AGAINST THE GODS

THE REMARKABLE STORY OF RISK

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The Fantastic System of Side Bets

Derivatives are the most sophisticated of financial instruments, the most intricate, the most arcane, even the most risky. Very 1990s, and to many people a dirty word.

Here is what *Time* magazine had to say in an April 1994 cover story:

> [T]his fantastic system of side bets is not based on old-fashioned human hunches but on calculations designed and monitored by computer wizards using abstruse mathematical formulas . . . developed by so-called quants, short for quantitative analysts.

We have just looked at the fantastic system of side bets based on old-fashioned human hunches. Now we turn to the fantastic system concocted by the quants.

Despite the mystery that has grown up about these instruments in recent years, there is nothing particularly modern about them. Derivatives go back so far in time that they have no identifiable inventors: no Cardano, Bernoulli, Graunt, or Gauss. The use of derivatives arose from the need to reduce uncertainty, and surely there is nothing new about that.

Derivatives are financial instruments that have no value of their own. That may sound weird, but it is the secret of what they are all

about. They are called derivatives because they derive their value from the value of some other asset, which is precisely why they serve so well to hedge the risk of unexpected price fluctuations. They hedge the risk in owning things like bushels of wheat, French francs, government bonds, and common stocks—in short any asset whose price is volatile.

Frank Knight once remarked, "Every act of production is a speculation in the relative value of money and the good produced."[1] Derivatives cannot reduce the risks that go with owning volatile assets, but they can determine who takes on the speculation and who avoids it.

Today's derivatives differ from their predecessors only in certain respects: they are valued mathematically instead of by seat-of-the-pants methods, the risks they are asked to respond to are more complex, they are designed and managed by computers, and they are put to novel purposes. None of these features is the root cause of the dramatic growth in the use of derivatives or the headlines they have grabbed.

Derivatives have value only in an environment of volatility; their proliferation is a commentary on our times. Over the past twenty years or so, volatility and uncertainty have emerged in areas long characterized by stability. Until the early 1970s, exchange rates were legally fixed, the price of oil varied over a narrow range, and the overall price level rose by no more than 3% or 4% a year. The abrupt appearance of new risks in areas so long considered stable has triggered a search for novel and more effective tools of risk management. Derivatives are symptomatic of the state of the economy and of the financial markets, not the cause of the volatility that is the focus of so much concern.

Derivatives come in two flavors: as futures (contracts for future delivery at specified prices), and as options that give one side the opportunity to buy from or sell to the other side at a prearranged price. Sophisticated as they may appear in the fancy dress in which we see them today, their role in the management of risk probably originated centuries ago down on the farm. The particulars may have changed over time, but the farmer's fundamental need for controlling risk has not. Farmers cannot tolerate volatility, because they are perennially in debt. Their huge investments in land and equipment and in inventories of seed and fertilizer make bank financing unavoidable. Before the

farmer sees any money coming his way, he has to pay for his inputs, plant his crop, and then, constantly fearful of flood, drought, and blight, wait months until harvest time. His great uncertainty is what the price will be when he is finally in a position to deliver his crop to the market. If the price he receives is below his cost of production, he might be unable to pay his debts and might lose everything.

The farmer is helpless before the risks of weather and insects, but he can at least escape the uncertainty of what his selling price will be. He can do that by selling his crop when he plants it, promising future delivery to the buyer at a prearranged price. He may miss out on some profit if prices rise, but the futures contract will protect him from catastrophe if prices fall. He has passed along the risk of lower prices to someone else.

That someone else is often a food processor who faces the opposite risk—he will gain if the prices of his inputs fall while the crop is still in the ground, but he will be in trouble if prices rise and boost the cost of his raw materials. By taking on the farmer's contract, the processor lets the farmer assume the risk that agricultural prices might rise. This transaction, involving supposedly risky contracts for both parties, actually *lowers* total risk in the economy.

On occasion, the other side of the deal is a speculator—someone who is willing to take over uncertainty from others out of a conviction about how matters will turn out. In theory at least, speculators in commodities will make money over the long run because there are so many people whose financial survival is vulnerable to the risks of volatility. As a result, volatility tends to be underpriced, especially in the commodity markets, and the producer's loss aversion gives the speculator a built-in advantage. This phenomen goes under the strange name of "backwardation."

In the twelfth century, sellers at medieval trade fairs signed contracts, called *lettres de faire*, promising future delivery of the items they sold. In the 1600s, Japanese feudal lords sold their rice for future delivery in a market called *cho-ai-mai* under contracts that protected them from bad weather or warfare. For many years, in markets such as metals, foreign exchange, agricultural products, and, more recently, stocks and bonds, the use of contracts for future delivery has been a common means of protection against the risks of volatile prices. Futures contracts

for commodities like wheat, pork bellies, and copper have been trading on the Chicago Board of Trade since 1865.

Options also have a long history. In Book I of *Politics*, Aristotle described an option as "a financial device which involves a principle of universal application." Much of the famous Dutch tulip bubble of the seventeenth century involved trading in options on tulips rather than in the tulips themselves, trading that was in many ways as sophisticated as anything that goes on in our own times. Tulip dealers bought options known as *calls* when they wanted the assurance that they could increase their inventories when prices were rising; these options gave the dealer the right, but not the obligation, to call on the other side to deliver tulips at a prearranged price. Growers seeking protection against falling prices would buy options known as *puts* that gave them the right to put, or sell, to the other side at a prearranged price. The other side of these options—the sellers—assumed these risks in return for premiums paid by the buyers of the options, premiums that would presumably compensate sellers of calls for taking the risk that prices would rise and to compensate sellers of puts for taking the risk that prices would fall.

Incidentally, recent research has punched a hole in the tales of the notorious mania for tulips in seventeenth-century Holland, supposedly fueled by the use of options. Actually, it seems, options gave more people an opportunity to participate in a market that had previously been closed to them. The opprobrium attached to options during the so-called tulip bubble was in fact cultivated by vested interests who resented the intrusion of interlopers onto their turf.[2]

In the United States, options appeared early on. Brokers were trading put and call options on stocks as early as the 1790s, not long after the famous Buttonwood Tree Agreement established what was to become the New York Stock Exchange.

An ingenious risk-management contract was issued on June 1, 1863, when the Confederate States of America, hard up for credit and desperate for money, issued the "7 Per Cent Cotton Loan." The loan had some unusual provisions that gave it the look of a derivative instrument.[3]

The principal amount was not repayable in Confederate dollars nor was it repayable at the Confederate capitol in Richmond, Virginia. Instead, it was set at "3 Millions Sterling Or 75 Millions Francs" and it was repayable in forty semiannual installments in Paris, London,

Amsterdam, or Frankfurt, at the option of the bondholder—who was given the additional option of taking payment in cotton rather than money, at the rate of sixpence sterling per pound, "at any time not later than six months after the ratification of a Treaty of Peace between the belligerents."

The embattled Confederate government was using a sophisticated form of risk management to tempt English and French investors to lend them urgently needed foreign exchange to finance their armament purchases abroad. At the same time, it was building up a foreign constituency with a vested interest in the Confederacy's survival. The risk of devaluation of the Confederate dollar was covered by the option of repayment in British or French money.* The option of collecting the debt in cotton was a hedge against inflation and was sweetened by offering cotton at sixpence when the prevailing price in Europe was 24 pence. Furthermore, as the obligation was convertible "at any time" into cotton, this option was something of a hedge against the fortunes of war for those lenders nimble enough to pick up their cotton before the Confederate States collapsed.

The Confederate States were the sellers of these options: they took on uncertain liabilities because they had no choice in the matter. A promise to repay the loan in Confederate dollars would have been laughed out of the credit markets or would have necessitated an intolerable double-digit interest rate. The premium the Confederates received in return from the lenders who acquired these options was a reduction in the interest rate on the loan: 7% was only about a percentage point more than the U.S. government was paying for long-term money at that time. The introduction of the options made this a transaction in which *uncertainty itself was an integral part.*

The history of these bonds is interesting. The subscription books were opened in March 1863, but, in keeping with the conventions of the times, the proceeds were not to be received by September. The bonds sold above their offering price for a brief period after the March offering, but then the price broke sharply as stories began to circulate about Jefferson Davis's connection with some repudiated bonds in

*The bond even offered protection against the possibility that one pound sterling might subsequently buy more or less than 25 francs. The French went off gold in 1870, at which time one pound sterling could buy substantially more than 25 francs.

Mississippi. Concerned that subscribers would reneg on the payments due in September, the Confederate Treasury went into the market to support the price by buying up some £1.4 million of the £3 million issued. The Confederates met the payments due in September 1863 and the two semiannual payments in 1864, but that was the end. Only about £370,000 par value was ever redeemed in cotton.

Many people are willing but unwitting buyers of options. Anyone who has ever taken out a mortgage with a prepayment privilege owns an option. Here it is the borrower—the homeowner—rather than the lender who has the option to determine the conditions of repayment. What is the price of that option? The interest rate the borrower pays to the bank is higher than it would be without the prepayment option. If mortgage rates fall, the homeowner will prepay the old mortgage and take out a new one at a lower rate, leaving the banker with the loss of a high-interest loan replaced by a low-interest loan. This option is such a conventional feature, often a mandated feature, of home mortgages today that most homeowners are not even aware that they are paying extra for the privilege—and neither are most of the bankers!*

There is more than meets the eye in the design of the cotton bond, the farmer's futures contracts, the tulip options, and mortgage prepayment privileges. Most business and financial transactions are a bet in which the buyer hopes to be buying low and the seller hopes to be selling high. One side is always doomed to disappointment. Risk-management products are different. They exist, not necessarily because someone is seeking a profit, but because there is a demand for instruments that transfer risk from a risk-averse party to someone willing to bear risk. In the case of the cotton loan, the Confederacy took on a foreign-exchange risk and even the risk of victory itself in order to save the difference between 7% and the interest that would have been demanded without the options; it may even have received money that would not have been forthcoming under other conditions. The lenders—the buyers of the Confederate bonds—acquired options that

*This is an oversimplification to make the basic point. Most individual home mortgages are packaged with other mortgages and sold off in the open market to a wide variety of investors. In effect, the bankers have traded off the risks of prepayment to a market more willing to bear that risk; these mortgage-backed securities are complex, volatile, and much too risky for amateur investors to play around with.

reduced their risk sufficiently to compensate for the lower interest rate or for the possibility that the Confederates would lose the war. By trading uncertainty, both parties were winners.

What is an option worth? How did the traders in tulip options decide how much to pay for a call or a put, and why did those values change over time? How did the lenders to the Confederates decide that the options to receive payment in sterling or francs or cotton were sufficient to hedge the risks they took in making the loans? How much extra is the homeowner with a prepayment privilege paying the mortgage banker?

The answers to these questions may become clearer if we look at an example of an actively traded option on a stock. On June 6, 1995, when AT&T stock was selling at 50, there was an option outstanding on AT&T stock that gave the owner the right to buy one share of stock at 50 1/4 until October 15, 1995. The stock was selling for less than 50 1/4—the "strike price"; if the stock remained below the strike price for the duration of the option, the option would be worthless and its owner would lose the entire premium paid for it. Yet that premium is all that the buyer of the option had at risk and all that the seller of the option could hope to gain. If AT&T stock rose above the strike price before October 15 by an amount greater than the option premium, the option would generate a profit. In fact, the potential profit on the option would be limitless.

The option on AT&T stock was selling for $2.50 on June 6, 1995. Why $2.50?

Resolving Paccioli's unfinished game of *balla* was kid stuff compared to this! We can only wonder whether two quants like Pascal and Fermat could have come up with an answer—and why they did not even try. The Dutch tulip mania, a striking example of what happens when "old-fashioned human hunches" take over, had occurred only twenty years before Pascal and Fermat first laid out the principles of probability theory; the memory of it must still have been vivid when they began their historic deliberations. Perhaps they ignored the challenge of valuing an option because the key to the puzzle is in the price of uncertainty, a concept that seems more appropriate to our own times than it may have seemed to theirs.

The first effort to use mathematics rather than intuition in valuing an option was made by Louis Bachelier back in 1900. In the 1950s and 1960s, a few more people tried their hands at it, including Paul Samuelson.

The puzzle was finally solved in the late 1960s by an odd threesome, none of whom was yet thirty years old when their collaboration began.[4] Fischer Black was a physicist-mathematician with a doctorate from Harvard who had never taken a course in economics or finance. He soon found his scientific academic studies too abstract for his taste and went to work at the Boston-based management consulting firm of Arthur D. Little. Myron Scholes had a fresh Ph.D. in finance from the Graduate School of Business at the University of Chicago, to which he had fled to escape his family's publishing enterprise; he had just joined the MIT faculty. Robert C. Merton, whose first published paper was titled "The 'Motionless' Motion of Swift's Flying Island," had received a B.S. degree in mathematical engineering at Columbia but was teaching economics at MIT as an assistant to Samuelson and was as yet without a Ph.D.

Black died in 1995 at the age of 57. He was a cool man of few words; his presidential address to the American Economic Association in 1985 had a one-word-one-syllable title—"Noise"—and took less than fifteen minutes to deliver. Scholes is dark, intense, and voluble. Merton is friendly and irrepressible. All three have been brilliant innovators in finance, beyond their contribution to option theory.

The story begins in 1965, when Black made friends with a colleague named Jack Treynor; Treynor was just starting on a path that would lead him to become a theoretical powerhouse in the field of finance. At the time, he was studying economics on the side under the guidance of Franco Modigliani of the MIT faculty, who would later earn a Nobel Prize in economics. When Treynor showed Black his early work on a model to explain how the markets trade off risk and return, Black was fascinated. A passionate believer in free markets, Black decided to apply Treynor's ideas to the valuation of options, and, to help himself along, he took Treynor's advice to join a Thursday evening finance workshop at MIT.

Three years later, Black was still staring at equations that refused to produce an answer. Treynor's analysis of how market fluctuations influence the valuation of individual securities simply did not fit the bill. At

that point, Black recalls, "Myron Scholes and I started working together." They had met each other at the Thursday evening workshops, where Black discovered that Scholes had been frustrated in taking the same approach to the same problem. The more they worked together over their equations, the clearer it seemed that the answer had nothing to do with Treynor's models of risk and reward.

In the spring of 1970, Scholes told Merton about the troubles he and Black were having. The problem appealed to Merton immediately. He soon resolved their dilemma by pointing out that they were on the right track for reasons they themselves had failed to recognize. The model was soon completed.

Despite its complex algebraic appearance, the basic ideas behind the model are easy to understand. The value of an option depends on four elements: time, prices, interest rates, and volatility. These elements apply to puts as well as to calls; in what follows, I explain how they work in terms of a call option, which gives the owner the right to buy the stock at a specified price.

The first element is the period of time until the option is due to expire; when the time to expiration is long, the option will be worth more than when the time is short. The second element is the spread between the current price of the stock and the price specified in the option contract at which the owner can buy or sell the stock—this is known as the strike price; the option will be worth more when the actual price is above the strike price than when it is below the strike price. Third, the value also depends on the interest the buyer can earn on his money while waiting to exercise the option as well as the income the seller can receive on the underlying asset over the same time period. But what really matters is the fourth element: the expected volatility of the underlying asset, such as the AT&T stock in the example above, where AT&T was selling for 50 and the owner of the option had the right to buy it at 50 1/4 any time between June 6 and October 15, 1995.

The probability that the price of AT&T stock might go up—or down—is irrelevant. The only thing that matters is how far the stock price might move, not the direction in which it moves. The notion that the direction of price change is irrelevant to the valuation of an option is so counterintuitive that it explains in part why Black and Scholes took so long to come up with the answer they were seeking—

even when it was right in front of them. But it unlocks the puzzle because of the asymmetric nature of the option itself: the investor's potential loss is limited to the premium, while the potential profit is unlimited.

If AT&T stock goes to 45, or 40, or even to 20 during the life of the option, the owner of the option still stands to lose no more than $2.50. Between 50 1/4 and 52 3/4, the owner will gain less than $2.50. Above 52 3/4, the potential profit is infinite—at least in theory. With all the variables cranked in, the Black-Scholes model indicates that the AT&T option was worth about $2.50 in June 1995 because investors expected AT&T stock to vary within a range of about 10%, or five points, in each direction during the four months the option would be in existence.

Volatility is always the key determinant. By way of contrast to AT&T, consider the stock of software leader Microsoft. On the same day that AT&T stock was at 50 and its option was selling for $2.50, Microsoft stock was selling at 83 1/8, and an option to buy a share of Microsoft within four months at 90 was trading for $4.50. The price of this option was 80% above the price of the AT&T option, although Microsoft stock was selling at only about 60% above AT&T. The price of Microsoft stock was nearly seven points away from the strike price, compared with the mere quarter of a point difference in the case of AT&T. The market clearly expected Microsoft to be more volatile than AT&T. According to the Black-Scholes model, the market expected Microsoft to be exactly twice as volatile as AT&T over the following four months.

Microsoft stock is a lot riskier than AT&T stock. In 1995, AT&T had revenues of nearly $90 billion, 2.3 million shareholders, a customer in just about every household and every business in the nation, a weakened but still powerful monopolistic position in its industry, and a long history of uninterrupted dividend payments. Microsoft stock had been available to the public only since 1982, its revenues at the time were just $6 billion, it had a much narrower customer base than AT&T, it had brilliant competitors straining to break its hold on the software industry, and it had never paid a dividend.

Option traders understand such differences. Anything that makes a stock move at all is what matters, because stocks that tend to drop fast also tend to rise fast. Buyers of options are looking for action; investors

who sell options like stocks that stand still. If Microsoft goes to 100 and the owner of the option exercises his right to "call" the stock at 90 from the seller of the option, the seller is going to be out ten points. But if Microsoft hangs in around 83, at which it was trading when the transaction took place, the seller of the option would walk away with the entire premium of $4.50. By the same token, the right to prepay a home mortgage is worth a lot more when interest rates are jumping around than when they are stable.

Options bear a strong family resemblance to insurance policies and are often bought and sold for the same reasons. Indeed, if insurance policies were converted into marketable securities, they would be priced in the marketplace exactly as options are priced. During the time period covered by the premium payment, the buyer of an insurance policy has the right to put something to the insurance company at a prearranged price—his burned-down house, destroyed car, medical bills, even his dead body—in return for which the insurance company is obliged to pay over to him the agreed-upon value of the loss he has sustained. If the house does not burn down, if the car never has an accident, if the policyholder enjoys perfect health, and if he lives beyond his life expectancy, he will be out the premiums he has paid and collects nothing. The premium itself will depend on the degree of uncertainty surrounding each outcome—the structure of the house, the age of the car (and its drivers), the policyholder's medical history, and whether the man is a coal miner or a computer operator. The derivatives we call options, by expanding the variety of risks that can be insured, help to create Kenneth Arrow's ideal world where all risks are insurable.

Derivatives are not transactions in shares of stock or interest rates, in human lives, in houses vulnerable to fire, or in home mortgages. *The product in derivative transactions is uncertainty itself.* That is why options on Microsoft cost more than options on AT&T, why earthquake insurance is more expensive in California than in Maine, why the lenders to the Confederate States were able to extract such onerous terms, and why bankers worry about a decline in mortgage rates.

Black and Scholes set down their ideas about option valuation in an article that they mailed in October 1970 to *The Journal of Political*

Economy, a prestigious journal published by Chicago University. The editors promptly rejected the paper, claiming that Black and Scholes had put too much finance into it and too little economics.* Harvard's *Review of Economics and Statistics* was equally prompt in returning the paper. Neither publication even bothered to have a referee review it. The paper finally saw the light of day in the May/June 1973 issue of *The Journal of Political Economy*, but only after two influential members of the Chicago faculty had interceded. The article turned out to be one of the most influential pieces of research ever published in the field of economics or finance.

In one of those strange coincidences in which events seem to happen in bunches, the Chicago Board Options Exchange opened for business in April 1973, just one month before the Black-Scholes paper appeared in print. That exchange, more familiarly known as the CBOE, began its operations in the smoking lounge of the Chicago Board of Trade, the established center for trading in commodities. The CBOE, for the first time, provided traders in stock options with standardized contracts and with market-makers who gave the options liquidity by standing ready to buy or sell them on demand. The CBOE also promised strict regulation of trading practices as well as prompt, public reporting of all transactions.

On the first day of trading, 911 options changed hands on 16 individual stock issues. By 1978, daily volume had climbed to an average of 100,000 contracts. By mid-1995, a million stock options were changing hands daily. Another 300,000 options were trading on four other exchanges around the country. With each option representing a hundred shares of stock, activity in the option markets is significant relative to the volume on the stock exchanges themselves.

The CBOE now boasts one of the most technologically sophisticated trading centers in the world. It consists of a spacious trading floor, a basement with an acre and a half of computers, enough wiring to reach twice around the Equator, and a telephone system that could service a city of 50,000.

*Black suspected that something more unpleasant was involved: that his lack of proper warpaint in the form of a degree in economics excluded him from the tribal membership that the editors considered essential for an appearance in the *JPE*.

There was a second coincidence. At the very time the Black-Scholes article appeared in *The Journal of Political Economy* and the CBOE started trading, the hand-held electronic calculator appeared on the scene. Within six months of the publication of the Black-Scholes model, Texas Instruments placed a half-page ad in *The Wall Street Journal* that proclaimed, "Now you can find the Black-Scholes value using our . . . calculator." Before long, options traders were using technical expressions right out of the Black-Scholes article, such as hedge ratios, deltas, and stochastic differential equations. The world of risk management had vaulted into a new era.

In September 1976, Hayne Leland, a 35-year-old finance professor at Berkeley, had a sleepless night worrying about his family's finances. As Leland tells the story, "Lifestyles were in danger, and it was time for invention."[5]

Necessity is the mother of invention: Leland had a brainstorm. He would singlehandedly overcome the intense risk aversion that dominated the capital markets in the wake of the debacle of simultaneous crashes in both the bond market and the stock market in 1973–1974. He set about developing a system that would insure investment portfolios against loss in the same way that an insurance company protects a policyholder from loss when an accident occurs. Insured investors could then take on the risk of carrying a large proportion—perhaps even all—of their wealth in stocks. Like any option holder, they would have unlimited upside and a downside limited to nothing more than an insurance premium. Sugarplums began to dance in Leland's head.

By dawn, he was convinced that he had the whole thing figured out. "Eureka!" he shouted. "Now I know how to do it." But after he got up and faced the day, he was beset by a host of theoretical and mechanical difficulties. He went immediately to the office of his friend Mark Rubinstein, a Berkeley colleague who Leland knew could be trusted with his secret. Rubinstein was not only a keen theoretician and a serious scholar; he had had experience trading options on the floor of the Pacific Stock Exchange.

Groggy but manic, Leland laid out his scheme. Rubinstein's first reaction was, "I'm surprised I never thought of that myself." He became an eager collaborator, to the point where the two men, at this very first meeting, agreed to form a company to market their product, which would be called, naturally, portfolio insurance.

As Leland described it, portfolio insurance would mimic the performance of a portfolio that owns a put option—the right to sell an asset to someone else at a stated price over a specific period of time. Suppose an investor buys 100 shares of AT&T at 50 and simultaneously buys a put on AT&T with an exercise price of 45. No matter how low AT&T may fall, this investor cannot lose more than five points. If AT&T drops to 42 before the option expires, the investor could put the stock to the seller of the option, receive $4500, and go into the market and buy back the stock at a cost of only $4,200. The put under these circumstances would have a value of $300. Net, the investor could lose no more than $500.

Leland's notion was to replicate the performance of a put option by what he called a dynamically programmed system that would instruct a client to sell stocks and increase the cash position as stock prices fell. By the time the stocks hit the floor that the client has designated—45 in the AT&T example—the portfolio would be 100% cash and could suffer no further loss. If the stocks went back up, the portfolio would reinvest the cash on a similar schedule. If stocks never declined at all below the starting price, the portfolio would enjoy all the appreciation. Just as with a plain-vanilla put option, details of the dynamic program would depend on the distance from the starting point to the floor, the time period involved, and the expected volatility of the portfolio.

The distance between the starting point and the floor was comparable to the deductible on an insurance policy: this much loss the policyholder would have to cover. The cost of the policy would be in its step-by-step character. As the market began to fall, the portfolio would gradually liquidate but would still hold some stock. As the market began to rise, the portfolio would start buying but would still be carrying some cash. The result would be a portfolio that underperformed slightly in both directions; that underperformance constituted the premium. The more volatile the market, the greater the underperformance premium, just as the premiums on conventional insurance policies depend on the uncertainty of what is insured.

Two years later after that fateful meeting, Leland and Rubinstein were ready to go, convinced that they had cleared away all the snags.

They had had many adventures along the way, including a catastrophic error in computer programming that had led them to believe for a time that the whole idea was impossible. Rubinstein started playing the system with his own money and was so successful at it that he was written up in *Fortune* magazine. Marketing began in earnest in 1979, but the concept turned out to be hard for two academics to sell. They brought on John O'Brien, a professional marketer and an expert in portfolio theory; O'Brien landed their first client in the fall of 1980. Before long, the demand for portfolio insurance was so intense that major competitors entered the field, notably the leading portfolio-management group at Wells Fargo Bank in San Francisco. By 1987, some $60 billion dollars in equity assets were covered by portfolio insurance, most of it on behalf of large pension funds.

Implementation was difficult at first, because handling simultaneous orders to buy or sell several hundred stocks was complicated and costly. In addition, active portfolio managers of pension funds resented having some outsider give them orders, with little or no warning, to add to or sell off parts of their portfolios.

These problems were resolved when the market for futures contracts on the S&P 500 opened up in 1983. These contracts are much like the farmer's contract described earlier, in that they promise delivery at a specified date and at a prearranged price. But there are two important differences. The other side of the S&P 500 futures contract is an organized, regulated exchange, not an individual or a business firm; this has long been the case with futures contracts on commodities as well. But unlike tangible commodities, the 500 stocks in the S&P index are not literally deliverable when the contract matures. Instead, the owner of the contract makes a cash settlement based on the variation in the index between the signing of the contract and its maturity. Investors must put up cash with the exchange each day to cover these variations, so that all contracts are fully collateralized at all times; that is how the exchange is in the position to take the other side when an investor wants to buy or sell a futures contract on the index.

The S&P futures have another attraction. They give an investor an effective and inexpensive method of buying or selling a proxy for the market as a whole, in preference to trying to unload or load up on a large number of securities in a limited period of time. The investor's underlying portfolio, and any managers of that portfolio, remain undisturbed. The index futures greatly simplified the mechanics of carrying out portfolio insurance programs.

To the clients who signed up, portfolio insurance appeared to be the ideal form of risk management that all investors dream about—a chance to get rich without any risk of loss. Its operation differed in only one way from an actual put option and in only one way from a true insurance policy.

But those differences were enormous and ultimately turned out to be critical. A put option is a contract: the seller of the AT&T put option is legally bound to buy if the owner of the option puts the stock. Put options on the CBOE require the seller to post cash collateral to be certain that the potential buyer is protected. Insurance companies also sign contracts obliging them to make good in the event of a claim of loss, and they set aside reserves to cover this eventuality.

Where does the necessary cash come from to reliquify insured portfolios when stock prices are falling? From the stock market itself—all the other investors to whom the insured investors will want to sell their stocks. But no reserves or collateral exist to guarantee that the liquidity will be there when called upon. The market had no legal obligation to bail out Leland and Rubinstein's clients and other insured portfolios against loss. Those other investors were not even aware of the role they were expected to play. Leland's brainstorm assumed that the buyers would be there, but he had no way to guarantee that they would actually show up when called upon to do their duty.

The chickens that Leland and Rubinstein hatched in their laboratory came home to roost on Monday, October 19, 1987. The preceding week had been a disaster. The Dow Jones Industrials had fallen by 250 points, or about 10%, with nearly half the drop occurring on Friday. A huge overhang of sell orders had then built up over the weekend, waiting to be executed at Monday's opening. The market dropped 100 points by noon, nearly another 200 points in the next two hours, and almost 300 points in the final hour and a quarter. Meanwhile, as the managers of insured portfolios struggled to carry out their programed sales, they were contributing to the waves of selling that overwhelmed the market.

When the dust had settled, the owners of the insured portfolios were in better shape than many other investors. They had all done some selling during the bad week that preceded October 19, and most

of them got out either at or only slightly below their designated floors. But the selling took place at prices far lower than anticipated. The dynamic programs that drove portfolio insurance underestimated the market's volatility and overestimated its liquidity. What happened was like a life insurance policy with a variable-rate instead of a fixed-rate premium, in which the company has the right to raise its premium as the insured's body temperature rises, degree by degree, increasing the probability of early demise. The cost of portfolio insurance in that feverish market turned out to be much higher than paper calculations had predicted.

The unhappy experience with portfolio insurance did nothing to quell the growing appetite for risk-management products, even though portfolio insurance itself virtually vanished from the scene. During the 1970s and 1980s, volatility seemed to be breaking out all over, even in places where it had been either absent or muted. Volatility erupted in the foreign exchange markets after the dollar was cut free from gold in 1981 and allowed to fluctuate freely; volatility overwhelmed the normally serene bond market during the wild swings in interest rates from 1979 to the mid-1980s; and volatility shot up in commodity markets during the huge jumps in oil prices in 1973 and again in 1978.

These unexpected outbreaks of volatility soon littered the corporate landscape with a growing number of dead carcasses, providing grim warnings to executives that a fundamental change in the economic environment was taking place. For example, Laker Airlines, a fabulously successful upstart in transatlantic travel, ended up in bankruptcy after ordering new McDonnell-Douglas aircraft in response to soaring demand; with most of its revenues in pounds and with the foreign exchange value of the dollar climbing higher and higher, Laker found it impossible to earn enough to pay off the dollar obligations on their DC-10s. Reputable savings and loan associations went under as the interest rates they had to pay their depositors mounted while the income they received on their fixed-rate mortgage loans never budged. Continental Airlines succumbed when oil prices went through the roof during the Gulf War.

As a consequence, a new kind of customer appeared in the financial markets: the corporation seeking to transfer the new risks in exchange rates, interest rates, and commodity prices to someone better equipped to carry them. The corporation was responding as Kahneman and Tversky would have predicted, but with an added flourish. As we might have expected, the pain of potential losses loomed larger than the satisfaction from potential gains, so that risk aversion influenced strategic decisions. But when volatility exploded in areas where it had never been much of a concern, corporate managers, like the farmers of yesteryear, began to worry about the very survival of their companies, not just about a sequence of earnings that was more irregular than they or their stockholders might have liked.

Even though corporations could execute hedges in the liquid and active markets for options and futures—which now included interest rate and foreign exchange contracts as well as commodities and stock indexes—these contracts were expressly designed to appeal to as many investors as possible. The risk-management needs of most corporations are too specific in terms of both coverage and time spans to find ready customers in the public markets.

Wall Street has always been a hothouse of financial innovation, and brokerage houses are quick to jump into the breach when a new demand for their talents arises. Major banks, insurance companies, and investment banking firms with worldwide business connections lost no time in establishing new units of specialized traders and financial engineers to design tailor-made risk-management products for corporate customers, some related to interest rates, some to currencies, and some to the prices of raw materials. Before long, the value of the underlying assets involved in these contracts—referred to as the "notional value"—was in the trillions of dollars, amounts that at first stunned and frightened people who were unaware of how the contracts actually worked.

Although approximately two hundred firms are in this business today, it is highly concentrated among the giants. In 1995, commercial banks alone held derivatives with a notional value of $18 trillion, of which $14 trillion was accounted for by just six institutions: Chemical, Citibank, Morgan, Bankers Trust, Bank of America, and Chase.[6]

Almost all of these arrangements function like the cash settlement conditions of the futures contracts, as described above. Each side is

obliged to pay to the other only the *changes* in the underlying values, not the far larger notional amounts. When the same institution or the same corporation has a variety of contracts in effect with a counterparty, payments frequently net out the impact of the entire set of contracts instead of treating each contract as a separate deal. As a result, the functional liabilities are far smaller than the staggering magnitudes of the notional values. According to a survey conducted during 1995 by the Bank for International Settlements, the notional value of all derivatives outstanding around the world, excluding derivatives traded in organized exchanges, amounted to $41 trillion, but if every party obligated to pay reneged on their payments, the loss to their creditors would run to only $1.7 trillion, or 4.3% of the notional value.[7]

These new products are in essence combinations of conventional options or futures contracts, but, in their most sophisticated versions, they incorporate all the risk-management inventions I have described, from Pascal's Triangle to Gauss's normal distribution, from Galton's regression to the mean to Markowitz's emphasis on covariance, and from Jacob Bernoulli's ideas on sampling to Arrow's search for universal insurance. The responsibility of pricing such complex arrangements goes well beyond what Black, Scholes, and Merton had so painstakingly worked out. Indeed, all three men ultimately showed up in Wall Street to help in designing and valuing these new risk-management products.

But who takes the other side of contracts that come into existence precisely because they are too specific in their coverage to trade in the public markets? Who would be in a position to play the role of speculator and assume the volatility that the corporations were so urgently trying to shed? Few of the counterparties to these tailor-made corporate deals are speculators.

In some instances, the counterparty is another company with opposite requirements. For example, an oil company seeking protection from a fall in the price of oil could accommodate an airline seeking protection from a rising oil price. A French company needing dollars for a U.S. subsidiary could assume the franc obligations of an American company with a French subsidiary, while the American company took care of the obligations of the dollar requirements of the French subsidiary.

But perfect matches are hard to find. In the majority of instances, the bank or the dealer who originated the deal assumes the role of counterparty in exchange for a fee or spread for executing it. These banks and

dealers are stand-ins for an insurance company: they can afford to take on the volatility that corporations are trying so hard to avoid because, unlike their customers, they can diversify their exposure by servicing a large number of customers with different needs. If their books become unbalanced, they can go into the public markets and use the options and futures contracts trading there to hedge their positions, at least in part. Combined with the risk-reducing features of diversification, the ingenuity of the financial markets has transformed the patterns of volatility in the modern age into risks that are far more manageable for business corporations than would have been the case under any other conditions.

In 1994, a few of these apparently sound, sane, rational, and efficient risk-management arrangements suddenly blew up, causing enormous losses among the customers that the risk-management dealers were supposedly sheltering from disaster. The surprise was not just in the events themselves; the real shocker was in the prestige and high reputation of the victims, which included such giants as Procter & Gamble, Gibson Greetings, and the German Metallgesellschaft AG.[8]

There is no inherent reason why a hedging instrument should wreak havoc on its owner. On the contrary, significant losses on a hedge should mean that the company's primary bet is simultaneously providing a big payoff. If an oil company loses on a hedge against a decline in the price of oil, it must be making a large profit on the higher price that caused the loss in the hedging contract; if an airline loses on a hedge against a rise in the price of oil, it must be because the price has fallen and lowered its operating costs.

These disasters in derivative deals among big-name companies occurred for the simple reason that corporate executives ended up adding to their exposure to volatility rather than limiting it. They turned the company's treasury into a profit center. They treated low-probability events as being impossible. When given a choice between a certain loss and a gamble, they chose the gamble. They ignored the most fundamental principle of investment theory: *you cannot expect to make large profits without taking the risk of large losses.*

In deep trouble in a series of derivative transactions with Bankers Trust, Gibson Greetings provided a perfect example of prospect theory

in action. Bankers Trust told the treasurer at one point in 1994 that Gibson's losses stood at $17.5 million, but, according to the treasurer, Bankers Trust also told him the losses could be "potentially without limit."[9] Gibson promptly signed a new arrangement that capped the loss at $27.5 million but, if everything worked exactly right, could reduce the loss to only $3 million. Prospect theory predicts that people with losses will gamble in preference to accepting a sure loss. Gibson could have liquidated out at $17.5 million for certain but chose the gamble instead. As a director of another company described what happens in such situations, "It's a lot like gambling. You get in deep. And you think 'I'll get out of it with this one last trade.'" But Gibson did not get out of it on one last trade. As the loss column headed toward $20.7 million, Gibson called it quits: it sued Bankers Trust for having violated a "fiduciary relationship."

Procter & Gamble, as described by Carol Loomis, a reporter for *Fortune* magazine, was being "chewed up [during 1994] by derivatives that incorporated astounding leverage and confounding complexity." These derivatives also were created by Bankers Trust, whose full-page ads in business and financial publications proclaimed, "Risk wears many disguises. Helping you see beneath its surface is the strength of Bankers Trust."

Procter & Gamble's management dutifully followed Gibson in acting out prospect theory. Whether Raymond Mains, the corporate treasurer, was doing a good job was not determined by the absolute level of interest rates that the company paid to borrow money; the company judged his performance on a what-have-you-done-for-us-lately basis. In other words, they looked only at how much less Mains was paying compared with what money had cost them the year before. The heat in that oven was hot. In a sarcastic comment on the company's disaster, Nobel Laureate Merton Miller joked, "You know Procter & Gamble? Procter is the widow and Gamble is the orphan."

The deal that triggered all the trouble was extremely complicated in detail—fun in the negotiating, like analyzing a case at Harvard Business School. It was signed in the fall of 1993, following four years in which short-term interest rates declined almost without interruption from about 10% to less than 3%; the deal revealed P&G's belief that, after such an extended decline, a significant increase in interest rates was so unlikely as to be impossible. Clearly, nobody in the executive offices had

read Galton—regression to the mean appears to have been unknown to them.

They bet the ranch on what would have been no more than a modest saving if interest rates had remained stable or had fallen further. The deal involved a notional amount of $200 million in the form of a five-year loan from Bankers to P&G, but the *maximum* interest saving to the company compared with what it would have paid in a straight commercial-paper borrowing would have been $7.5 million over the life of the loan. According to the *Fortune* article, if things went wrong instead of right—if interest rates rose instead of continuing to fall—the exposure would put the company into the position of "covering the risks of interest rate earthquakes."

On February 4, 1994, only four months after the deal was signed, the Federal Reserve startled the markets by raising short-term interest rates. As Loomis reported, "With remarkable fury, these quakes then occurred." It is obvious that the P&G executives had never heard of Kahneman and Tversky either, for on February 14, already showing losses, the company entered into yet another contract, this one for $94 million over 4 1/4 years, that had them betting once again that interest rates would fall.

Interest rates did not fall. The interest rate on commercial paper had climbed from 3 1/4% in February to 6 1/2% in December while the prime rate moved from 6% to 8 1/2%. It was a catastrophe for P&G. Under the initial contract, they were left with a commitment to pay Bankers Trust 14 1/2 percentage points in interest until late 1998 and, under the second contract, to pay 16.4 percentage points in interest over the same period.

Bankers Trust is being sued here, too, and has received no payments from P&G at this writing. Mr. Mains is no longer with the company.

What are we to make of all this? Are derivatives a suicidal invention of the devil or the last word in risk management?* Bad enough that fine

*The literature on derivatives is massive, but I especially recommend the Fall 1994 issue of the *Journal of Applied Corporate Finance*, which is entirely devoted to the subject, and Smithson and Smith's book on managing risk (Smithson and Smith, 1995).

companies like Procter & Gamble and Gibson Greetings can get into trouble, but is the entire financial system at risk because so many people are trying to shed risks and slough them off onto someone else? How well can the someone else manage that responsibility? In a more fundamental sense, as the twentieth century draws to a close, what does the immense popularity of derivatives tell us about society's view of risk and the uncertain future that lies ahead? I shall postpone my response to that last question to the next, and final, chapter.

James Morgan, a columnist for the *Financial Times*, once remarked, "A derivative is like a razor. You can use it to shave yourself. . . . Or you can use it to commit suicide."[10] Users of derivatives have that choice. They do not have to use derivatives to commit suicide.

Precisely who persuaded whom to do what in the case of Procter & Gamble and the other companies remains obscure, but the cause of the disasters is clear enough: they took the risk of volatility instead of hedging it. They made the stability of their cash flows, and thereby the integrity of their long-term future, hostages to the accuracy of their interest-rate forecasts. While Bankers Trust and the other dealers in derivatives were managing their books on the basis of Pascal's Triangle, Gauss's bell curves, and Markowitz's covariances, the corporate risk-takers were relying on Keynesian degrees of belief. This was not the place to bet the corporate ranch or to act out failures of invariance.

Speculators who think they know what the future holds always risk being wrong and losing out. The long history of finance is cluttered with stories of fortunes lost on big bets. No one needed derivatives in order to go broke in a hurry. No one need go broke any faster just because derivatives have become a widely used financial instrument in our times. The instrument is the messenger; the investor is the message.

The losses at a few corporations in 1994 made banner headlines but posed no threat to anyone else. But suppose the errors had run in the other direction—that is, suppose the corporation had had huge winnings instead of losses. Would the counterparties to these transactions have been able to pay? The counterparties to most of the big tailor-made derivatives contracts are major money-center banks and top-tier investment bankers and insurance companies. The big players all made

a lot less money in 1994, the year of surprises, than they had made in 1993, but *none of them was at any point in trouble*. Bankers Trust, for example, reported that losses "were all within our capital limits and we knew the extent of our exposures all the time. . . . The risk control processes worked fine."

The financial solvency of these institutions supports the financial solvency of the world economic system itself. Every single day, they are involved in millions of transactions involving trillions of dollars in a complex set of arrangements whose smooth functioning is essential. The margin for error is miniscule. Poor controls over the size and diversification of exposures are intolerable when the underlying volatility of the derivatives is so high and when so much is at stake beyond the fortunes of any single institution.

Everyone is aware of the dangers inherent in this situation, from the management of each institution on up to the governmental regulatory agencies that supervise the system. So-called "systemic risk" has become a parlor word in those circles and is the focus of attention at central banks and ministries of finance around the world. The measurement of the overall risk exposure in the system has been progressing in both comprehensiveness and sophistication.*

But there is only a fine line between guaranteeing absolute safety and stifling the development of financial innovations that, properly handled, could reduce the volatility of corporate cash flows. Corporations that shelter their cash flows from volatility can afford to take greater internal risks in the form of higher levels of investment or expenditures on research and development. Financial institutions themselves are vulnerable to volatility in interest rates and exchange rates; to the extent that they can hedge that volatility, they can extend more credit to a wider universe of deserving borrowers.

*In July 1995, the Federal Reserve Board, the Treasury Department, and the FDIC requested comments on a proposal to revise their requirements for commercial bank risk controls on transactions involving foreign exchange, commodities, and trading in debt and equity instruments. The document runs to 130 single-spaced pages. The so-called Basle Committee, consisting of representatives of central bankers from major economies, has issued the authoritative framework for the supervision of derivatives activities of banks and securities firms; it was published as a Federal Reserve press release on May 16, 1995.

Society stands to benefit from such an environment. In November 1994, Alan Greenspan, Chairman of the Federal Reserve Board, declared:

> There are some who would argue that the role of the bank supervisor is to minimize or even eliminate bank failure; but this view is mistaken, in my judgment. The willingness to take risk is essential to the growth of a free market economy. . . . [I]f all savers and their financial intermediaries invested only in risk-free assets, the potential for business growth would never be realized.[11]