Chapter 10: Easy Travel to Other Planets

The history of options theory
Meeting and working with Fischer Black

The Black-Derman-Toy model

I had left Fischer's office a little chastened by his sharp remarks about the names of the fields on my calculator, but in a few days he let me know that I could join him and Bill Toy in their effort to create a new bond options model. It was a singular opportunity that had a large and beneficial effect on my life.

That spring of 1986 I attended my first options conference, an annual event organized by Howard Baker, Menachem Brenner, and Dan Galai at the Amex. I was one of about a hundred participating quants, traders and academics, all of us actively involved in the field at a time when options meetings were still a rarity, before the conference for profit organizations like Risk magazine began to dominate the market and eventually put the Amex options conference out of business. I recall several presentations on new models for valuing bond options, one in particular by Rick Bookstaber, then at Morgan Stanley. You could sense a rising urgency, almost a race, to solve the problem. Fischer told Bill and me that Bob Merton was working on the same problem as a consultant for another investment bank.

The Goldman contingent at the conference had more than an academic interest—our traders were making daily markets in long-expiration options on long-dated bonds, precisely the domain where the contradictions in Ravi's model were most severe. The traders were aware of their need for a better model, and as such were at the forefront of the impetus to replace it.

![FIGURE 10.3: Yield curves can vary during the day](image)

We knew that we had to model the future behavior of all Treasury bonds, that is, the evolution of the entire yield curve. How to set about it was neither obvious nor easy. A stock price is a single number, and when you model its evolution, you project only one number into an uncertain future. In contrast, the yield curve is a continuum, a string or rubber band whose every point, at any instant, represents the yield of a bond with
corresponding maturity. As time passes and bond prices change, the yield curve moves, as illustrated in Figure 10.3. To evolve the entire yield curve forward in time is a much more difficult task: Just as you cannot move the different points on a string completely independently of each other, because the string must stay connected, so bonds close to each other must stay connected, too.

How, then, to project bond prices into the future? Fischer, Bill, and I were pragmatists. We were building a model for traders, and we wanted it to be simple, consistent, and reasonably realistic. Simple meant that only one random factor drove all changes. Consistent meant that it had to value all bonds in agreement with their current market prices; if it produced the wrong bond prices, it was pointless to use it to value options on those bonds. Finally, realistic meant that the model's future yield curves should move through ranges similar to those experienced by actual yield curves.

When physicists build models, they often first resort to a toy representation of the world in which space and time are discrete and exist only at points on a lattice—it makes picturing the mathematics much easier. We built our model in the same vein. We imagined a world in which the shortest investment you could make lasted exactly one year, and was represented by the one-year Treasury bill interest rate. Longer term rates would then be a reflection of the market's perception of the probable range of future short-term (that is, one-year) rates.

FIGURE 10.4: The Black-Derman-Toy model focuses on the distribution of future short-term rates. Here, each dot corresponds to a particular value of the future one-year rate. The more time passes, the greater the uncertainty of future rate.

In this spirit, we built a simple model of future one-year rates that resembled a discrete version of the stock price distributions. The initial one-year rate, as shown in Figure 10.4, was known from the current yield curve. As you looked further out into the future, rates could range over progressively wider values.

In order to complete our model, we now had to determine the range of future one-year rates at every year in the future. In our model, the key principle was to think of longer-term bonds as
being generated by successive investments in short-term bonds. From this point of view, two years of interest is obtained by two successive one-year investments, the first at a known rate, the second at an uncertain one. The market's price for a two-year bond today depends on its view of the distribution of future one-year rates. You can calculate the logical value of the current two-year bond yield, from the current one-year yield and the distribution of one-year rates one year hence. Similarly, you can calculate the volatility or uncertainty of the current two-year yield from the volatility of the distribution of one-year rates one year hence. Alternatively, working backwards, since the current two-year yield and its volatility is known from the market, you can deduce the distribution of one-year rates one-year hence, as shown in Figure 10.5.

**FIGURE 10.5:** How the distribution of future one-year rates is deduced from the current yield curve in the Black-Derman-Toy model. The two-year yield to maturity fixes the distribution of one-year rates after one year, the three-year yield to maturity fixes the distribution of one-year rates after two years, and so on.

In the same way, the value of the current three-year yield can be found from the current one-year rate, the known distribution of one-year rates one year hence (already deduced from the current two-year yield) and the distribution of one-year rates two years hence. But, since the value of the current three-year yield is known, you can use it to deduce the distribution of one-year rates two years hence. Continuing in this way, you can use the current yield curve at any instant to pin down the range of all future one-year rates, as illustrated in Figure 10.5.

This was the essence of our model. When Bill and I programmed it, it seemed to work-we could extract the market's expectation of the distributions of future one-year rates from the current yield curve and its volatility. There was nothing holy about the one-year time steps we started with. Once the model worked, we used monthly, weekly, or sometimes even daily steps on a lattice, determining the market's view of the distribution of future short-term rates at any instant from the current yield curve. A typical lattice (or tree, as we called it, because of the way an initial interest rate forked out into progressively wider branches) had hundreds or thousands of equally spaced short periods, as illustrated in Figure 10.6.
We had aimed to make our model simple and consistent, and it was—we could match all current bond prices with one tree. We could then use the same calibrated tree to value any security whose payouts in the future had a known dependence on interest rates by averaging those payouts over the distribution. In particular, we could value the payout of an option of any expiration on a bond of any maturity.

It was particularly attractive that our new model satisfied the law of one price. Our tree functioned as a computational engine that produced the current value of a security by averaging its future payouts; you put future payouts onto the end of the tree, cranked the handle that averaged and then discounted them over the interest rate distribution, and ended up with the current price. The engine didn't care what name you gave to the security that produced the payout—bond, option, call it what you like. As long as the future payouts were identical, the engine produced the same price.

I met with Fischer regularly over the next eight years, though we never again worked as closely as we did when we developed BDT (Black-Derman-Toy model). He was the most remarkable person I met at Goldman.

His most noticeable quality was his stubborn and meticulous devotion to clarity and simplicity. In writing and speaking, he put weight on both content and style. When we wrote the first draft of our paper on a one-factor model of interest rates, Fischer wanted no equations in it, and I had to struggle long and hard to satisfy his standards: He wanted accuracy and honesty without the technical details, which meant that you had to understand the model viscerally, and then explain that understanding. I think it was the clarity of the mechanics of our model that made it so popular and widely used.
Because he liked clarity, and perhaps because his training was not in economics, Fischer avoided excessive formalization. His papers were the antithesis of the unnecessarily rigorous lemma-filled research papers of financial economics journals. He tried to write as he spoke, in a terse but good-natured conversational style, using clear but casual, unadorned English. There was a touch of jerkiness to his prose because it lacked the technically superfluous conjunctions-and, but, thus, and therefore-that people commonly use to link the flow of sentences in scientific articles.

Fischer expected clarity and directness from others, too. Though he was generous with his time and didn't care about rank, you had to prepare for an audience with him. If it was evident that you hadn't thought carefully about your question, you quickly discovered that he wasn't going to do the thinking for you. And, if you didn't grasp his answer and repeated your question, he would simply repeat his answer.

A very direct man, he was uncomfortable with small talk. When he had nothing to say, he said nothing; this could be disconcerting on the telephone, where he often simply kept silent for a minute or two without terminating the conversation. Sometimes, this led you to babble in an attempt to fill the silence, until Fischer simply said an abrupt goodbye and hung up.

He once told me that one of the things that limited his influence was the fact that he always told people the truth, even if they didn't want to hear it, a characteristic I can vouch for myself. When he grew skeptical of some of the information technology managers in his division at Goldman in the early 1990s, he purposefully met with them all and then made a frank list of who was good and who was bad, and handed it over to his bosses. He laughed sheepishly but half-proudly when he conceded that he had been naive to think that he would gain anything from this.

Among Goldman partners he struck me as always a bit of an outsider. In the era before the firm went public, a "class" of partners was appointed once every two years, and each of them then advanced by being allowed to buy progressively larger shares of the company. Fischer once said to me that he was proud of possessing fewer shares than anyone else in his class of 1986.

This directness and informality characterized his research, too. His approach seemed to me to consist of unafraid hard thinking, intuition, and no great reliance on advanced mathematics. This was inspiring to lesser mortals. He attacked problems directly, with whatever skills he had at his command, and often they worked. He gave you the sense (perhaps misguided) that you could
discover deep truths with whatever skills you had, too, if you were willing to think hard. He was guided by his great economic intuition; though his mathematical skills were unexceptional, his instinct was strong, and he was tenacious in trying to attain insight before resorting to mathematics.

In modeling he had a taste for the concrete: He liked to describe the financial world with variables that represented observable phenomena rather than hidden statistical or econometric factors. He thought practical usefulness and accuracy were more important than elegance, despite the unquestionable elegance that lends so much appeal to the Black-Scholes-Merton framework he founded. He had a strong pragmatic streak; he was at least as much a practitioner as an academic, willing to devote time and attention to software, trading systems, and user interfaces. He thought that these were just as important as the models themselves.

Chapter 12: A Severed Head

A troubled year at Salomon Brothers

Modeling mortgages

Salomon's skill at quantitative marketing

Mercifully laid off

Salomon was a tough place. The first thing I noticed when I started work was that everyone came late for meetings. The most senior people arrived last, each of them popping their heads into the door to see if everyone else was there and then quickly leaving again if they weren't. The junior people took advantage of this chronic lateness to be late themselves. Everyone was so determined to not have his or her own time wasted that they collectively wasted everyone else's. This would not have happened at Goldman.

The level of fear that permeated Salomon was more evident, too. Friends of mine who wanted to leave the firm were semi paranoid that their bosses would discover that they were interviewing elsewhere and then fire them before they left. I never heard anyone at Goldman speak this way; despite the natural tension between employer and employee, most Goldman workers never imagined that exercising their right to look at other jobs would naturally lead to being fired.
There were other signs of Salomon's take-no-prisoners culture. In the 1980s, the Bond Portfolio Analysis (BPA) group had written a series of renowned reports for clients on valuing swaps and other recently invented derivatives contracts. Each report's distinctive light brown cover bore the names of its authors printed in a darker brown. Then, over the years, as one or more of the original authors left the firm for other banks or trading houses, BPA would reprint the report, having removed the departed authors' names. Eventually there were old but popular reports still being distributed that apparently had no author at all. This Orwellian rewriting of history struck me as particularly petty and ineffective, an affront to the notion of research.

At Goldman the enemies were competing firms; at Salomon the enemies were competing colleagues. Shortly before they were acquired by Citigroup, I met with an old friend still working there and asked him what had caused a well-known acquaintance of ours to have been laid off by the firm. "Oh him," my friend said, "It turned out he couldn't even code a Black-Scholes model!" Now, the Black-Scholes model is so fundamental and ubiquitous that I had little doubt that this was false. But, more interestingly, I asked, how did anyone actually know that our friend couldn't code the model? Who had put him to the test?

Everyone in the Salomon quant group, I was told, had to recreate their own computer code for even the simplest things that other people could already do, because no one who had created something independently was willing to share it. This was in diametric contrast to the situation at Goldman, where, because this kind of backstabbing was frowned upon, software was shared. At Goldman it would have taken longer to find out that someone couldn't do something as straightforward as code a simple model.

The most impenetrable barrier was the wall between Meriwether's group and everyone else. Occasionally I would catch distant glimpses of the arb group. Meriwether, Haghani, Hawkins, Krasker and their colleagues sat together in the center of the trading floor, a world apart from everyone else, a little Persian carpet marking the center of their privileged domain, an exalted clique of happy people who awed everyone and knew it. They had their own inviolably secret models, their own inaccessible data, their own computer systems and system administrators, all exclusively theirs. They also had access, if they wanted it, to the best models and minds in BPA, via a one-way street that ran only in their direction. They were an elite force, a Republican guard
who could do whatever they wanted, and everyone half-envied, half-resented them for it. They had it all—knowledge, independence, prestige, and lots of money.

I attributed many of these cultural divergences between Salomon and Goldman to the structural differences between a public company and a private partnership. Goldman, then still private, functioned more smoothly because it was run by partners seeded uniformly throughout the firm. They were the daily overseers who didn’t possess a liquid stock to sell, and so their long-term profit depended on the firm remaining intact. As a result, any excessive egotism was eventually squelched, sooner rather than later, because someone in control, despite his or her desire to win that particular battle, realized that it was harmful to the firm. Goldman people always told you that Goldman people were nicer, worked better together, were less political. Though this was not entirely true, the constant talking about it helped make it a self-fulfilling prophecy. No matter how self-interested the partners were, their long-term interests were tied up in the entire company, not just in their little piece of it.

In the words of a famous Goldman ex-partner, Gus Levy, Goldman was long-term greedy rather than short-term greedy. At Salomon, I thought, it was every man for himself and God against them all.

Chapter 13: Civilization and Its Discontents

Goldman as home

Heading the Quantitative Strategies (QS) Group

Equity derivatives

The Nikkei puts and exotic options

Nothing beats working closely with traders

Financial engineering becomes a real field
The new new thing in the derivatives world in 1990 was exotic options. My absorption in this world was triggered by the excitement at Goldman over what we all referred to as the "Kingdom of Denmark puts."

On the last trading day of 1989, the Nikkei 225 index of Japanese stocks reached its zenith of 38,915.90. Throughout its ascent during what is in retrospect called the Japanese equity bubble, many Japanese companies had come to the capital markets to borrow from investors. Sometimes, in order to pay even lower interest rates, the companies had promised to eventually pay back more than they had initially borrowed, provided the Nikkei were to drop by the time the loan came due, an event to which they ascribed little probability. The greater the drop, the more yen the companies promised to repay. In options parlance, the companies had given their bondholders put options on the Nikkei, thus providing them with an insurance policy against a Nikkei decline. Some bondholders kept the bonds but sold the attached puts for cash to interested parties.

As the Nikkei ascended to ever higher levels during the late 1980s, Granny had adroitly and systematically bought large numbers of these puts that now collectively constituted a gigantic insurance policy against a decline in the Nikkei. He had bought them inexpensively, probably because the companies that issued them did not believe a sustained decline in the Nikkei was possible back in those days of soaring Tokyo property values and rising Japanese equity markets.

When I arrived in QS at the start of that year, everyone in derivatives was talking about the Kingdom of Denmark Nikkei put warrants. I heard that it was puzzled-looking Granny who had come up with the idea that Goldman issue a listed put on the Nikkei. Since we owned the inexpensive insurance against a Nikkei decline that Granny had bought, we could now sell similar protection to the public. So, in January 1990 Goldman created the Kingdom of Denmark Nikkei put warrants, struck at a Nikkei level of ¥37,516.77 with an expiration date in early 1993. They were listed on the American Stock Exchange, and the Kingdom-of-Denmark prefix referred to the issuer of the warrants, the sovereign Kingdom of Denmark to whom we paid a fee to guarantee that they would stand behind the put warrants in the event that Goldman’s credit failed.
Our issuance was exquisitely timed; the Nikkei was just past its peak, and many buyers were willing to bet on its further decline. Granny had bought cheap Nikkei volatility from Japanese yen-based counterparties who didn't believe that the Nikkei would drop, and was now able to sell it to American dollar-based investors who were betting it would. Most profitable options strategies I have seen have had the same formula: Buy some simple, less attractive product wholesale, use financial engineering to transform it into something more appealing, and then sell it retail. It's a transformation that requires an understanding of clients' needs as well as technical skills.

To accomplish this, Granny added a custom-tailored, exotic subtlety to the structure of the Kingdom of Denmark Nikkei put warrants that I haven't yet mentioned. The Nikkei is an index of 225 Japanese stocks whose prices are quoted in yen. An American dollar-based investor in the Nikkei index effectively owns Japanese stocks denominated in yen, and then faces two risks: that the Nikkei drops and that the yen weakens against the dollar. American investors were happy to buy insurance against a drop in the Nikkei, of course, but they didn't want their insurance payment to decline if the yen were to simultaneously weaken as the Nikkei fell, a not unlikely occurrence. Therefore, the Kingdom of Denmark Nikkei put warrants also carried built-in protection against a drop in the yen by guaranteeing that, irrespective of what happened to the actual yen-dollar exchange rate, the payoff of the warrant would be converted to dollars at an exchange rate guaranteed in advance.

For example, if the Nikkei were to drop from 37,500 to 25,000, a drop of 12,500 index points or 33 percent, the holder of a put warrant with a face value of $1,000 and a guaranteed conversion rate of $1 per yen would receive $333, even if the yen (to take an extreme scenario) were to become worthless in dollar terms. If the conversion rate had not been guaranteed, the holder of a warrant whose payoff was converted to dollars at the prevailing exchange rate would have received no dollars at all. This was a very attractive feature for American investors, who naturally measure their profits or losses in dollars—it allowed them to profit from an overdue decline in the Japanese stock market without worrying about its effect on the yen.

The market came to refer to this feature as a "quanto" option, though I always preferred calling it a "guaranteed exchange rate" (GER) option, which seemed more apt.
structured products, its payoff reflected investors' needs.

This is where the role of financial engineering enters the picture. Even though Granny had bought yen-based puts cheaply and sold the Kingdom of Denmark puts more expensively to avid investors and speculators, there was a dangerous mismatch between their payoffs that could have eliminated our profit. The options we bought would pay us in yen if the Nikkei declined, but the Kingdom of Denmark puts we sold would oblige us to pay our counterparties in dollars. A move in the dollar-yen exchange rate could therefore diminish or even wipe out our profit. To prevent this from occurring, we would have to continually hedge the effect of any move in the dollar-yen exchange rate on the value of both the options we had bought and those we had sold.

Just as a clothing designer must factor the cost of labor, cloth, and trimmings into a garment's price, so we had to reflect the cost of hedging in the price we charged for our GER option. The hedging strategy involved daily trading in the Nikkei and the yen, a strategy whose estimated cost we had to include in the price we charged for the Kingdom of Denmark puts.

Black and Scholes had shown in 1973 that the fair value of a standard stock option was the price of hedging it over its lifetime. They derived a partial differential equation for the option's value and had shown how to solve it. Ever since, academics and practitioners had kept busy by extending that insight to all sorts of other options. Now, in late 1989, Piotr Karasinski had found an analogous partial differential equation for the fair value of the Kingdom of Denmark GER put. Much to the surprise and near disbelief of everyone on the desk, he had shown that its value depends on the correlation between moves in the dollar-yen exchange rate and moves in the Nikkei index. It was counterintuitive, almost paradoxical that the degree of correlation between the Nikkei level and the yen should influence the value of a GER Nikkei put whose payoff was designed to be independent of the value of the yen.