply the Capital Asset Pricing Model to assets other than stocks. He experimented with it on bonds, corporate decisions on direct investments in plant and equipment, and the pricing of warrants.

Black chose to work on warrants rather than options because the pricing of options in the over-the-counter market at that time—the market in which my firm was dabbling—was less efficient than the pricing of warrants, which traded on the active markets at the New York and American stock exchanges.

When he applied the Capital Asset Pricing Model to the valuation of warrants, Black assumed that both the warrant and the

associated stock would obey the model at every moment and at every possible price of the stock. In other words, each would have an expected gain "proportional to the part of its risk that can't be diversified away"—proportional, that is, to its beta, or its relative volatility.[6]

That assumption can be expressed by means of calculus, which is a method for comparing rates of change among different variables. That comparison, in turn, coupled with the assumption that both the stock and the warrant are priced according to the Capital Asset Pricing Model, leads to an equation known as a differential equation. Black expected that solving this equation would give him a formula for finding the value of the warrant at any given price of the associated stock.

Deriving the differential equation was the easiest part of the task, because, as Black admits, he did not know the standard methods for solving such equations. Converting the differential equation into a formula that would give the value of the warrant turned out to be far more difficult than deriving it in the first place.

But for Black persistence is the name of the game. A poster in his office shows a man running down a long country road, with the caption "The race is not always to the swift but to those who keep running." Black recalls the frustration he felt:

> I applied the Capital Asset Pricing Model to every moment in a warrant's life, for every possible stock price and warrant value. . . . I stared at the differential equation for many, many months. I made hundreds of silly mistakes that led me down blind alleys. Nothing worked. . . .
>
> [The calculations revealed that] the warrant value did not depend on the stock's expected return, or on any other asset's expected return. That fascinated me.
>
> He adds: "Then Myron Scholes and I started working together."[7]

That was in 1968. Scholes, who had graduated from McMaster University in Hamilton, Ontario, in 1962, had recently received his doctorate in finance from the Graduate School of Business at the University of Chicago, at which point he had two job offers: The University of Texas at Austin offered him a teaching job at $17,000 but held out the temptation of juicy fees from consulting work with the local millionaires. MIT offered him an $11,500

teaching job, with no hint of side benefits. Scholes chose the MIT offer.

Black and Scholes were an even odder couple than Modigliani and Miller. Black is fair, blue-eyed, cool, soft-spoken, tall, and courtly. His words are few and usually monosyllabic, his sentences mostly declarative (though he asks questions too). His presidential address to the American Finance Association in 1985, with the simple title "Noise," took him less than fifteen minutes to deliver; such speeches usually run at least three-quarters of an hour. That paper has turned out to be one of the most frequently cited papers in the literature. The paper on option pricing that he wrote with Scholes, though extremely complicated, begins: "The simplest kind of option is one that gives the right to buy a single share of common stock."[8]

Scholes is dark, voluble, and temperamental. Always ready for an argument, he would have made an unbeatable litigator. When Merton Miller, no shrinking violet, sent me a photograph of himself walking with Scholes on the University of Chicago campus, he remarked, "Guess who's doing the talking!"[9] Yet Scholes is often disarmingly gracious, and his friends are deeply attached to him.

I first met Scholes when he was the discussant for a paper I gave in December 1972 at the annual meeting of the American Finance Association. The subject was "What Rate of Return Can You Expect?" I concluded that the stock market was so high that, even under the best of circumstances, the rate of return I could foresee was too small to justify the risk of staying in. Scholes, immersed in the philosophy of the efficient market, argued that my kind of forecast was impossible.* If the expected rate of return was as poor as I found it to be, investors would refuse to buy stocks and stock prices would already have fallen. He had no confidence in the ability of any one individual to know more about the future than all the informed individuals whose buying and selling set the prices of stocks and bonds each day. He declared that he expected a much higher return than what I was predicting and that he would continue to be fully invested in a diversified portfolio of common stocks.

*This assertion is comparable to the apocryphal story about the Chicago University professor whose student spotted a $100 bill on the sidewalk. "The bill is not there," expostulated the professor. "If it were, the market is so efficient that someone would already have picked it up." But how many $100 bills do we find lying on the sidewalk?

Luck was with me on this occasion, though I would still defend my analysis. The stock market did not return to the levels of late 1972 for another ten years. Scholes recently asked me, "Are you still keeping score?"[10]

Like many of the other actors in this story, Scholes did not start off with his eye on finance. He had originally planned to go to law school after college, but his family wanted him to join them in their book publishing business. "Naturally rebellious," as he describes himself, he decided he was not ready to go into business and enrolled at Chicago Business School. He loved it: "I will never get over the joy and excitement those professors had about their work."[11]

Scholes turned down his family's invitation to spend his summer vacation working in the family business and took a job at the University that he hoped would help him to learn about computers. He was low man at the computer programming center, but no one showed up to help him out. So he taught himself. He got so good at programming that he became the favorite programmer among the school's professors, who were still, in Fama's phrase, "computer illiterates." One of those professors was Merton Miller, who introduced Scholes to financial theory and encouraged him to enter the Ph.D. program at Chicago.

Scholes's doctoral dissertation was an original and powerful piece of theoretical and empirical research that supported the efficient market hypothesis. He took as his subject the impact on the market of large sales of stock by major holders.

Scholes argued that investors are more interested in portfolios than in individual holdings, which means that all securities are potential candidates for inclusion in investor portfolios. If each security is only a small percentage of the assets held in a portfolio, many securities are readily substitutable for one another. "The efficient market will price assets such that the expected returns of assets of similar risk are equal," he concluded.[12] Under these conditions, the price of a stock should not decline just because some larger seller wants to get rid of it—unless, that is, the fact that that particular investor wants to sell the stock constitutes new information.

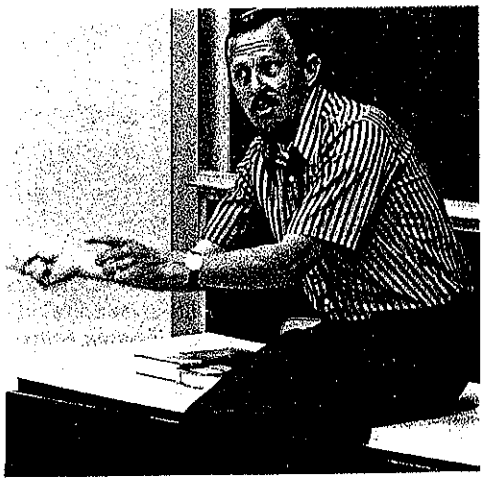
Scholes's painstakingly thorough empirical analysis demonstrated that prices do tend to move when the seller is likely to have adverse information not available to the public, such as information available only to the corporation itself or to its officers

"The industrial market is destined to be the great speculative market in the United States," declared Charles Dow in 1882, at a time when less than a dozen industrial stocks were listed on the New York Stock Exchange. Dow was also convinced that stock prices were predictable—an assertion that would fire controversy for decades to come; it met its first powerful theoretical challenge twenty years later from Louis Bachelier. Dow started his Wall Street career in 1879 writing news bulletins carried to subscribers by messenger boys and was the first editor of the *Wall Street Journal. (Courtesy Dow Jones & Company, Inc.)*

An enthusiastic amateur statistician and scion of a Chicago Tribune fortune, Alfred Cowles was inspired by the Great Crash of 1929 to launch the first investigation into whether the experts can predict stock prices. Foreshadowing the work of future scholars, his pioneering statistical analysis arrived at the blunt conclusion, "It is doubtful." He founded the Cowles Commission in Economic Research, bankrolled the Econometric Society, and his work formed the basis for what is now known as Standard & Poor's stock indexes. *(Photo by Moffett Studio)*

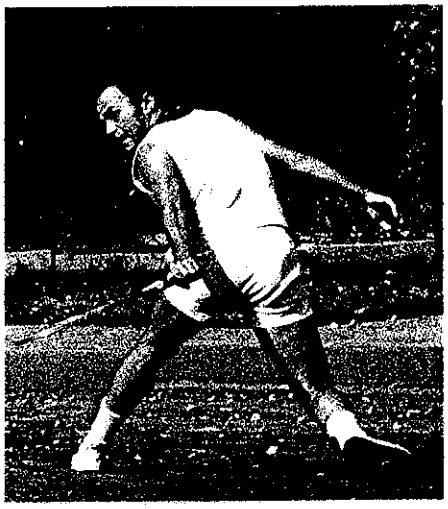
"Nothing ventured, nothing gained" and "Don't put all your eggs in one basket" are the immutable principles for selecting securities for an investment portfolio. In 1952, Harry Markowitz *(above left)*, a graduate student in economics at the University of Chicago, took only one afternoon to convert these homespun notions into a set of rules involving the use of diversification and optimization of the tradeoff between risk and return. Markowitz's ideas became the building blocks for all future advances in financial theory and practice, and he won the Nobel Prize in economic sciences in 1990. Just four months after Markowitz's article on portfolio selection appeared in 1952, Cambridge University professor and former artillery officer Andrew Roy *(above right)* published an article on the same topic that followed an almost identical line of argument. Yet Roy and Markowitz had never heard of each other. The resemblance between the two articles was all the more remarkable because no one had ever before tried to develop a theory of portfolio selection.

Investors taking a traditional approach to portfolio management would be shocked at the suggestion that an elderly widow with modest capital should hold the identical set of common stocks to a successful young business executive. One reason that James Tobin of Yale *(left)* won the Nobel Prize in 1981 was his 1958 paper that turned the traditional theory of portfolio management on its head. Tobin's analysis demonstrated that the appropriate equity portfolio for any investor should be independent of the investor's attitude toward risk. *(Photo by T. Charles Erickson, Yale University Office of Public Information)*



In 1961, William Sharpe *(left)*, who was studying under Harry Markowitz at the time, took a footnote in Markowitz's Ph.D. dissertation and combined it with Tobin's work to explain how the behavior of the market as a whole determines the performance of individual portfolios. Sharpe subsequently used these ideas to build asset-pricing theories. In 1990, he shared the Nobel Prize with his mentor, Markowitz. *(Courtesy of News and Publication Service, Stanford University)*

"It is not easy to get rich in Las Vegas, at Churchill Downs, or at the local Merrill Lynch office," proclaimed Paul Samuelson of MIT *(right)* in a paper in the early 1960s that was to form the basis for the development of the random-walk concept and the efficient-market hypothesis. Samuelson was among the first economists to resurrect Louis Bachelier's argument of 1900 that stock picking is a zero-sum game. Shown here in the 1950s, Samuelson was the first American to win the Nobel Prize in economic sciences.

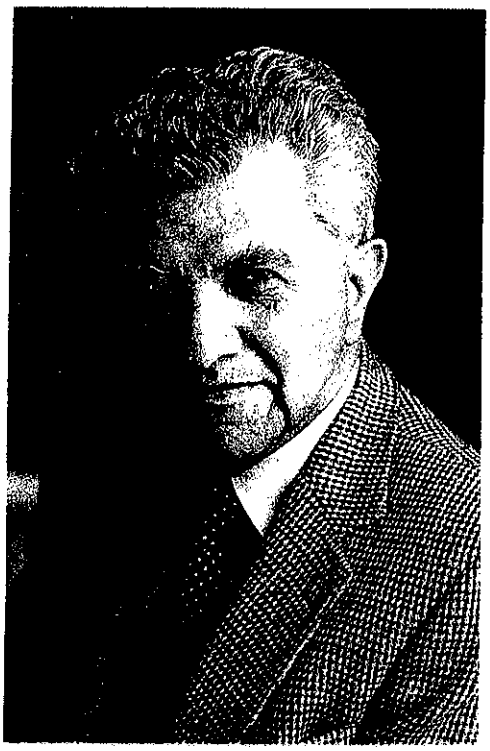


Eugene Fama *(left)* deserted the study of French civilization to find out why his after-school job trying to develop profitable investment strategies produced such impressive results on paper and such disappointing results in practice. His efforts led to proofs supporting the hypothesis that even the smartest analysts cannot beat the market, primarily because there are so many smart analysts trying to do just that.

In the mid-1950s, the investment course at Harvard Business School was so boring students dubbed it "Darkness at Noon." Jack Treynor left HBS at that time "with an enormous impression that finance needed help." Three weeks of "unremitting meditation" resulted in his most important paper – never published – a theory of how investors incorporate risk into the pricing of stocks; his approach was almost identical to Sharpe's and was developed at just about the same moment. *(Photo by Fabian Bachrach)*

After a notable professional career at Chicago and MIT, Fischer Black led the parade from gown to town by joining Goldman Sachs in 1984. He originally started out in science and mathematics and never had a course in economics or finance. In 1965 while working at Arthur D. Little in Boston, he met Jack Treynor and was captivated by his theories. Although not yet an academic, Black collaborated with Myron Scholes and Robert Merton in the early 1970s to develop the most widely used formula for pricing options.

Nobel Laureate Franco Modigliani of MIT was described by his younger colleague Merton Miller, with whom he worked "cheek by jowl" at Carnegie Tech in the late 1950s, as having "the mind of an Italian arbitrageur." This was not altogether in jest:Modigliani and Miller made arbitrage the central feature of their argument that the value of the corporation is independent of its capital structure. In doing so, they took the crude rules of thumb that had dominated corporate financial decisions and replaced them with rigorous theoretical analysis.

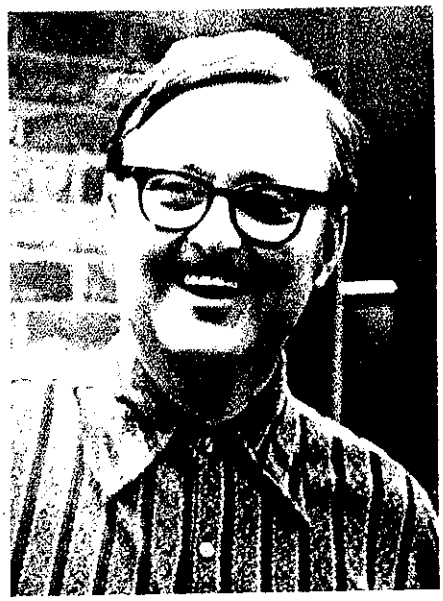


Merton Miller, who shared his Nobel Prize in 1990 with Harry Markowitz and William Sharpe, is the other "M" of the "MM" propositions. Miller excels in the art of the controversial. He has employed his knowledge of taxation and finance to defend the leveraging of corporations in the 1980s and to play down widespread alarm at these developments. He played a critical role in shaping the careers of such younger scholars as Fischer Black, Eugene Fama, Myron Scholes, William Sharpe, and Jack Treynor.

Fischer Black had been stuck on the options problem for "many, many months" when he started working with Myron Scholes. Scholes collaborated with Black to unlock the puzzles of option pricing. Their article on the subject was rejected at first as excessively specialized, but thanks to Merton Miller's intervention it finally appeared just as the Chicago Board Options Exchange opened for business in 1973. The Black–Scholes formula was soon in general use there and has subsequently formed the basis for many investment, trading, and corporate finance strategies. *(©1990 photography by Andy Feldman)*

In 1968, MIT was the only graduate school that would accept Robert Merton, now of Harvard Business School, when he decided to abandon math for economics. Paul Samuelson immediately selected Merton as an assistant and collaborator and stimulated his interest in option pricing. Merton was also an active participant with Black and Scholes in working out their formula for pricing options. His development of the concept of continuous-time finance has dramatically extended the power of finance theory and enhanced the practical applications of asset pricing and option pricing theories. *(Photo by Bradford F. Herzog)*

"Can you really run money with this stuff?" asked the chairman of Wells Fargo Bank in 1963 when John McQuown offered to provide the bank with real-time investment applications of theories of Markowitz, Sharpe, and Fama. McQuown leaned heavily on the academics to help him pull Wells Fargo—and Wall Street—into the space age.



When John McQuown arrived at Wells Fargo in 1963, James Vertin *(above left)* was in charge of trust investments and "could just see the fin of the shark cutting through the water." At first worried about "guys in white smocks with computers whirring," Vertin was soon converted to the new ideas and became an evangelist for the cause. After attending MIT "for retrofitting," he transformed his department into an organization that spearheaded the development of the index fund. In 1969, convinced that professional portfolio management sorely lacked discipline, William Fouse *(above right)* proposed the establishment of an index fund to his boss at Mellon Bank's trust department, and was "figuratively thrown out of the policy meeting" for his efforts. He left after this confrontation to work for McQuown and Vertin at Wells Fargo. There he led them in developing applications of the new thinking, including the dividend discount model, asset allocation, and indexing.

While living on a tugboat and teaching at Berkeley, Barr Rosenberg *(left)* launched a consulting practice in 1969 that played a dominant role in introducing portfolio managers to applications of the theories of Sharpe, Markowitz, and Fama. He left consulting in 1985 to start his own portfolio management group, which now has some $10 billion under management.

When Berkeley economist Hayne Leland *(above left)* found his personal finances deteriorating in 1976, he decided that "lifestyles were in danger, and it was time for invention." The invention was portfolio insurance, the most controversial portfolio strategy of the 1980s. "I'm surprised I never thought of that myself," declared Hayne Leland's Berkeley colleague Mark Rubinstein *(above right)* when Leland described the broad outlines of his scheme for portfolio insurance. Rubinstein was a distinguished options theorist, and he and Leland immediately formed a consulting firm that by 1987 was supervising over $60 billion of assets under insurance programs and still innovating new applications of their basic theoretical ideas.

and directors. Most other sellers, no matter how large their positions, have little or no apparent impact on the price of the stock when they offer their shares for sale.

When I told Scholes that I had found his paper especially interesting because it was both counter-intuitive and persuasive, he laughed. "That was just one idea," he said, "there are so many ideas."[13]

At the time he first met Black, Scholes was himself already deep into the option pricing puzzle and had considered how the Capital Asset Pricing Model could be used to solve it. When they realized they were both wrestling with the same problem, they joined forces. Their association soon produced major progress toward a solution.

They found to their surprise that neither risk nor expected return, the two integral elements of CAPM, belonged in the equation after all. Risk and expected return disappeared from the equation because they canceled each other out. Consider two stocks, one much riskier than the other, but each selling for $20 a share. To simplify matters, assume that neither pays a dividend. The market believes that the less risky stock will be selling for $32 five years from now, or within a range of, say, $30 to $34, for an average expected return of 10 percent a year. The market believes that the riskier stock will be selling for $40, within a much wider range of $32 to $48, for an average expected return of 15 percent a year.

But the two stocks are selling at the same price of $20 today because investors have taken into consideration the differences in risk, even though the expected future prices of the stocks differ widely. The higher risk cancels out the higher expected return and leads to the same price today for the risky stock as for the less risky stock.

With differences in risk canceling out differences in expected gain for all securities, Black and Scholes concluded that the expected gain on a stock, option, or warrant is irrelevant in calculating what the current price of an option or warrant should be. This insight allowed them to solve the option equation and derive their formula for setting a value on the option. But they arrived at this original derivation by building their structure on the foundations of the Capital Asset Pricing Model.

At this point, enter Robert C. Merton, a round-faced, curly-haired, friendly colleague on the MIT finance faculty. Merton was

younger than Black and Scholes and had not yet earned his Ph.D. He had studied engineering mathematics at Columbia and then at California Institute of Technology but his first published paper, "The 'Motionless' Motion of Swift's Flying Island," was about *Gulliver's Travels.* It appeared in the *Journal of the History of Ideas* in 1966, the year he earned his B.S. degree at Columbia.

Friends in the Cal Tech economics department had attracted Merton to their circle. His appetite for economics and finance had already been whetted by his experiences in trading convertible bonds and warrants with his own money. So Merton decided to switch to economics. When he canvassed the graduate schools, he found that his lack of formal training in economics was an obstacle, but MIT accepted him and gave him a fellowship to boot.

Good luck set him to work in 1968 as a research assistant to Samuelson, who was still exploring the theory of warrant pricing. Merton's performance in that role led Samuelson to suggest that they write a paper together. "I thought that was very nice," Merton recalls. Then Samuelson suggested that they present the paper to the inaugural session of the Harvard-MIT mathematical economics seminar. "That was terrific." Then Samuelson proposed that Merton present the paper by himself. "That was more terrific." Merton confessed to me that he has never worked on anything as hard as he worked on that maiden presentation. "After that, nothing fazed me about giving papers."[14]

Samuelson has long been an enthusiastic admirer of Merton's. Recently, in the introduction to a collection of Merton's essays, he wrote:

> Among connoisseurs, Robert C. Merton is known as an expert among experts, a giant who stands on the shoulders of such giants as Louis Bachelier. . . . I am proud to have figured in the Mertonian march to fame. . . . One of the great pleasures of academic life is . . . the rare sight of the companion at arms who forges ahead of you as you were able to do at the inflection point of your own career.[15]

Merton's work on warrant pricing soon led him to portfolio theory, which was still an unknown subject for most economists in the late 1960s. No courses on the subject were available at MIT at that time. Even with Samuelson, Sidney Alexander, and Franco

Modigliani on the premises, the work done by Markowitz, Tobin, and Sharpe was rarely mentioned.

Merton immediately set about developing a dynamic version of portfolio theory and came up with the "intertemporal capital asset pricing model." Until then, CAPM had described only how the market values assets at a given moment. Recognizing that financial markets around the world are open for trading virtually around the clock, Merton used a concept known as "continuous time analysis" to transform CAPM into a description of what happens over a sequence of time periods during which conditions are changing rather than standing still. Rather than diluting the importance of the earlier work, his dynamic analysis reinforced the static models that preceded it.

It was this shift from static to dynamic modeling that had led Modigliani to discourage Treynor from pursuing his explorations into asset pricing any further, given Treynor's limitations in mathematics. Merton had no such limitations. In the spring of 1969, he decided to incorporate Ito's lemma "and all that stuff," as he puts it, into his intertemporal model of portfolio selection.[16]

Merton first applied this concept to the valuation of warrants and options. When he applied it to the Capital Asset Pricing Model, he was able to write out the dynamics of the whole process. Unfortunately, nobody in economics had even heard of Ito's lemma. According to Merton, Samuelson himself "could not tell whether the mathematics was right or wrong."[17]

Markowitz has made some interesting comments about Merton's achievement. In a letter to Samuelson in October 1985, he wrote: "Ito's lemma turned out to be a cornucopia of interesting results, and Bob's work has become central to much of the modern theory of finance. The one thing that bothers me about continuous portfolio selection is that I don't really understand it."*[18]

Despite the mathematical complexity of his work, Merton had made a giant leap. As he himself has described it: "The mathematics of the continuous-time model contains some of the most beau-

*In a note written shortly after receiving the Nobel Prize in October 1990, Markowitz told me that "after much intense study, I am almost mediocre in the mathematics of continuous time models." Merton doubts that Markowitz is expressing false modesty: "Harry probably imposes such exacting standards on himself that, should the rest of us do the same, we would be *well below* mediocre." Yet, Ito's lemma is now standard operating procedure in the finance courses at many of the leading business schools.

tiful applications of probability and optimization theory. But, of course, not all that is beautiful in science need also be practical. And surely, not all that is practical in science is beautiful. Here we have both."[19]

Although it bears an unmistakable resemblance to the Capital Asset Pricing Model, Merton's theory has philosophical roots in the work of Kenneth Arrow and Gerard Debreu, both Nobel Prize winners. Arrow and Debreu describe a world in which everything is tradable, from the value of an education to the housewife's ironing of the family sheets, and under an infinite variety of conditions, or "states of nature." The continuous-time model provides a framework for converting such "pure" securities into a form that will permit them to be traded. Merton also pays his respects to Bachelier's "magnificent dissertation on the theory of speculation."[20] On the more practical side, Merton incorporates into his theoretical structure the institutional functions and risk-taking activities of financial intermediaries such as banks and mutual funds.

When Merton went looking for a job in late 1969, he did not have to look far. At Modigliani's suggestion, he stayed on at MIT and joined the faculty at the Sloan School of Management. Scholes had arrived on the scene about a year before, and he and Merton soon became good friends.

In the spring of 1970, Scholes told Merton what he and Black were trying to accomplish and how far they had progressed. Their challenging problem was just the kind of thing that Merton enjoyed sinking his teeth into, especially as his interest in Samuelson's work on warrant pricing was still running strong.

Black and Scholes had advanced to a point where they were linking options to the underlying assets in a wide variety of combinations. They were particularly interested in what happened when they combined stocks with different quantities of options in such a way that, at any given moment, the values of the options and the values of their underlying stocks would move in opposite directions by *precisely* the same amount. They found that, whether the stock rose or fell in price, the value of the combination would be independent of what the market was doing. As the option-holder gained on one side what he was losing on the other, he could predict precisely where he would stand at any given moment in the future.

How can two securities, each of which is risky in its own right, be combined to mimic the behavior of an asset that has no risk at all? Suppose an investor buys a stock and, at the same moment, also buys a put. The put gives him the right to sell the stock at a predetermined price within a stated period of time. No matter how low the stock might fall, the investor's loss will be limited, because he will be able to sell the stock at that predetermined price. The put will become more valuable when the stock is falling, but it will be less valuable when the stock climbs away from the exercise price of the option.

An investor who buys a stock and a put option at the same time can easily turn into a manic-depressive. If the stock rises in price, that is good news. But as the stock moves further away from the exercise price, the put will lose value. That is bad news. Now look at it the other way. If the price of the stock falls, the investor will be sorry he owns it, but, at the same time, he will be glad he was prescient enough to buy the protective put.

Merton was not convinced that Black and Scholes had unlocked the secret of the puzzle by basing their solution on the Capital Asset Pricing Model. Black and Scholes were convinced that they had. Intense discussions followed. Scholes recalls those days with nostalgia: "Bob Merton is a great colleague—he pushes you all the way."[21]

One Saturday afternoon, Merton called Scholes on the phone and exclaimed, "You're right!"[22] They were right, however, for a reason that they themselves had failed to recognize. Merton was able to offer them a more elegant derivation of the option pricing formula.

He pointed out that investors will seek out combinations of stocks and options in which the good news will outweigh the bad. If the prices of the stock and the put option are out of line with each other, the stock might rise in price by more than the value of the put falls. The news, in other words, would be net good, with more gained from the rising stock price than lost from the shrinking value of the put. Such strokes of luck are to be taken advantage of.

Modigliani and Miller had emphasized that active capital markets are crowded with investors looking for free lunches. As arbitragers rush to take advantage of such opportunities by buying the stock and selling the put, the stock will become more expensive while the put gets cheaper. The free lunch will disappear, and

the symmetry between the two assets will return as they move back into proper alignment.

If the gain on one side of the combination is precisely offset by a loss on the other, the investor will be holding a riskless position that is the equivalent of holding a Treasury bill or some other liquid asset with a certain return known in advance. If the combination of stock and option offered more than this risk-free rate, investors would compete for the opportunity to own it and would bid the opportunity away. If it offered less, investors would shun it and its value would fall to a point where it once again offered the riskless rate of return.

Only one small step remained. The option-pricing formula had to calculate the price of the option that would give the stock-option combination that risk-free result. In an efficient market, there is no other price that the option could command.

In our unsophisticated fashion, my firm had had the correct intuition. The prevailing rate of interest on risk-free assets like short-term Treasury bills is an essential input to the option-pricing formula. As we had also recognized, the inputs must include the price of the underlying stock, the price at which the option is selling, and the time remaining until the option expires.

But there was one more item to be plugged into the formula. No investor will buy or sell an option on a stock without some expectation about what the future action of the stock will be. Will the stock be volatile, like Apple Computer, or sleepy, like Consolidated Edison? In valuing options, volatility matters a lot. The option-holder has a claim on which he can lose relatively little: Thales made only small deposits on the olive presses. But the option-holder can gain a great deal: Thales made a killing when the olive crop turned out to be unexpectedly large. This means that options are more interesting to their owners in cases where something big is likely to happen than when nothing is likely to happen. If conditions promise to be stable, why spend money for an opportunity that will be profitable only when conditions change?

More is involved here than just beta—that is, a stock's volatility relative to the market as a whole. Expectations about whether the stock is going to move *at all* dominate expectations about whether the stock is going to move up or move down. To owners of call options, who have the right to buy at a specified price, big downward movements in the stock price do not matter, because

the risk of loss is limited to the premium paid; big upward movements are what matter. So long as the other four inputs are the same, an option on Apple is going to be a lot more interesting than an option on Con Ed.

The sellers of options have the opposite requirement. They like stocks that stand still. They simply pocket the premiums they collect on the sale without having to take any further action. They are like a company that sells insurance: they collect the insurance premiums while hoping that nothing will happen to the policyowner—no houses burning down, no premature deaths, no burglaries, no catastrophic illness.

Investors who use options to hedge their risks will also be more eager to hedge big risks than small ones. If the olive harvest is about the same every year, there is little risk that press capacity and olive production will be badly matched. If the harvest is unexpectedly large, the olive grower will want to hedge against the possibility that he will have no access to the presses when his crop comes in.

In light of all these considerations, how does an investor determine whether an option is cheap, expensive, or priced about right? The answer is to use the Black-Scholes formula. The investor knows the current prices of the stock and the option, the price at which the option can be exercised, the time to expiration, and the going rate of interest. With this information, the model will provide an estimate of the stock's volatility that is implied in the price of the option. Then it is up to the investor to judge whether the market's expectations about volatility look too low, too high, or about right.

This game is fun as well as essential for option-traders. Take the option on the Standard & Poor's Composite Index of 500 stocks, which trades on the Chicago Board Options Exchange. On September 23, 1990, the S&P 500 closed at 311.32. An investor could buy a one-month call on the index, carrying the right to buy at 310, for a cost of $9.38. That option would be slightly in-the-money: the actual price of 311.32 was just above the exercise price of 310. At the same moment, the interest rate on Treasury bills was 7.50 percent.

When this information is put into a computer, the pricing model reveals that the market was expecting the monthly volatility of the S&P 500 to be 7.4 percent. In other words, people were

expecting the index during the month ahead to move generally within a range of plus or minus 7.4 percent, or 23 points, on either side of 311.32.

With concerns about the crisis in Kuwait and impending recession running high, this volatility estimate in September 1990 turned out to be considerably above the long-run volatility of the index, which was 5.9 percent a month, and even further above the 4.4 percent average of the preceding twelve months. A volatility estimate this far above past experience was unusual: most of the time, people expect the near future to look pretty much the way the recent past has looked.

The same experiment revealed that the implied volatility of individual stocks reflected the differences in their fundamental characteristics. American Telephone and Telegraph's implied monthly volatility was only 10.8 percent, compared to 19.3 percent for Chrysler, a company that was in deep trouble at that moment. The implied volatility for UAL was way up at 22.8 percent, reflecting the uncertainty about the airline's takeover prospects.

Note that each of these stocks had an implied volatility above the 7.4 percent of the S&P 500. That should come as no surprise. The index is a widely diversified portfolio; an individual stock, no matter how stable, is still a totally undiversified portfolio. Eggs in one basket are a lot riskier than eggs distributed among many baskets.

After Black and Scholes had committed their ideas to paper, they started off on a frustrating adventure. Their first draft, titled "A Theoretical Valuation Formula for Options, Warrants, and Other Securities," was dated October 1970. Black sent it to the *Journal of Political Economy,* a Chicago University publication. It was promptly rejected. The *JPE* said the paper was excessively specialized, because it had too much to do with finance and not enough to do with economics—the same problem Harry Markowitz had had with his thesis on portfolio selection. Then Black tried Harvard's *Review of Economics and Statistics.* Another prompt rejection. Neither journal even sent the paper out for review. Although both authors were surprised by the rejections, Black suspects that part of the problem was his nonacademic return address. Scholes adds, "Who knew me?"[23] In any case, they decided to rewrite the paper with more attention to its broader economic implications.

The title of their new draft, dated January 1971, reflected their effort to beam their ideas to economists. They titled the paper "Capital Market Equilibrium and the Pricing of Corporate Liabilities." At this point they received help from another quarter. Eugene Fama and Merton Miller had been aware of their work, had given them extensive comments on it, and were following their publishing ordeal. Now these two Chicago professors put in a good word for them at the *Journal of Political Economy.* That did the trick.

Throughout this story, Merton Miller has played the role of power-broker. He had encouraged Eugene Fama, still a novice, to teach entirely new material. He had guided Scholes into finance. He had introduced Treynor to Modigliani. He had immediately recognized Sharpe's talent. And finally he was instrumental in providing Black and Scholes with the notice that their work surely deserved.

The final draft, carrying the simpler title, "The Pricing of Options and Corporate Liabilities," was dated May 1972, but it was not published in the *Journal of Political Economy* until the issue of May/June 1973. In one of those odd twists of academic journalism, the *Journal of Finance* of May 1972 had carried a paper by Black and Scholes that reported their successful empirical results with their formula, but the theoretical paper on the formula did not appear for another full year.

That delay created a problem for Robert Merton. Following up on his collaboration with Samuelson, he had continued to work on options valuation and its broader applications to the valuation of the corporation as a whole. He had drafted a major paper on the subject titled "The Theory of Rational Option Pricing."

While Merton was considering where to send his paper for publication, a colleague at the Sloan School, Paul McAvoy, had recently become editor of a new journal to be published by the Bell Laboratories, the research arm of the American Telephone Company. McAvoy expressed interest in Merton's work, even though Merton warned him that it was "pretty thick" and would probably run to about forty pages in print. McAvoy, eager to get his new journal off the ground, said, "We'll publish any size paper. We'll also pay you $500 for the manuscript." This was irresistible bait for a young assistant professor still earning a starting salary of $11,500.[24]

Merton was reluctant to have his article appear ahead of Black

and Scholes's main paper, because his paper drew on and commented on theirs. So he asked McAvoy to hold up publication until the Black-Scholes paper had appeared. But, as Merton recalls, Black and Scholes were "having this dance with the JPE. I heard only the entrails of it from Myron."[25] As a result, even though the last version of Merton's paper is dated August 1972, it appeared in the *Bell Journal* issue of Spring 1973, almost simultaneously with the appearance of Black-Scholes.

The friendly rivalry among these three men has another twist. Separately, but early on, Black, Scholes, and Merton had recognized the significance of options theory for valuing the corporation as a whole. As Modigliani and Miller had demonstrated, the total value of the corporation is determined by its earning power, and the claims against the corporation—the value of its outstanding debts and shares of stock—must equal that total value. If one claim rises in value, another must fall. They are all in the same boat. Once this is recognized, the corporation turns out to be a complex maze of options.

Are the stockholders the true owners of a company? Not really. The creditors—the people who have lent the company money—have the first claim on the company's assets. The stockholders are entitled only to what is left after the creditors have taken what they are entitled to. The stockholders are the true owners of the company only when they do not owe a single cent to anyone other than themselves.

Although the stockholders do not own the company, they have a call option on its assets. They can exercise that option by paying off the company's debts. The exercise price of the option is the principal amount borrowed. And its expiration date is the due date on which the debts are payable.

When the company's debts come due, the stockholders have the right to let their call option on the assets lapse, leaving the bondholders in possession of the company's assets—or holding the bag, as Wall Street puts it. This is exactly what happens when the owners refuse to pay their debts and let a company go into bankruptcy. Most of the time, the stockholders exercise the option and redeem their debts—until they borrow fresh money and activate a brand-new option.

The price the stockholders pay for the option of walking away from their obligations is reflected in the interest rate on the com-

pany's debts. The cost of that option is determined just like any other. The interest rate will be low when the company's assets are large relative to its liabilities—if, in technical terms, the option is deep in-the-money. The interest rate will be low when the debts come due sooner rather than later, and if the company's business is stable and predictable rather than volatile. The interest rate will be high when the company is deeply in debt, when the maturity of the debts is far off, and when its business is exceptionally volatile. American Telephone and Telegraph pays a lower rate of interest on its bonds than Chrysler or Citicorp.

This use of options to value corporate liabilities has come to be known as Contingent Claims Analysis. Merton, who was one of the pioneers in the development of this concept, has commented that the nomenclature "sounds like an insurance adjuster,"[26] but it has become the richest vein in the gold mine of options theory.

Meanwhile, Scholes, who enjoyed "teaching the Young Turks who would become the mavens of the quant world,"[27] had been actively involved in a major consulting arrangement with Wells Fargo Bank in San Francisco. In July 1970, he arranged for Wells Fargo to sponsor a conference at the Sloan School at MIT, where he and Black gave an early version of their options pricing paper. Merton was also planning to give a paper at this conference. Black and Scholes included in their presentation their ideas on the applicability of the option-pricing process to the valuation of corporate liabilities, and the 1971 draft of their paper makes specific reference to this in its title. Merton inconveniently overslept that morning and missed their paper. It was only later that he discovered that they were all working the same side of the street.

Despite the competition for ideas, there was nothing among these men that smacked of the abrasive relationship that had developed between Sharpe and Lintner. Nearly twenty years after Merton's alarm clock failed him, Black had this to say on the occasion of Merton's leaving MIT to cross the Charles River and join Harvard Business School: "A key part of the option paper I wrote with Myron Scholes was the arbitrage argument for deriving the formula. Bob gave us that argument. It should probably be called the Black-Merton-Scholes paper."[28]

The friendly rivalry that Black, Scholes, and Merton enjoyed reflected the unique atmosphere in which they were working. At the time, the finance department at the Sloan School consisted of only four assistant professors, Merton, Scholes, Gerald Pogue

(now at the City University of New York, Markowitz's home base), and Stewart Myers, who is still at Sloan. None of the four had tenure, and none was the designated leader. Though Black was an eager participant in their activities, he was still in the consulting business. Modigliani had a joint appointment at the Sloan School and the economics department and provided some intellectual leadership, but he did not take part in the day-to-day master's degree program or administrative activities in the area. Samuelson was barely acquainted with any of the four other than Merton.

Merton describes the little group during this short period of the early 1970s, with the whole world open to them, like "kids in a candy store, with more to do than we had time to do. Research results were flowing so rapidly that we sometimes didn't even bother to write them all down."[29] As the efficient-market theory, the CRSP data tapes, and Sharpe's CAPM had stirred the research pot at the University of Chicago to the boiling point in the last half of the 1960s, so option pricing, corporate liability valuation theories, and intertemporal portfolio selection provided a research monopoly at the Sloan School in the early 1970s.* The whole environment had moved far away from the traditional finance setting, where accounting and the elements of corporate finance were the daily fare.

It was not all teaching and research. Black recalls that, "though the search for the formula was an academic search for truth, we did try to use it to make money." They started with warrants. First, they estimated the volatility of the stocks of companies with warrants outstanding. Then, when their own estimates differed from the volatility implied in the prices of the warrants, they bought the warrants that seemed very low in price and waited for them to go up. "As it turned out, we did not make money," says Black, "but we did learn some more truth." Scholes insists that Black's assessment of their financial results is hyperbole, but the lesson learned was an important one nonetheless.[30]

The lesson came from warrants issued by a company known as National General, which, though out-of-the-money (the stock price was below the exercise price on the warrant), appeared to be the best buy of all. In the summer of 1972, Scholes, Merton,

*In a kind of hands-across-the-sea gesture, Chicago granted Merton an honorary degree at the commencement exercises in June 1991.

and Black jumped in and bought a bunch of these warrants. At first, things looked great. Then, all of a sudden, there was a takeover bid for National General, and the warrants dropped rapidly in price. The takeover bid had prematurely ended the lives of the warrants but had failed to push the stock price up far enough to give the warrants value.

The lesson the MIT investors learned was that the market sometimes knows things the option formula does not know. The warrants appeared cheap because the market knew the takeover bid was a strong possibility. The three professors had never thought of that.

One of the most important early tests of the model was conducted in 1975 by Dan Galai, a Chicago Ph.D. candidate. Galai used daily data over the period July 1973 to April 1974 to estimate volatility and then used the formula to look for undervalued and overvalued options. He made some unrealistic assumptions about trading costs, but, even so, his simulated strategy was impressive evidence of the validity and integrity of the Black-Scholes formula.

"Opportunities like this are harder to come by these days," Black recently observed, and for a good reason: "Traders now use the formula and its variants extensively. They use it so much that market prices are usually close to formula values even in situations where there should be a large difference: situations, for example, where a cash takeover is likely to end the life of the option or the warrant."[31]

The extensive use of the formula depended on the success with which it did its job, but something else was needed: an options market that would be more active than the traditional negotiated, cumbersome, primitive over-the-counter system.

By coincidence, the Chicago Board Options Exchange opened for business in April 1973, exactly one month before the University of Chicago's *Journal of Political Economy* published "The Pricing of Options and Corporate Liabilities." That event made for a revolutionary transformation of options trading that provided a perfect setting for the practical implementation of the model.

The CBOE was a success from the start, though its early days were bizarre. Trading began in the smoking lounge of the Board of Trade, a limited space that had been converted for the purpose.

Soon traders were standing on counters because there was no room on the floor.

The Chicago Board of Trade soon decided to build a new and proper floor for the CBOE. The old trading floor of the Board of Trade occupied an enormous space, about five stories high, with architecture and decoration appropriate to the importance of the commodities traded there. A new floor was suspended between the old floor and the ceiling, and in 1976 that floor of 30,000 square feet became the home of the Chicago Board Options Exchange.

From the beginning, the Exchange furnished its customers with market-makers committed to providing liquidity, standardized option contracts, strict regulation, and sophisticated electronic equipment to report all trades on computer screens the instant they occurred. Today, with an even larger trading floor, the Exchange has one and a half acres of computers in its basement, wiring for its electronic equipment that would reach twice around the Equator, and a telephone system that would service a city of 50,000 people.

On the first day of trading in 1973, with 284 members on the floor making markets, just 911 call option contracts on 16 underlying stock issues changed hands. A year later, even in the dark days of mid-1974, more than 20,000 contracts a day on 32 underlying stocks were trading, 567 members were making markets on the floor, and the cost of membership had risen from $10,000 to over $40,000. Three years later, the daily volume was up to 100,000 contracts.

At the peak of feverish market activity in 1987, daily volume averaged 700,000 call and put contracts and covered options on bonds and market indexes in addition to stocks. As each contract reflects the right to buy or sell 100 shares of stock, this was the equivalent of 70 million shares, at a time when the average daily trading on the New York Stock Exchange was 190 million shares. In 1989, a quieter year, the price of a membership on the CBOE had leapt to $250,000 and daily trading averaged about 450,000 contracts. In that same year, the competitors that had arisen since 1973—the New York Stock Exchange, the American Stock Exchange, and the Philadelphia and Pacific Stock Exchanges—together accounted for roughly another 400,000 contracts a day.

Keeping track of that volume of transactions would confound a less sophisticated system. The stocks with options trading on

the CBOE have many puts and calls outstanding, with exercise prices that often range from far above to far below the current price. In September 1990, for example, Boeing had 29 puts and calls outstanding, with exercise prices ranging from 40 up to 60 at a time when the stock was trading at around 43; UAL, at the center of a takeover battle, had 60 options outstanding, with exercise prices from as low as 90 to as high as 175. Every time the price of the underlying stock changes, the prices of all those options change at the same instant.

The buyers and sellers of options have an equally elaborate task. Merton chuckles as he remembers the early days of the CBOE. In the spring of 1973, right after the CBOE opened up for business, he and Scholes designed an option pricing and hedging model for the Wall Street firm of Donaldson, Lufkin, and Jenrette, where considerable skepticism persisted about whether it would be needed. Within six months after the publication of the Black-Scholes model, Texas Instruments took a half-page advertisement in the *Wall Street Journal* to say "Now you can find the Black-Scholes value using our . . . calculator." Within a year, the transition was complete. Merton remarks:

> I got the biggest kick out of hearing those options traders routinely talk about hedge ratios and deltas, partial differential equations, and stochastic differential equations. Who would ever think that people would be talking like that. . . .
>
> People had no choice. They couldn't deal with it the way they dealt with it over-the-counter. There is no other way to deal with the complexity of the option. The models made sense intuitively and seemed to work.[32]

The important observation here is that "People had no choice." The options traders who ignored the Black-Scholes model and its variants did so at their peril: without it, they were destined to get the short end of the stick. Soon people were going about with little hand-held calculators that had been programmed to perform the necessary calculations once the inputs had been punched in. Many options traders operate with powerful computers at their beck and call.

Here, too, they have no choice. The formula is not exactly designed for quick calculations on the back of an envelope. By the

time anyone figures out the answers by hand to something that looks like this:

$$C = S\,N(d_1) - E\,e^{-R_f T}\,N(d_2)$$

where:

$$d^1 = \frac{ln(S/E) + [R_f + (1/2)\,\sigma^2]T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

$N(d_1)$, $N(d_2)$ = cumulative normal probability values of d_1 and d_2, respectively
S = stock price
E = exercise price
R_f = the risk-free rate of interest
σ = the instantaneous variance rate of the stock
T = time to expiration of the option

the world will have moved on so far that the whole result will be obsolete even before the calculations are done.

Fischer Black was no longer in the Boston area among his MIT friends when the paper finally appeared in print. The whole experience had inducted him into the world of academe, and in 1971 he accepted a visiting professorship at the University of Chicago. Given his fascination with free-market ideas, this was the perfect place for him. As Robert Merton puts it, "Fischer out-Chicago'd Chicago."[33] In 1972, Black accepted a permanent appointment as Executive Director of the Center for Research in Security Prices (CRSP). Two years later he became Director of the Center.

In 1973, Scholes accepted Miller's offer of a temporary appointment at Chicago with the mouth-filling title Ford Foundation Visiting Research Associate Professor of Finance. In 1975, he accepted a permanent appointment as both associate professor and as Executive Director of CRSP. He became a full professor and replaced Black as Director of CRSP the following year. At CRSP, he supervised a major update of the original Fisher and Lorie study, gathering and pricing a daily data base, as well as adjusting for dividends, splits, and other capitalization changes. Meanwhile, Merton continued to hold the fort back in Cambridge, until he left MIT in 1988 for Harvard Business School.

Black's wife was not happy in Chicago and returned with their children to the Boston area, leaving Black to commute every weekend between Chicago and Boston, an expensive as well as an unpleasant arrangement. In 1975, Merton got the idea that MIT might lure Black back, not just for auld lang syne, but because he would be with his family and, incidentally, save the cost of commuting. Then Merton had another idea: Why not try to bring Scholes back at the same time?

It took Black just two days to say yes. Soon he moved into an office next door to Merton's, where they lived happily ever after until 1984, when Wall Street enticed him to New York. There he develops complex trading strategies for the customers of the investment banking firm of Goldman Sachs.

A year later, Scholes called Merton at home on a weekend to tell him that he too had succumbed. The following Monday, he called back to say he was staying at Chicago. Merton Miller, ever the power-broker, had prevailed.

Scholes continued to write as co-author with the others. Not counting the basic paper with Black on options pricing, he has published four articles with Black, two with Merton, and four with Miller.

Even before their option-pricing paper saw the light of day, Black and Scholes had shared another exciting experience. With Michael Jensen, they had conducted an important test of the Capital Asset Pricing Model and had discovered that stocks with low betas, or low volatility, tended to earn higher returns than the model predicted, while stocks with high betas did worse than expected. Their results were published in 1972.

Acting on these findings, Black and Scholes persuaded Wells Fargo to sponsor a mutual fund that would invest in low-beta stocks. In order to offer the investor a bigger bang for the buck, with more volatility than a low-beta portfolio would provide, the fund would borrow money to buy additional shares of these stocks. I remember hearing Black, in his laconic fashion, trying to make the selling pitch at a Wall Street gathering for what was to be called The Stagecoach Fund.

The horses never got attached to that stagecoach. Quite aside from the regulatory problems that would be created by a bank managing a publicly offered mutual fund, Wells Fargo planned to launch the fund just as the stock market was diving into the worst

of the 1974 bear market. The environment was hardly favorable for anything as adventuresome as this, and the whole scheme died aborning. I will have more on this story in Chapter 12.

About a year later, Scholes and Merton also tried to launch a mutual fund to deal in options. This fund offered a capital-preserving strategy that they thought would be irresistible in the wake of the 1974 bear market. Here, too, events intervened. The vibrant bull market of late 1975 and early 1976 was precisely the wrong environment for a conservative strategy. A fund that the underwriters had originally pegged at $100 million turned out to raise a mere $17 million—"hardly a smashing success," as Merton admits.[34]

These disappointments aside, the three scholars at MIT had turned Thales's financial device into an instrument of great power and overwhelming importance. Options enable investors to control risk and to shape the outcomes they face: at a cost, losses can be limited while upsides can be magnified. This is the most attractive feature of options. As investors, borrowers, and lenders increased their understanding of these basic concepts, the flow of applications grew from a trickle to a flood.

Options were incorporated into the entirely new and complex debt instruments that blossomed during the 1980s. They are responsible for the mushrooming of the market for government-guaranteed home mortgages. Their hedging features made possible the development of the so-called interest rate swaps between major financial institutions, the explosion in daily trading in the foreign exchange markets, the ability of banks to shield themselves from the vagaries of the money markets, and the willingness of major investment banking firms to provide many millions of dollars of instant liquidity to their institutional customers.

Seldom has the marriage of theory and practice been so productive. Every time an institution uses these instruments, a corporation issues them, or a homeowner takes out a mortgage, they are paying their respects, not just to Black, Scholes, and Merton, but to Bachelier, Samuelson, Fama, Markowitz, Tobin, Treynor, and Sharpe as well.