# The Use and Misuse of Models in Investment Management

Douglas T. Breeden
*William W. Priest Professor of Finance*
*Duke University*
*Durham, North Carolina*

Financial models can be extremely helpful in adding disciplined thinking to the investment decision-making process. A failure to recognize some common misuses of models, however, such as overreliance on recent historical experiences and volatilities or a failure to identify nonlinear relationships, makes the use of models less effective than they would be otherwise. Understanding the difficulties and estimation risks associated with modeling complex securities can lead to better investment decisions in the future.

A problem with using models is that they are always imperfect descriptions of economic behavior and human decision making. Although they are often very useful, it is also easy to misuse them. Unfortunately, in the last two years, it seems that the latter has been more the case. Oftentimes, we are overconfident in the efficacy of our models. Still, models can be very useful as long as investors remember their proper roles and limitations in the decision-making process.

## Where Financial Models Are Useful

Having been trained by Bob Merton and Myron Scholes, I became quite familiar with option-pricing models at Massachusetts Institute of Technology (and later at Stanford University with John Cox, Bill Sharpe, and Bob Litzenberger as teachers). When I cofounded Smith Breeden in 1982, I brought this type of modeling to mortgage-backed securities (MBS) when we began building prepayment models. Then through the latter part of the 1980s, we built price elasticity and duration models, as well as pricing models for the MBS market. In the 1990s, I focused on studying empirical durations and brokers' forecasts of risks and returns and published that applied mortgage research in the *Journal of Fixed Income* in 1991, 1994, and 1997.

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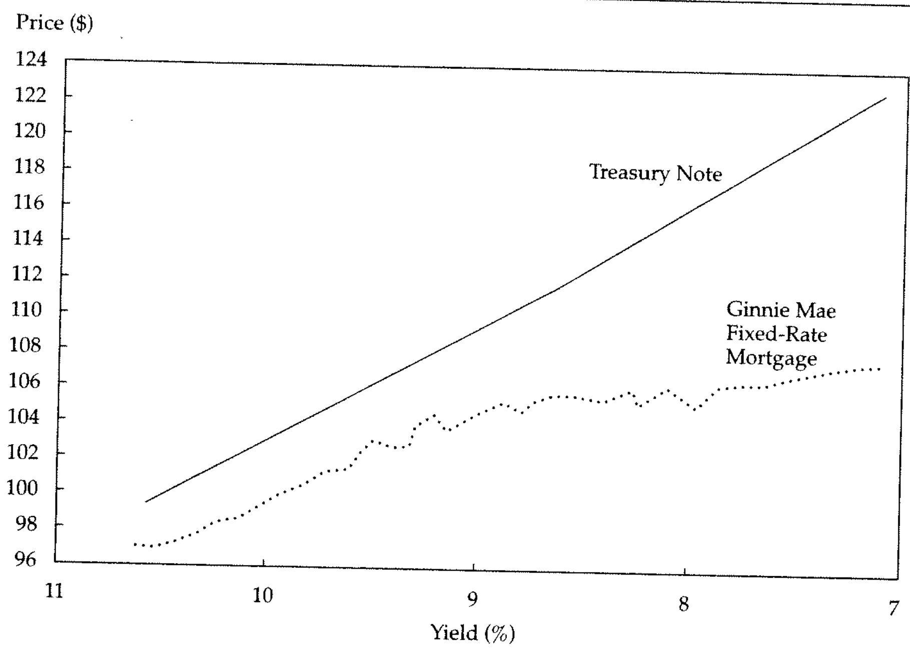
One thing that struck me about the models that Fischer Black, Scholes, and Merton gave us was that they were really good about giving us the *shapes* of the curves but not always so good about the *locations*. That is, in options pricing, many of the pricing patterns, such as deltas, exhibit S-curve shapes. I checked and noticed that the same pattern emerged in mortgage price data as the theory predicted. It was really helpful to us in risk management to know that mortgage price data were not a straight line. The pattern was a curve and not a curve that went up forever. The curve flattened out at some point.

**Figure 1** illustrates what I mean. The figure plots the price of a U.S. Treasury note versus the price of a Ginnie Mae mortgage-backed security as interest rates decline. As shown, the price increase of the Ginnie Mae loan flattens out as interest rates decrease because mortgages have an embedded prepayment option. As interest rates drop, homeowners refinance their mortgages, and the refinancing holds down the price growth of the mortgage security. The price of the Treasury security, however, which does not have a prepayment option, keeps going up. This figure illustrates the negative convexity of MBS as opposed to the positive convexity of noncallable Treasuries, which is very important.

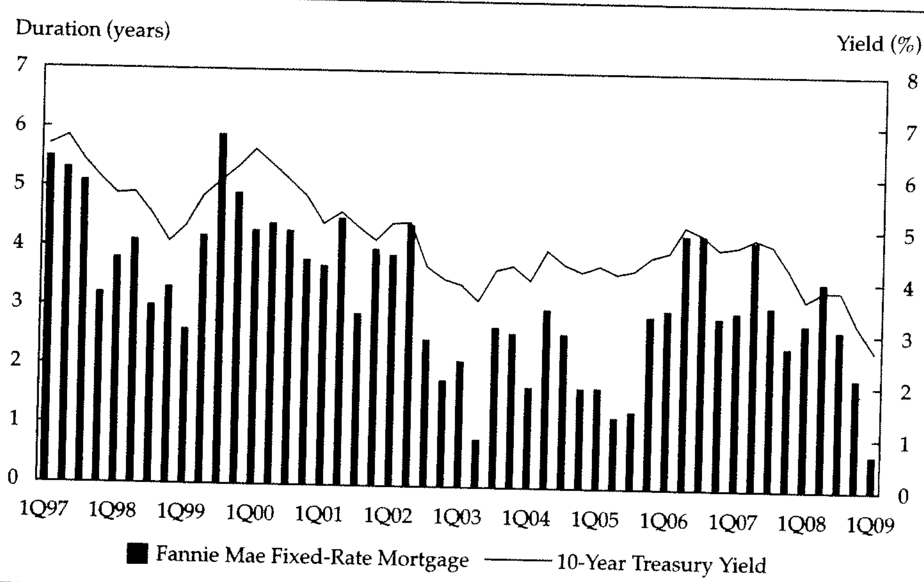
**Figure 2** shows the 10-year Treasury rate (right axis) against the duration of a Fannie Mae 6 percent fixed-rate mortgage (left axis) from the first quarter of 1997 to the first quarter of 2009. The Fannie Mae mortgage has a beginning duration of about 5.5

**Figure 1. Price of a 10-Year Treasury Note Compared with a Ginnie Mae MBS as Yield Decreases**




*Source*: Merrill Lynch.

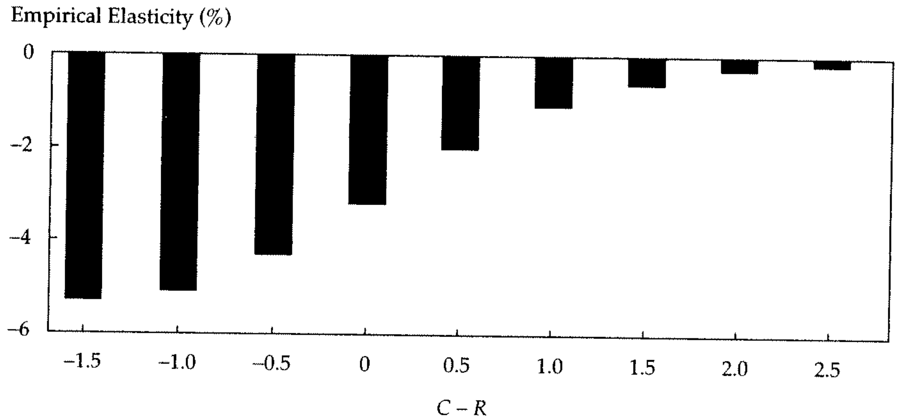
**Figure 2. Quarterly Comparison of 10-Year Treasury Rates and a Fannie Mae Fixed-Rate Mortgage, 1997–1Q2009**




years, which means that if rates go up 1 percent, the mortgage will lose about 5.5 percent of its value. If rates go down 1 percent, however, the Fannie Mae mortgage will gain about 5.5 percent. Notice that as interest rates declined in 2003, duration came down as well. During this period, duration declined from about five years to about two years. This decline means that price volatility decreased by half as interest rates came down. Conversely, higher yields mean lower prepayments, a longer duration, and thus greater price volatility. If you are managing risk, then you need to be able to model this risk. Theory predicted this relationship, and we found it in the data.

Another way of demonstrating the S-curve nature of the relationship between mortgage prepayments and duration is shown in **Figure 3**. This

**Figure 3. Empirical Price Elasticity of Ginnie Mae Mortgage vs. the Coupon minus the Refinancing Rate, 2000–2008**




graph shows the empirical price elasticity of Ginnie Mae mortgages versus the coupon ($C$) minus the refinancing rate ($R$)—that is, if $C - R$ is –1.5, then the mortgage coupon is 1.5 percent below the current refinancing rate. This figure is analogous to holding a bond with a 4.0 percent coupon that is currently selling with a yield to maturity of 5.5 percent. The bond, as a result, would be selling at a discount. This Ginnie Mae mortgage is prepaying very little because it has such a low interest rate, which means it has a long duration and a high price risk. In the figure, the length of the bar indicates the amount of risk. Once again, the shape of the risk takes on the characteristic S-curve.

Of course, the major brokerage firms that are active participants in the MBS market have a lot of incentive to forecast mortgage durations and price volatility for standard fixed-rate mortgages guaranteed by Ginnie Mae, Fannie Mae, and Freddie Mac. In general, these forecasts are quite useful and good predictors of actual price volatility. But the models do make errors, even the best of them. One of the typical errors is to overestimate the durations of high-coupon, super-premium mortgages. When brokers see the empirical data indicating a systematic error in their models, they will override their models and use actual empirical durations. For example, at one time in the 1990s, Salomon Brothers' model indicated that a 6 percent, 30-year Ginnie Mae mortgage had a duration of six years. But as the systematic error in their models became evident, Salomon's traders would use a 3.7-year duration for trading purposes. Risk managers want hedging done with actual price sensitivities, not simulated ones, because the profit fluctuations experienced are quite real, not simulated.

In recognition of these systematic errors, rather than simply ignoring the models, today's researchers now use empirical data to better calibrate their models. As a result, a closer correlation exists between the output of the computer models and the data the traders actually use.

Duration is related to the first derivative of mortgage prices with respect to interest rates. In option-pricing terminology, delta measures the sensitivity (or price risk) of the option price to changes in the price of the underlying security. I want to look at the second derivative, convexity, which measures the curvature of the payoff function for an MBS. For an option, this second derivative is called gamma, a measure of the rate of change of delta. An idea of what this second derivative, gamma, looks like is shown in **Figure 4**. It shows that the changeability in price risk for an option is greatest when that option is approximately at the money, which makes intuitive sense. Consider a call option to buy a stock at \$10 a share. The option price will change the most when the stock price is around \$10. If the stock increases in price by \$1, to \$11, the option is suddenly in the money. Yet, if the stock goes down by \$1, to \$9, the option is out of the money.

**Figure 5** applies the idea of gamma to the pricing of mortgages. The figure plots the broker forecast of option costs in mortgages against empirically derived option costs. As you can see, the shape of the broker forecast takes on what I describe as a "mountain shape," with a peak that is highest in the middle and then falls off rapidly. It is also lowest for the very high and very low coupons. When compared with the empirical data, a general, if imperfect, correlation exists between the two. Option-pricing theory predicted the mountain shape—the models recognized it and the empirical data verified it. I think predicting and characterizing these shapes are examples of how models can be useful.

**Figure 4. Illustration of Gamma**

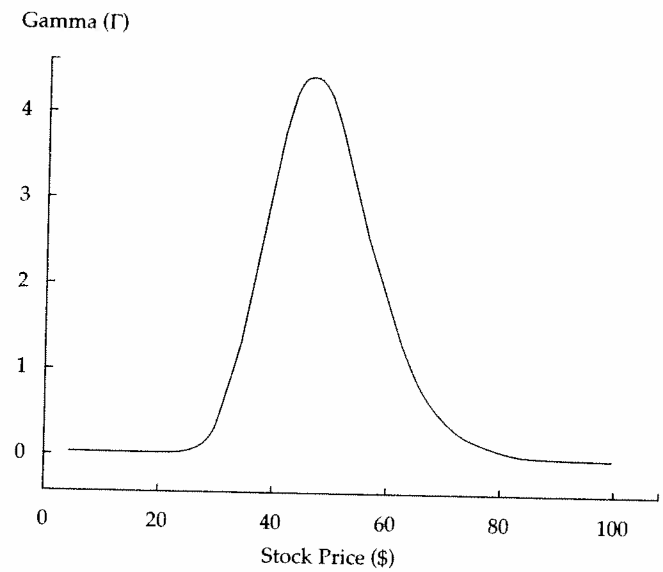
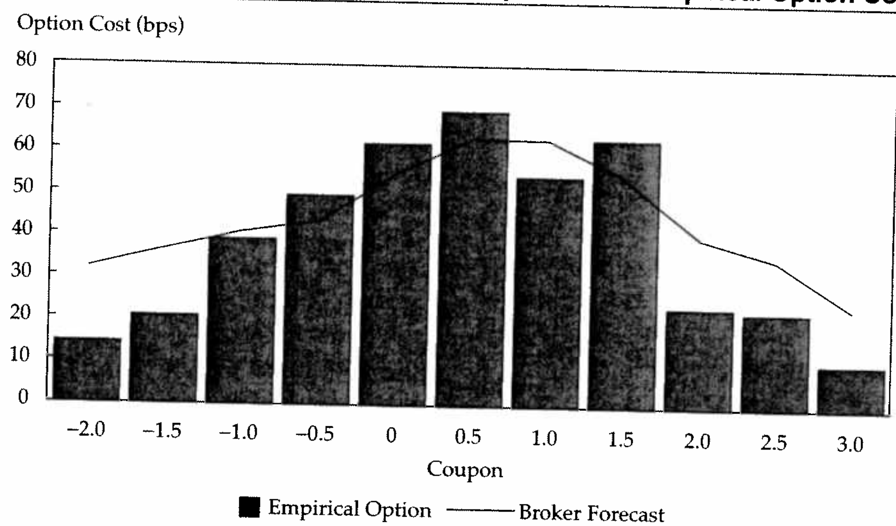



**Figure 5. Broker Forecast of Risks Compared with Empirical Option Costs**




## Implications for Hedging

The rapidly changing risk associated with the MBS prepayment option has important implications for hedging. To hedge a mortgage's prepayment option, one needs to short more bond futures as prices fall and buy them back as prices rise (i.e., as durations shorten). In other words, hedging must be dynamic. And it should not be underestimated how much back-and-forth dynamic hedging can involve. Furthermore, it requires hedgers to adopt a behavior that is not natural—hedgers must "buy high and sell low." This behavior inevitably generates losses that constitute the cost of dynamically hedging the prepayment option.

Although this approach is the discipline that dynamic hedging requires, it is important to recognize how much this behavior goes against the grain of traders. Typically, traders feel that securities become more attractive to buy as prices decline. And yet, as prices decline, durations lengthen (because prepayments slow), thereby requiring traders to sell into the price decline. Moreover, falling prices are generally accompanied by a widening of spreads. Traders who believe in the mean reversion of spreads will similarly have a difficult time choosing to increase their short hedges under these circumstances. For a speculator, it takes much discipline to sell as prices fall.

Let me give you an example of why dynamic hedging is so important by discussing something that we investors collectively are not very good at. **Figure 6** shows the spread between commercial MBS and LIBOR for the 2007–08 period. As you can see, before the crisis hit in July of 2007, the spread was in the 25–30 bp range. Then, in the course of about one month, it more than doubled to 75 bps. In November of 2007, it increased to 120 bps, which, by historical standards, was really getting high. And by March of 2008, the spread was about 350 bps. When investors are used to getting just 25 bps, spreads of 120–350 bps look like wonderful returns. So, it should not be surprising that many investors stepped in at a time when spreads were really wide, hoping that they would tighten later on. As the figure shows, spreads did subsequently narrow.

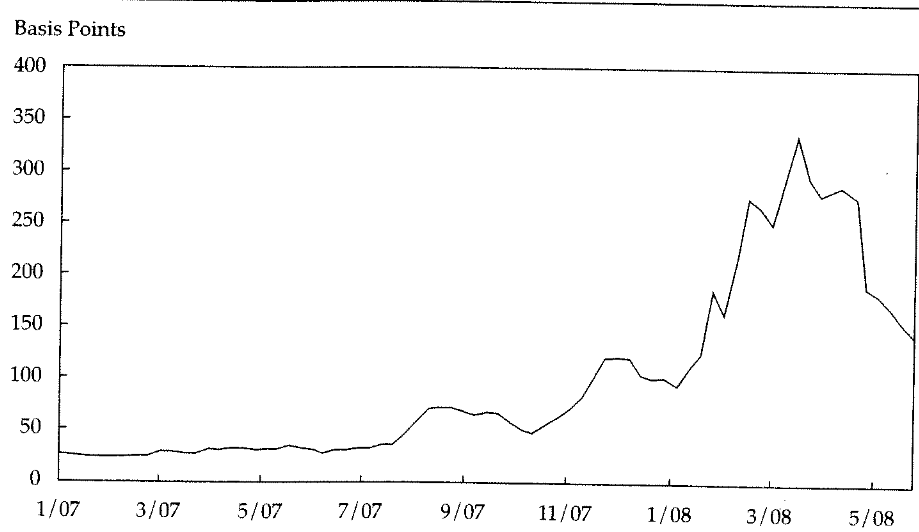
What the figure does not show, however, is that by late 2008, the spread not only widened to about 300 bps but also kept increasing to almost 700 bps. The point is that investors who took a large position when spreads were at 350 bps ended up being really wrong and took substantial losses. In this case, dynamic hedging required that the investor sell more commercial MBS as the spread widened in recognition that risk was increasing. This example illustrates that, frequently, investors are not good at forecasting short-term spread changes. So, they should be wary of large positions that cannot be sustained if they are wrong. With full disclosure, I should listen to my own advice.

## Misuses of Models

I would like to give a few examples of situations in which models can be misused. The first misuse concerns the false sense of certainty models can convey. Consider an old, yet all-too-current, example of a simple interest-only (IO) strip. An IO strip is created by breaking a conventional Fannie Mae 9 percent mortgage into its component parts of interest-only and principal-only, as shown in **Figure 7**. Our analysis indicated that when the refinance rate is around 12 percent, thus making $C - R = -3$, the IO's duration should start at about zero. As the refinance rate decreases, the duration increases to 20 years ($C - R = 1$) and then declines to 5 years ($C - R = 5$), which is a very dramatic change, as interest rates decline.

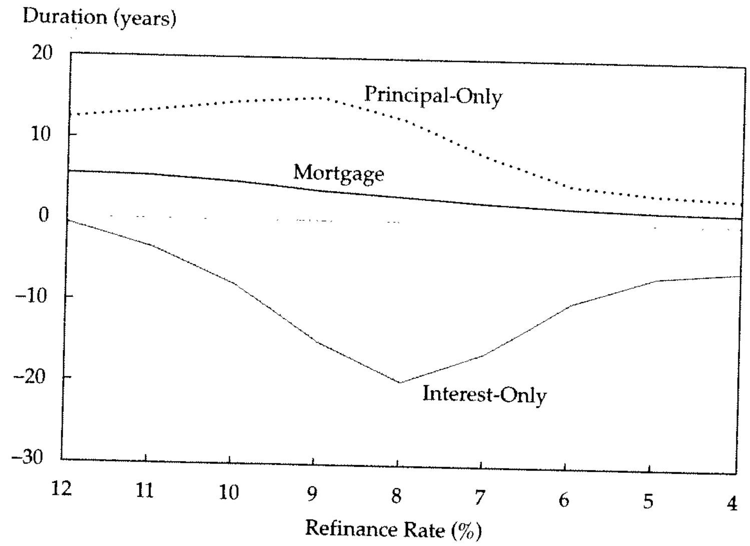
Of course, brokers are trying to forecast these duration changes for IOs, and I collected their forecasts (data from more than 10 years ago). Despite their best efforts, they were all very different. For example, in one forecast, JPMorgan estimated duration at 11.8 years, but the Goldman Sachs estimate was 4.5 years, Bear Stearns was 5.8, and DLJ (Donaldson, Lufkin, and Jenrette) was 15.4. These huge differences indicate that the risks of comparatively simple derivatives are extremely difficult to estimate. Notably, the structured securities associated with the subprime crisis are far more complex and no doubt would lead to even greater differences in their risk estimates. I think this example can certainly be said to constitute one of the misuses of models. Each broker's clients may well have looked at the risk forecasts and believed the forecasts to be very precise when they were not.

**Figure 6. Spread of Commercial MBS and LIBOR, 1 January 2007 through 1 May 2008**




*Source*: Morgan Stanley.

**Figure 7. Interest-Only and Principal-Only Components of a Fixed-Rate 9 Percent Fannie Mae Mortgage**



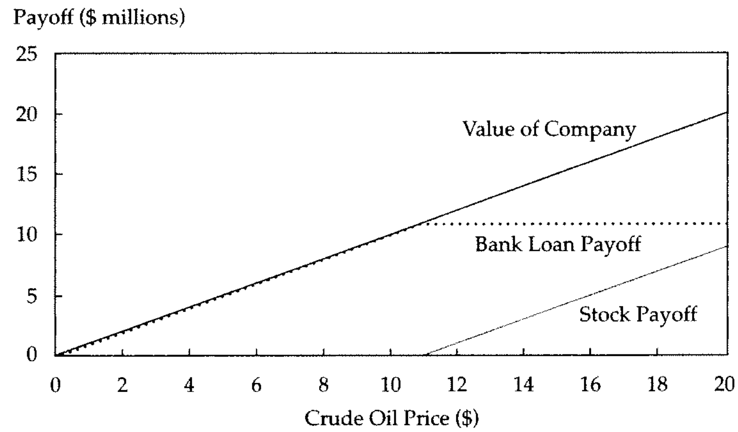

Another situation that brought down a number of hedge funds and major traders during the crisis was changing correlations. They can be deadly, especially for levered hedgers. During the last quarter of 2008, to hedge the interest rate risk associated with a long exposure to a 10-year corporate bond, funds would short a Treasury security or Treasury future of the same maturity. The goal was that if interest rates declined, the loss on the Treasury position would offset the gain on the corporate bond. What actually happened, however, is that interest rates did indeed decline significantly, resulting in a loss on the short Treasury position. And corporate bond prices did not increase, but they also declined because spreads widened. If investors were long corporate bonds and short Treasuries, they lost on both sides of the transaction because of the changing correlations. And this outcome is not that unusual. Correlations often do change, especially in volatile times.

Consider the relationship between oil prices and economic growth and whether oil prices are positively or negatively correlated with economic growth. It is not as simple a question as one might think. In earlier periods of rising oil prices, such as 1974–1975 and 1981–1982, oil price increases led to a declining economy. But in the mid-2000s, oil prices surged because economic growth was high. The difficulty is knowing how to manage risk when a critical correlation is sometimes positive and sometimes negative. Similar to trading long corporate–short Treasuries, if the correlation suddenly goes in the opposite direction of what investors think, they can lose a great deal of money quickly, especially if they are levered. In my opinion, changing correlations are one of the most dangerous aspects of investment management, and failing to recognize changing correlations is one of the main sources of error in most models.

## Models for Nonlinearities in Corporate Bond and Banking Risks

In addition to the mortgage prepayment option I already discussed, hedging corporate bond and banking risks displays nonlinearities that can be modeled by using options theory. Payoffs to stockholders and bondholders can be thought of as a function of the value of the company. If the bondholders are owed $11 million and the company is worth that much or less, the company will default and all the value will go to the bondholders. Essentially, the stockholders have a call option on the residual value of the company above $11 million. Thus, the bondholders' position can be viewed as owners of the company and with a call option written to the stockholders. On the basis of put–call parity, however, the bondholders' position can be equivalently described as owners of a riskless asset with a put option on the value of the company written to the stockholders. This setup is a "credit put option" in which stockholders can put the company to bondholders. In **Figure 8**, which shows the loan payoffs on stocks and bonds of an oil company, the value of the equity is zero for company values at or below $11 million. Also, by virtue of their short put position, the value of the bondholders' position goes down with company values below $11 million. To hedge this credit exposure, bondholders could theoretically buy puts on the oil price.

**Figure 8. Illustration of Payoffs on Stocks and Bonds of an Oil Company's Loan Risk**




Looking at credit risk as the equivalent of being short a put option allows investors to make sense of interest rates. That is, they are aware of the fact that, all other things being equal, an increase in volatility increases the prices of options. But if options are used to hedge credit risks, then the fair interest rate on a loan must be higher to cover the higher option costs. Correspondingly, lower volatility leads to lower option costs and, in turn, to lower interest rates.

The discussion so far has assumed a more or less constant relationship, or beta, between corporate bonds and stocks. To examine this relationship in greater detail, I separately estimated the betas of Baa rated corporate bonds and junk bonds relative to the S&P 500 Index when the junk-bond spread to Treasuries was (1) less than 500 bps and (2) greater than 500 bps. When times are good and junk-bond spreads are tight, betas on corporate bonds are low: 0.11 for Baa bonds and 0.21 for junk bonds. But when times are bad and junk-bond spreads to Treasuries exceed 500 bps, the betas increase to 0.28 for Baa bonds and to 0.48 for junk bonds. During 2008, the beta of junk bonds relative to the S&P 500 increased to 0.70. The point is that betas change and correlations change, and they change with the economy in systematic ways that are predicted by theory. Moreover, as predicted by theory, these changes will occur in a nonlinear manner and model designers must be aware of this possibility.

Another aspect modelers need to be aware of is that expected relationships may hold in general but not hold in a particular instance. Consider Bear Stearns, whose stock went from $169 to $2. Not unexpectedly, Bear Stearns' bonds also declined to about 10 cents on the dollar. When JPMorgan purchased Bear Stearns, however, JPMorgan put its credit behind the Bear Stearns' bonds and they went up in value, ultimately even back above par. Bear Stearns' stock price did not follow, which is not what theory says should happen. The expectation is that the more the stock is down (up), the more the bonds will be down (up), but unfortunately, it does not always work that way when mergers or government interventions happen.

## Real Estate Risks Never Seen Before

One thing investors should have learned by now is that historical statistics are insufficient for accurately assessing risk. Since 1975, housing prices have never declined in the United States for a full 5- to 10-year period. The lowest 5-year rate of price appreciation was 2 percent from 1990 to 1995; the lowest 10-year rate was 3 percent from 1989 to 1999. The highest 5-year growth rate (1975–1980) was 11 percent; the highest 10-year rate (1975–1985) was 7.5 percent. The average growth rate in housing price appreciation over the last 30 years has been 5 percent. In terms of risk and return, it would be hard to imagine a more attractive asset class. Yet, price declines have occurred in 2008 and 2009 that have never been seen, or even imagined, since the Great Depression of the 1930s. The S&P/Case–Shiller Home Price Index showed a 20 percent decline nationally in 2008. Individual housing markets, such as Phoenix (down 45 percent) and Las Vegas and Miami (each down 40 percent), have clearly fared much worse than the national average. One of the worst misuses of models is to look at history to determine the worst that has been seen and conclude that it is the worst that can be. The problem is that the historical scenario may not be bad enough. We need to think about circumstances that have not occurred but are possible.

Hints of how bad it can get are often out there. In a prescient 1992 article in the *Journal of Fixed Income*, authors Pestre, Richardson, and Webster examined the impact of changes in home price values on default probabilities. They found decidedly nonlinear relationships. For example, one of their findings was that, although a 10 percent decline in home prices increased default probabilities by about 2.5 times, a 20 percent decline translated to an increase in default probabilities of about 7 times. If the financial industry had paid more attention to this paper, it might have been better able to anticipate the situation it is in today with the enormous surge in defaults.

## Conclusion

A long time ago, Paul Samuelson (1937) noted that model assumptions should be treated as nothing more than hypotheses. But somewhere along the way, hypotheses became gospel. The current financial crisis is forcing investors to question some of their most basic assumptions. Among the assumptions being questioned (which now must be factored into models) are the following:

- Liquidity—Investors have been taught that securities can always be sold at market prices, which, although low, will be available. Instead, markets for many fixed-income securities have almost completely dried up. Where prices are being quoted, wide variations are found in dealer-quoted prices along with enormous bid–ask spreads.
- Price Continuity—Investors have believed that prices move continuously in major markets. But a lesson that should have been learned from the 1998 collapse of Long-Term Capital Management (LTCM) is that price continuity cannot be assumed. In that situation, in what was thought to be a highly liquid market, interest rate swaps, an enormous pricing discontinuity occurred in which spreads widened by 30 bps in a single day. It has been said that LTCM lost more than $500 million in that one day alone, or about 25 percent of its capital.
- Response of Arbitrageurs—Many of the "best and brightest" in fixed income bought when spreads were thought to be extremely wide, taking on considerable leverage in the process. They counted on arbitrageurs to come into the markets if spreads widened further. But when spreads went through the roof, the arbitrageurs did not arrive as expected. Perhaps pools of arbitrageurs exist who need time to acquire the necessary expertise and to overcome the skepticism from what happened to the previous pool of arbitrageurs before they can exploit apparent opportunities.
- Size of Tail Risk—Investors have often assumed tail risk to be normally distributed with historical standard deviations. But instead, negative events seem to be happening more regularly than normal distributions would predict, which suggests that tail risk is much bigger than anticipated. It may be that even the most liquid markets are susceptible to self-reinforcing herd behavior and momentum effects that contribute to increased probability of tail events.
- Economic Equilibrium—As an economist, I am amazed by the recognition that, contrary to what I was taught, economies seem to have multiple equilibriums. By that, I mean that prior to the current crisis, economies seemed to be functioning smoothly with no obvious imbalances. Then, with little warning, economies shifted into a totally different economic state. Within a couple of years, a new equilibrium will likely be established with very different relative prices and wealth levels. But economists find it hard to explain how two very different equilibriums can be valid when resources, education, technology, and talents have changed very little.
- Government Behavior—Government behavior is important and influential but also erratic and unpredictable. Despite near failure, Bear Stearns' bonds became worth more than par again. Lehman's bondholders, however, did not fare so well because prices were 15–30 cents on the dollar in much of 2009.
- Academics vs. Warren Buffett—Some investors have tried the "put your eggs in one basket, then watch the basket" approach. They thought they knew banking and mortgages well and took multiple positions in that area while keeping other risks low. Unfortunately, they did not know banking and mortgages as well as they thought and took a beating. So, diversification still matters. And worse than being undiversified is to be undiversified and levered.
- Human Decision Making—Humans (and groups of humans) make documented behavioral errors. But human decision making can be improved with training. As I look back on the *ex post* errors made in the past two years, it looks like investors were overconfident and prideful and made several classic behavioral errors.

Clearly, model builders have much to consider before building the next generation of models.

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This article qualifies for 0.5 CE credits.

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# Question and Answer Session

Douglas T. Breeden

**Question:** What are your thoughts about how to supplement traditional quantitative modeling with behavioral finance?

**Breeden:** Clearly, everyone is making more use of scenario analysis, in general, and building in more dire scenarios to see how their portfolios respond, in particular. But scenario analysis is often a difficult technique to use in practice. One approach currently gaining favor is to encourage the following thought experiment.

Let us say that it is the beginning of 2009, but we imagine a group of managers looking back on 2009 from the perspective of January 2010. We consider the thought experiment in which all we know for certain is that in 2009, we lost a great deal of money. The question is then asked of the group, how did we lose the money? Answers to this question from informed managers and modelers can be quite revealing about model risks. I think this approach is a good way to think about scenario analysis because it forces those who know the portfolio the best to construct reasonable sequences of events that can lead to the outcome of losing a great deal of money. For example, this approach might have prompted investors to think about the possibility of a real estate crash.

I remember driving along the East Coast of the United States and thinking that too many vacation homes are unoccupied most of the time. It occurred to me that if economic conditions deteriorate, few of the homeowners would want to maintain the homes, which means the potential for a huge excess supply of homes exists with the corresponding impact on their prices. This approach needs to be encouraged. In fact, I wish I had paid more attention to this thought!

From the behavioral perspective, because investment decisions are usually made in groups who are subject to errors predicted by behavioral finance theory, I think improving group decision making is key. Groups do not always make better decisions. It depends on how the group is put together. Groups that include members with different points of view tend to be very helpful. But if all the members of the group have the same point of view, that tends to be unhelpful.

Also, a group that corresponds by e-mail will produce different results from those of a group that meets face to face. In the former approach, members have more differences of opinion. In the latter, social concerns have been shown to constrain the expression of different opinions. Research is also recognizing the important role of the leader in driving successful group outcomes. These are all contributions from behavioral economics and finance that need to be incorporated in the decision-making processes.

**Question:** Should value-at-risk analysis for assessing bank risk be replaced with fundamental credit analysis?

**Breeden:** In application, value-at-risk analysis has been a disaster in panic situations because it relies on diversification to cancel out many risks. Unfortunately, this cancellation process does not occur in extreme markets because correlations tend toward unity in extreme markets. When analysts first started analyzing investment risks, they looked at interest rate risk and considered the effect of a 1 percent increase in interest rates.

Then they realized that the slope of the term structure of interest rates is also very important, so they put in a second risk. Then they realized that it matters what swap spreads do and put in a third risk. Finally, they also realized that bond market volatility and the VIX (Chicago Board Options Exchange Volatility Index) represented a fourth risk. The end result was a multidimensional risk analysis that was more complicated than a simple value-at-risk analysis. It is a complicated process to estimate the risk of a company. As a result, I think using more fundamental analysis with multiple dimensions for risk is really the way to go.