Principles of Investment Risk Management

Executive Summary

The credit crisis that began in 2007 emphasized the importance of some basic principles of investment risk management. This white paper articulates three principles that we believe to be applicable in all markets:

- **Prediction is very difficult, especially if it's about the future.**
  Asset management firms are paid to make predictions. Characterizing and understanding the margin of error around those predictions affords a process better suited to making robust decisions in the presence of uncertainty.

- **Investing is not a game.**
  All financial markets eventually experience a massive break from normal behavior, whether it's total (the end of the Russian stock market in 1917) or partial (the Great Depression). Investing in financial markets is not a game in which the rules are clearly specified and known in advance. Investment risk management must take into account the possibility of deep regime change.

- **Clarity is imperative.**
  The separation of duties between investment managers and their clients must be clearly understood. The client must understand which decisions the manager is making and which decisions the manager is leaving to the client. All parties stewarding the client's capital must have precise definitions of their responsibilities so they can move quickly and decisively.

A stylized fact in the investment business is that whenever you hear someone say "it's different this time," you should be very cautious. Because that's usually a sign that the speaker thinks that unbreakable rules can be broken—that this time, trees will grow to the skies.

So let's start out by saying: It's the same this time. The credit crisis that began in 2007 reminded us of some lessons about risk management that we may have forgotten, but it didn't show that fundamental principles have to be rethought. In fact, the credit crisis emphasized the importance of those very same principles. Accordingly, we articulate three basic principles of investment risk management that we believe to be applicable always and everywhere.

Principle 1: Prediction is Very Difficult, Especially if it's About the Future[1]

Asset management firms are paid to make predictions, and every prediction has a margin of error. Investment risk management seeks to understand these margins of error and to use this understanding to aid the decision-making process in the presence of uncertainty.

Principle 2: Investing is Not a Game

There were 36 active stock markets in 1900 (Dimson 2002). Many (Russia, China, Poland, Hungary, Havana) did not survive the 20th century uninterrupted. Over even longer periods than the decades since 1900, history indicates that virtually all financial markets ultimately do not survive. Even over periods where financial markets were continuously in operation, the rules governing these markets were in constant flux. Investing in financial markets is not a game in which the rules are clearly specified and known in advance.

Principle 3: Clarity is Imperative

There is a separation of duties between investment managers and their clients. It is rare that a client will hire an investment manager and place no constraints on investment activities. Typically, some part of the capital markets will be specified: a mutual fund might be required to invest in US small cap growth equities; a sovereign wealth fund might hire a manager to put money to work in the European credit markets. The investment manager must clearly indicate which risks it will take and which risks it will not. The client must understand which decisions the manager is making and which decisions the manager is leaving to the client.

We believe that it is crucial to focus on these three principles at all times—in up markets as well as in down markets, in times of high volatility and in times of low volatility, and in functioning markets as well as in disrupted markets. Adherence to these principles will produce better portfolios and align client interests more closely with the portfolio construction process. Furthermore, these three principles help guide investment risk managers to design techniques that are effective in all market conditions.

The Principles

Principle 1: Prediction is Very Difficult, Especially if it's About the Future

1.1 Predictability Without Prediction

In the 1930's, a Russian named Andrey Kolmogorov was a leader in developing a disciplined way of thinking about the future. This discipline suggested that in some area of interest, one should make a detailed list of all the possible things that could happen: these are called *outcomes*. The area of interest might be as specific as what can happen on the next turn of an American roulette wheel—in which there are 38 possible outcomes—or it might be as imposing as specifying the future position of every subatomic particle in the universe. As the future of the universe seems difficult to tackle, we'll use a roulette wheel as an example.

Kolmogorov's discipline further suggested that all relevant combinations of outcomes, called *events*, could be listed as well. In American roulette there are 36 slots numbered 1–36, and zero/double-zero which are considered non-numeric. So "even" is a roulette wheel event, consisting of the combined 18 outcomes where the ball lands in an even-numbered slot.

Each event has an associated *probability*, which is the chance that it will happen. The sum of the probabilities of all outcomes is one (100%). The probability of the even event in roulette is 18/38, or 47.37%.

What we have just described is called a *probability space*—indeed, Kolmogorov is one of the founders of modern probability theory. The genius of this approach is that it doesn't require a prediction of what outcome will occur. A PhD in probability theory has no more idea of where the roulette ball will land than does Paris Hilton's dog. Probability theory takes to heart our first principle simply by reminding us to avoid certain predictions altogether.

Despite avoiding predictions, casinos operating roulette wheels make money very predictably using Kolmogorov's discipline. The casino—regulated by government authorities so that the roulette wheel is fair—does not have any knowledge over the gambler about where the ball will land. However, the casino sets the payouts so that a $1 bet on "even" pays $2. As we noted above, "even" only occurs 18/38 = 47.37% of the time, not half (50%) of the time. Because of this, the casino expects to make about 5.26 cents every time someone bets a dollar on "even." The casino further knows that there is an unlikely but nonzero chance that it could be bankrupted by someone having a good run and defying its expectations. It deals with the "casino bankruptcy" event[2] by setting table limits.

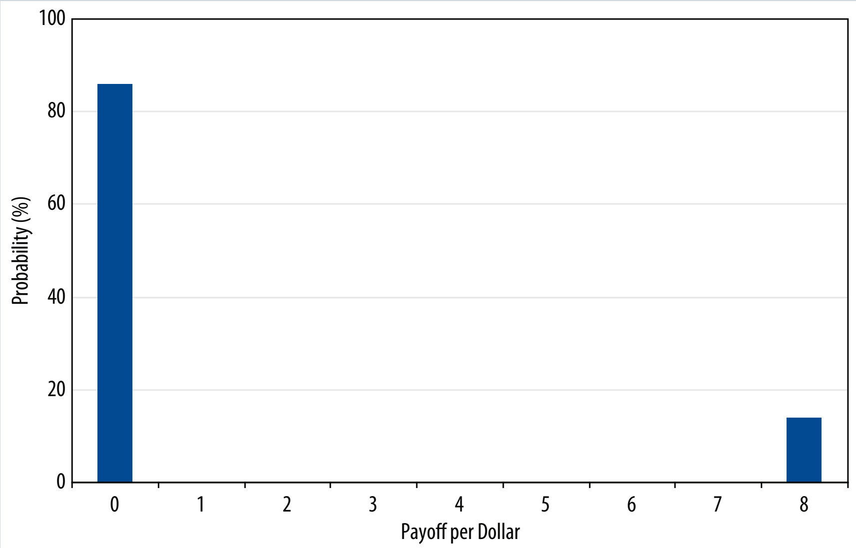
1.2 The Role of Skill

Of course, we don't think that investment management is really equivalent to a gambling game, and in fact will discuss the differences in detail below. But at this stage of our exposition, let's make a simple analogy. We might find that the "even" event in roulette is like interest rates rising; the "odd" event is like interest rates falling, and the zero/double zero events are placeholders for transaction costs and other factors. In this analogy, an investment manager can decide to bet on even or odd but not on zero/double zero.

In roulette, skill—predicting where the ball will land—is not possible.[3] In investment management, skill is necessary. Skill is necessary even in passive investment management (where the manager seeks to replicate a benchmark and must overcome frictions and transaction costs), and is needed by definition in active investment management (where the manager seeks to outperform the benchmark).

Under this analogy, a manager with no skill—one who makes the right call on interest rates 50% of the time—will lose. This is because we assumed roulette-like odds in which 2/38 = 5.26% of the time, the manager can't win (zero/double zero = transaction costs). Under these assumptions, the manager must make the right interest rate call 52.78% of the time just to overcome transaction costs and break even. To generate positive expected performance, a manager must have more skill than that. For example, under our assumptions, a manager who is right 55% of

Exhibit 1
Payoff Pattern After 3 Months — 55% Skill



Source: Western Asset

the time will generate an expected $1.04 for each dollar invested in an interest rate call.

A manager who can make the right interest rate call 55% of the time should be able to do a very effective job in growing client assets. With a $1.04 payoff per dollar expected each time a rate call is made, the manager merely needs to make one call a month to generate an annual compound rate of return of $1.04^{12} - 1 = 64\%$ a year. The fact that we don't often see such spectacular rates of return is a clue that something is wrong with this approach to thinking about investment management.

One problem is apparent if we look at the payoff pattern after only three months of interest rate calls by a 55%-skilled manager (Exhibit 1).

Exhibit 1 is a common way of displaying Kolmogorov's discipline: the outcomes are listed along the horizontal axis, and their associated probabilities are listed along the vertical axis. This is called a *probability distribution*. In order to compound the 4% expected payoff ($1.04 expected to be returned for every $1 invested in a rate call), the manager must take the winnings from the previous month and reinvest them in another interest rate call. But the nature of the payoff pattern is that if the manager makes a wrong call—or if the frictional cost outcome occurs—the manager loses everything.

This results in the highly skewed payoff pattern shown. If the manager is correct three times in a row and the transaction cost outcomes don't happen, then $8 is earned on each $1 invested. That only happens 14%[4] of the time. The other 86% of the time, all the original capital is lost. The average still looks good: 14% times a payoff of 8 is 1.1317, or a 13.17% return in three months. But this high average comes at the cost of an undesirable payoff pattern—one in which there is a single, increasingly unlikely but increasingly huge payoff. As time goes on, the chance of getting that huge payoff approaches zero. Most investors would not choose such a payoff pattern, which we recognize as something like a lottery ticket.

1.3 The Interplay of Skill and Risk

One aspect of investment risk management is helping find methods of deploying skills to produce a payoff pattern within the client's risk tolerance. Our principle—***Prediction is very difficult***—plays a key part here. Even though we have assumed that there is skill in predicting the direction of interest rates, we found in the example above that we could produce a very unattractive payoff pattern. Being right 55% of the time means being wrong 45% of the time (plus frictional drag). That substantial minority of the time that prediction fails can be deadly if it isn't properly handled.

One way to manage the risk is to form a portfolio consisting of diversified sources of outperformance. Let's suppose that a manager has 55% skill in calling the direction of three independent areas, say, interest rates, credit spreads and breakeven inflation. We'll assume these items are independent; in other words, a correct call in any one does not make a correct call in any other either more or less likely. This assumption of independence is likely not true in real situations, but is helpful for illustration.

Suppose that in each period, 25% of portfolio assets are placed in each of the following four items:

- Interest rate call
- Credit spread call
- Breakeven inflation call
- Cash (by "cash" we mean that no change in value occurs from one period to the next. We're not assuming any risk-free rate of interest)

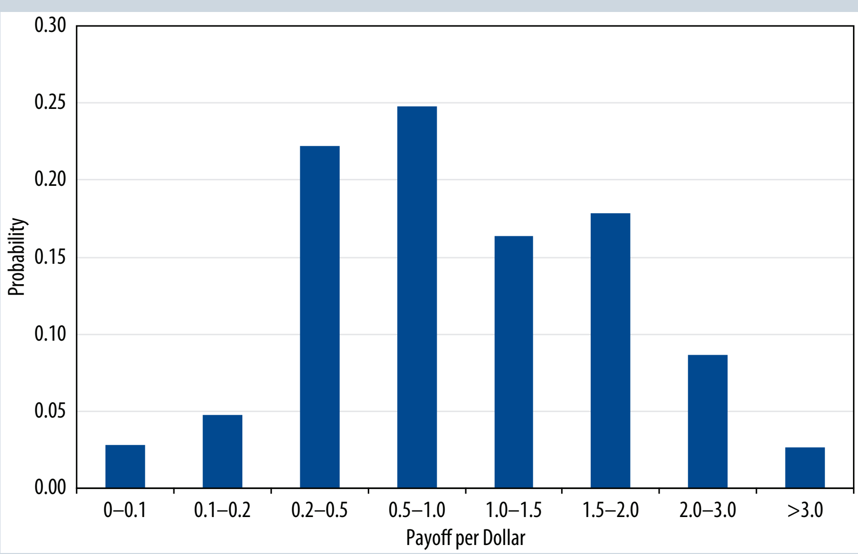
We have adopted a couple of risk management techniques to help use the manager's skill to its best advantage. While these are not necessarily what we would use in all cases, in appropriate circumstances the following strategies can be useful:

- A portion of the portfolio is placed in a lower risk "anchor"
- The sources of outperformance are diversified

After three months, the possibilities are far more diverse than the mere two possibilities we saw in Exhibit 1 (Exhibit 2).

The average return is now 9.78% over three months. The worst outcome is to be wrong on all three exposures all three months and have only 1.56 cents, with a very low probability of 0.13%. Recall that without risk management, we had an 86% chance of losing everything. We have given up some average return—the non-risk-managed average was 13.17% over three months—in order to avoid the extreme payoff pattern of Exhibit 1. As time goes on, the payoff pattern from the risk-managed approach represented by Exhibit 2 squeezes toward the middle, with a more and more likely chance of approaching the excellent average return produced by manager skill. The non-risk-managed approach represented by Exhibit 1 does the opposite, gravitating to more and more extreme outcomes.

Exhibit 2
Payoff Pattern After 3 Months — 55% Skill + Risk Management



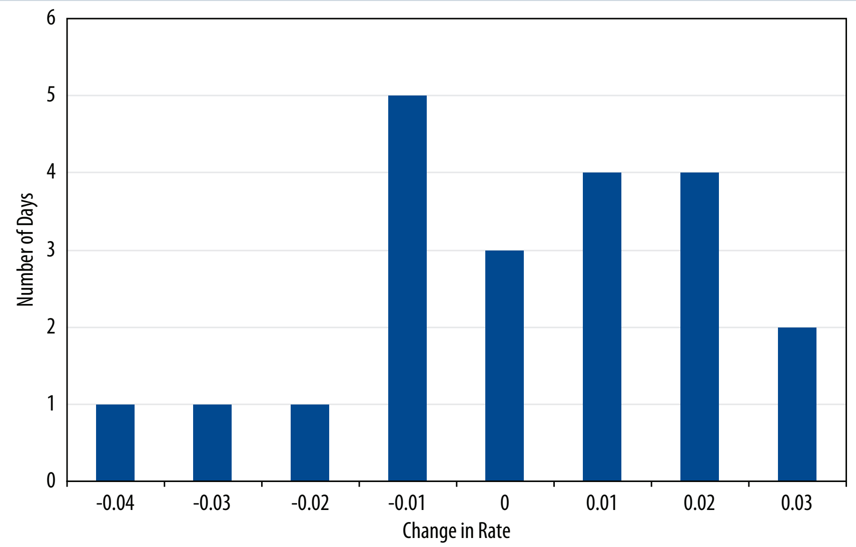
Source: Western Asset

1.4 The Bell Curve

There are a number of mathematical statements showing that reliable statistical patterns will emerge out of apparent chaos under certain conditions. The most widely used of these statements is the Central Limit Theorem (CLT).[5] The CLT says that if we look at a series of independently generated random numbers (perhaps like changes in interest rates day over day), then under certain conditions they will eventually form a pattern like a bell-shaped curve, which is more precisely called a normal or Gaussian probability distribution. The CLT is a theorem, not a theory. In other words, it is a universal law of mathematics that is always and everywhere true.

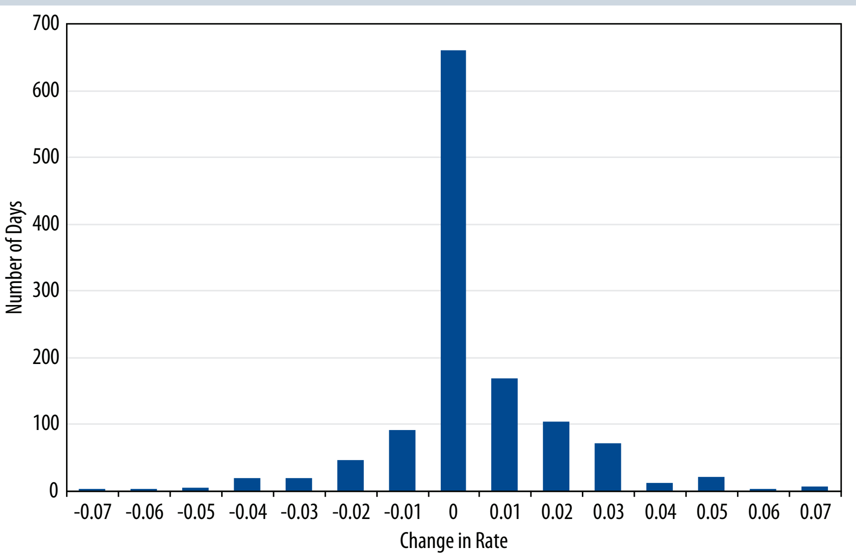
Consider the 11,986 daily observations of the constant maturity US Treasury (UST)

Exhibit 3
Distribution of Changes in UST 10-Year Rates, January 1962



Source: Federal Reserve Board

Exhibit 4
Distribution of Changes in UST 10-Year Rates, 1962–1966



Source: Federal Reserve Board

10-year Index from 1962–2009, available from the US Federal Reserve's H15 release (Federal Reserve Statistical Release, 2010). In the month of January, 1962, the following distribution of outcomes occurred (Exhibit 3).

From Exhibit 3 we can see that there was one day in the month when the 10-year rate went down 4 basis points (bps), and four days were it went up 1 bp. There isn't a very recognizable pattern here. However, for the five years 1962–1966 (1247 days), the picture looks like Exhibit 4.

Here we see a bell-shaped pattern emerging.[6] The mathematics behind this pattern are well known—for example, we can use functions like NORMSDIST and NORMSINV in popular software like Microsoft Excel to extract probabilities of observing different outcomes quite easily. This leads to the tantalizing thought that the CLT will force financial phenomena into patterns that we can assess using the discipline of probability theory.[7] In that case, we can avoid the pitfalls of our first principle, ***Prediction is very difficult***, by deploying manager skill in a careful risk-controlled fashion.

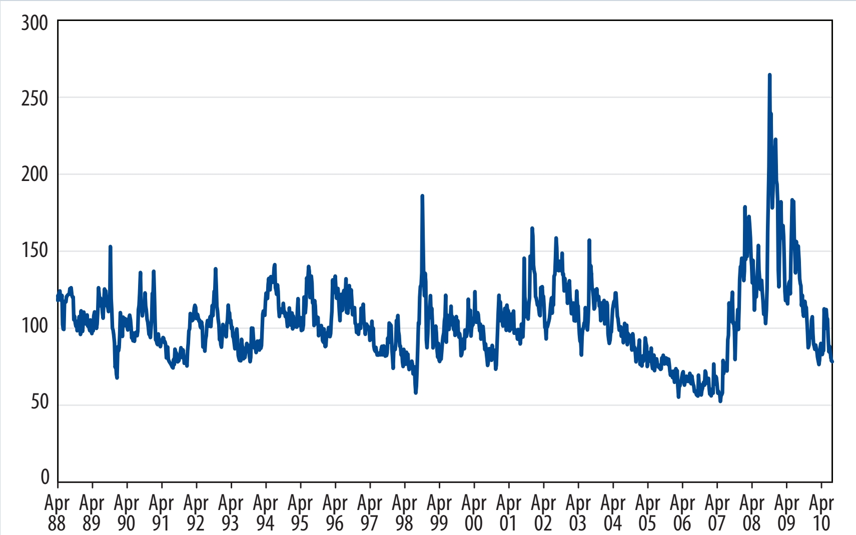
1.5 How to Manage Risk, Take 1

We'll soon see that the world is a more complex place than this line of reasoning would indicate. But before we deal with this complexity, let's see what practical steps we can take based on what we've seen so far.

Volatility is one way of measuring the difficulty of predicting the future behavior of a portfolio: the higher the volatility, the lower the predictability. Thus we start by making our best estimates of volatilities of portfolio exposures. We distinguish between *systematic* exposures (exposures to marketwide phenomena such as interest rates, credit spreads, and inflation) and *specific* or *idiosyncratic* exposures (exposures to individual company outcomes that are unrelated to anything else). For example, if a pharmaceutical company is running a trial of a potential blockbuster drug, the success or failure of that trial is probably unrelated to most other economic conditions.

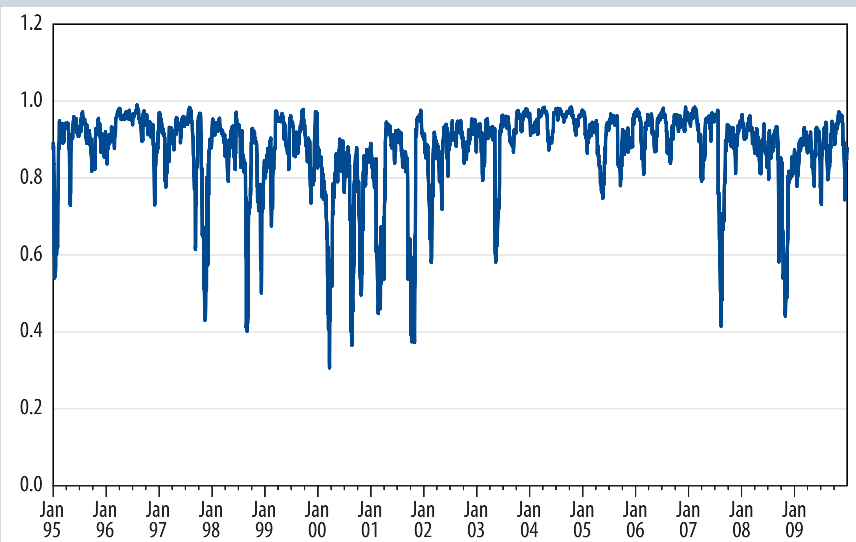
In a typical large portfolio managed by a professional investment management organization, systematic exposures are the major determinants of portfolio behavior. However, individual exposures can also be important, especially in fixed-income portfolios in which a default can overwhelm other sources of variation.

Exhibit 5
Merrill Lynch Option Volatility Estimate (MOVE) Index



Source: Bloomberg

Exhibit 6
Correlations — UST 10-Year versus Moody's Baa Yields



Source: Bloomberg, Federal Reserve Board

Volatilities can change even in stable markets. Both academics and practitioners have produced and continue to produce massive amounts of research regarding the changing nature of volatility. In 2003, Robert Engle won a Nobel Memorial Prize in Economic Sciences for methods of analyzing economic time series with time varying volatility. These methods have sprouted into an exhausting litany of acronyms like GARCH (Generalized Auto Regressive Conditional Heteroskedacticity). A key insight of GARCH modeling is that financial volatility follows regimes, where the market is "nervous" (high volatility) for prolonged periods and "calm" (low volatility) at other times, with transition periods in between. This phenomenon is visible in Exhibit 5, which shows an average of implied volatilities of interest rate options computed by Merrill Lynch.

While it appears that there is a long term average of about 100 bps (1%) annualized standard deviation of interest rates, there are prolonged regimes of low volatility (late 2004 to late 2007) and prolonged regimes of high volatility (2008–2009). Given that volatility is time varying, it is important to recall that our task is to anticipate what volatilities will be in the future. Using past volatility patterns is a start, but careful thought is necessary to project forward.

Disciplined investment risk management must estimate future relationships between different parts of portfolios. If one part of the portfolio goes in one direction while another goes the other way, the net effect will be to dampen portfolio volatility. Correlation is one measure of relationships. A correlation of 100% means two items move together with perfect reliability; a correlation of -100% means they move in opposite ways with perfect reliability, and a correlation of 0 means their movements are unrelated.

As Exhibit 6 shows, correlations between important elements of fixed-income portfolios can change. While much of the time correlations between Treasury yields and yields on Baa credits are above 80%, there are clearly periods during which this relationship breaks down. A common fixed-income risk management technique is to hedge interest rate risk incurred with cash bonds using US Treasuries futures. If the relationship between these items breaks down as it did for much of 2000–2001 and in 2007–2008, the portfolio's realized behavior may be very different than anticipated.

Thus, as with volatility estimates, forward looking techniques must be used to anticipate correlations. In fact, the title of a 2008 book by Robert Engle is *Anticipating Correlations*, succinctly capturing this forward looking nature of the problem. If the book had been titled *Measuring Correlations*, we might have been tempted to believe that observing the past was sufficient.

While Exhibit 4 above was formed from patterns of interest rates, we can also form such a graph from patterns of portfolio returns. It turns out that volatilities and correlations of the key exposures in a portfolio are exactly what we need in order to compute the precise probabilities for such a graph. If we find the graph has a pattern that looks something like Exhibit 1 (unacceptably like a lottery ticket) we can explore how to reallocate exposures and manager skill to produce a more reasonable pattern. In this way, we can deal with the difficulty of prediction by embodying manager skill in a combination of exposures that produces a desirable portfolio-level payoff pattern.

Thus our first attempt at dealing with the uncertainty of prediction involves the use of disciplined processes to estimate outcomes and probabilities. That in turn leads us to try to find ways to estimate volatilities and correlations of portfolio exposures, which together give us a view of the degree of difficulty we can have in trying to predict the behavior of the portfolio. Using the distribution patterns we get from this process, we can figure out how to avoid unattractive patterns and how to squeeze the most attractive patterns from manager skill.

Principle 2: Investing is Not a Game

2.1 Risk and Uncertainty

In the 1920s, University of Chicago economist Frank Knight sought to define a discipline for thinking about how the future might unfold (Knight 1921). In some respects Knight's framework was similar to that of probability theorists like Andrey Kolmogorov. Knight—who was not handicapped by living in the Soviet Union—was particularly interested in developing such a discipline in relation to financial profits.

Knight noted that a key aspect of financial activity is risk. A dictionary definition of risk is: "a source of danger, a possibility of incurring loss or misfortune."[8] In financial economics, this is actually a definition of hazard. Knight suggested that in economics, risk should be thought of more broadly than as hazard. A more appropriate way of thinking about risk, he suggested, is: *lack of knowledge about the future*, without assuming that this lack of knowledge would necessarily lead to bad outcomes.

In fact, Knight divided risk in the broad sense into two specific categories:

– *Knightian Risk*, in which we know all of the possible outcomes and their associated probabilities, but not what will actually happen.

– *Knightian Uncertainty*, in which we do not know all of the probabilities, or even all of the possible outcomes.

The game of roulette is an example of Knightian Risk. As we noted, this kind of risk has very similar characteristics to the framework used by probability theorists. But Knightian Uncertainty includes an entirely different kind of knowledge deficit about the future. John Maynard Keynes took up Knight's theme, explaining in 1937 that the game of roulette is subject to Knightian Risk, but not to Knightian Uncertainty:

> By "uncertain" knowledge, let me explain, I do not mean merely to distinguish what is known for certain from what is only probable. The game of roulette is not subject,

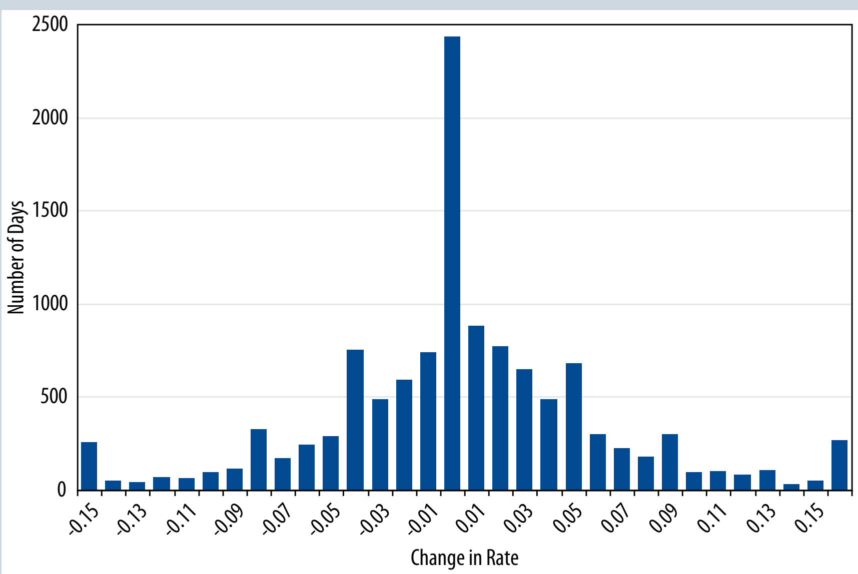
> in this sense, to uncertainty…The sense in which I am using the term is that in which the prospect of a European war is uncertain, or the price of copper and the rate of interest twenty years hence, or the obsolescence of a new invention, or the position of private wealth—owners in the social system in 1970. About these matters there is no scientific basis on which to form any calculable probability whatever. We simply do not know. Nevertheless, the necessity for action and for decision compels us as practical men to do our best to overlook this awkward fact and to behave exactly as we should if we had behind us a good Benthamite[9] calculation of a series of prospective advantages and disadvantages, each multiplied by its appropriate probability, waiting to be summed (Keynes 1937).

We cannot in fact simply treat most real world activities as if they are games like roulette, where we know all the possible outcomes and all their associated probabilities. Investment management is a real-world activity, leading to our second principle:

Investing is not a game.

If we know that investing is not a game, why did we go into some detail above with an analogy of investment management to roulette? One reason is embodied in Keynes' dictum: "…the necessity for action and for decision compels us as practical men to do our best to overlook this awkward fact." In the words of another famous probabilist[10], "Il faut parier, cela n'est pas volontaire" (you have to make a bet; it is not optional). Asset managers make choices about those investments into which their clients' capital flows, and about which investments are avoided. Asset managers have no choice; they must make a bet, since their function is to allocate capital. Making our best effort to understand outcomes and probabilities is a useful tool—not the only tool, but a useful one—in an overall program that leads to constructing the best possible portfolios for clients.

Exhibit 7
Distribution of Changes in UST 10-Year Rates, 1962–2009



Source: Federal Reserve Board

2.2 Why Gaming Does Not Suffice

Let's extend the time period for Exhibits 3 and 4 to encompass the 48 years (11,985 daily change observations) from 1962–2009 (Exhibit 7).

The central part of this pattern looks very much like a normal distribution, with a few bumps caused by the fact that the Federal Reserve rounds to the nearest bp. However, the spikes at either end (-15 bps and +15 bps) are not caused by round-off. They are "fat tails."[11] Unusual things—very big moves down or up in rates—happen more frequently than they would in a normal distribution. This is emphatically not a normal distribution.

We grandiosely pronounced the CLT is always and everywhere true. We pointed out that the CLT would cause a pattern to emerge that would give us computable probabilities for the outcomes, reducing investing from Knightian Uncertainty (very difficult) to Knightian Risk (still hard, but more manageable). While the Exhibit 7 pattern has some regularity to it, the CLT fails to work for us in some of the areas where it counts the most: when there are very large moves. Why?

If we go back and carefully parse the description of the CLT, we can see the problem:

> The CLT says that if we look at a series of independently generated random numbers—perhaps like changes in interest rates day over day—then under certain conditions they will eventually form a pattern like a bell-shaped curve…

Two phrases are crucial here: "independently generated" and "under certain conditions."

In 1961, mathematician Benoit Mandlebrot reviewed patterns in the prices of cotton.[12] He found fat-tailed (the technical term is leptokurtic) behavior like the pattern we noted in Exhibit 7. Mandlebrot was well aware of the power of the CLT, so he reasoned backward: if the CLT did not work, then the "certain conditions" it needs in order to work must have been violated.

The fine print on the CLT's warranty says it only works when the individual observations (in our example, the daily changes in interest rates) have *finite standard deviation*. This has a particular statistical meaning, but intuitively it simply means that the chance of a very large observation is essentially nil. With a normal distribution, the chance of observing a 200% move in interest rates in a single day should for all practical purposes be zero. Mandlebrot hypothesized that this wasn't true. In some sense, in Mandlebrot's world anything can happen.[13]

A 200% move in interest rates is absurd. Or is it? In a world where the rule of law holds and orderly markets are maintained by stable governments, a 200% move in interest rates might be absurd. Economists in stable societies tend to project the stability of their environment into their thinking. But history tells us that most societies—from Pharaonic Egypt to the Holy Roman Empire—eventually disintegrate, and, indeed, often do so suddenly and violently.

Massive interest rate changes are often associated with hyperinflation. The world record appears to be held by Hungary in 1946. At its peak, it took 15 hours for money to lose half its value (Hanke and Kwok 2009). Interest rates in such an environment are difficult to calculate in familiar annualized terms, but a rough estimate would produce an 18-digit number. To the extent that interest rates were a meaningful concept in 1946 Hungary, 200% moves were unlikely only because they were so small.

Mandlebrot's backward logic—if the CLT doesn't apply, then one of its premises must be violated—is inescapable. The violation that Mandlebrot chose (that of the finite standard deviation premise) has good grounding in economic history, based on numerous partial or total breakdowns of societies and their economic systems.

Modern financial theorists generally focus more on another CLT premise that can be violated even in the absence of a total societal breakdown: that of independence. When we noted that the CLT requires "independently generated" numbers, we meant that each time a number is generated, the probabilities of its outcomes are unaffected by previous events.

In roulette, this is obvious: if "even" came up on the previous turn of the wheel, it doesn't affect whether or not "even" will come up on the next turn of the wheel. In financial markets, this is not at all obvious. In fact it is pretty clear that market participants look at past patterns and adjust their behaviors going forward. Roulette balls don't think; financial market participants do.

Thus there is a second reason for the CLT to fail, throwing our careful calculations of probabilities and outcomes (Knightian Risk) into the more treacherous world of Knightian Uncertainty: there is a feedback loop in which market participants observe each other observing each other, and adjust, sometimes with extreme consequences. In some cases, the adjustments are overt, as when central banks intervene to cool down what they see as overheated economies, or heat up cool ones. In other cases, the adjustments might not be obvious until after the fact. For example, market participants scour data for patterns from which they hope to profit, but by piling on (a "crowded trade") they can cause violent reversals.

The CLT is not the only mathematical force causing regular statistical patterns to emerge. Under different circumstances, for example, patterns called *generalized extreme value distributions must emerge*. But all mathematical theorems require certain precise conditions in order to work, and the fact that humans rather than roulette balls are involved will eventually cause any mathematical conditions to fail.

2.3 How to Manage Risk, Take 2

Powerful forces determine the nature of our knowledge deficit about the financial future, including the following:

- The imperative that independent, finite volatility observations converge to a normal distribution;
- The economic history of adjustments, sometimes violent, in societies, and
- The tendency of market participants to adjust to perceived patterns in markets, thereby destroying those patterns.

Do we believe that the financial phenomenon we are assessing—and perhaps considering directing client capital to—is part of a stable, repeatable regime? If so, then perhaps we can take advantage of the power of statistics to assess risk and reward in the strict framework of Knightian Risk.

Or, alternatively, do we believe that the more disruptive forces will hold sway, leading us to a world of Knightian Uncertainty?

There is a clear answer: Yes.

Both of these scenarios—the more orderly world of Knightian Risk and the more chaotic world of Knightian Uncertainty—can occur. An investment risk program aimed at a breakdown of the world as we know it (but used during a period of economic stability) can be disastrous. So can an investment risk program designed for statistically derived outcomes but used during societal breakdown or intense market feedback.

To address this problem, investment risk management proceeds on two tracks. We first use the discipline described above (in "How to Manage Risk, Take 1"), overlooking Keynes's "awkward fact" that the rigorous mathematical strictures of probability theory, the CLT and Knightian Risk are not always applicable. We know that if we are driving a car, it's possible that another car will come along and crash into us, destroying all the engineering that went into designing good steering and a tight suspension. This does not excuse the engineers from making their best efforts to design proper steering and suspension systems.

But the possibility of a crash—of the breakdown of Knightian Risk and the presence Knightian Uncertainty—means that we can't stop at good engineering of steering and suspension alone. We also have to prepare for extreme circumstances.

One approach to managing risk given the extra dimension of Knightian Uncertainty is to adjust the probabilities of extreme events upward. We saw above that the large moves (more than 15 bps either way) in Exhibit 7 occurred more often than a normal distribution would indicate. Exhibit 7 represents 48 years of data from 1962–2009, covering a wide variety of market conditions, so perhaps it is indicative of what will happen in the future. We could simply adjust a normal distribution by thickening the tail probabilities (the probabilities of seeing moves more than 15 basis points either way) until the tail thickness matches that of Exhibit 7. We would simultaneously have to scale down the probabilities of more prosaic interest rate moves (less than 15 bps either way) so that the sum of all probabilities was still 100%.

That's a simple way to reflect the kinds of unusual behavior we've seen in the past. There is in fact a library full of more sophisticated techniques to do this, searchable under "extreme value theory."[14]

Assuming higher probabilities of unusual events is not a bad idea, but it doesn't fully deal with the problem of Knightian Uncertainty. There are infinitely many unusual events. Knowing that some of them are going to happen more often than we might have previously thought doesn't help us narrow things down. War could break out between Monaco and Mongolia over the exclusive right to have a country name containing the word "moo." Haiti could discover that it's sitting on a rich vein of a previously unknown substance that will supply the planet's energy needs for the next 200 centuries. What probabilities do we assign to these events, and how do we think these events will affect financial markets? This is the fuzzy world of Knightian Uncertainty.

To deal with this we must adopt a different approach than the outcomes/probabilities framework arising from probability theory. We must use a combination of qualitative thinking and quantitative testing to generate scenarios and stress tests of extreme behavior. A stress test is done by shocking one or a very small number of financial variables far more than they would usually move—for example, by assuming an overnight move of 1% in interest rates. Such a move is rare but is not beyond the realm of possibility.

Scenario analysis attempts to create a fuller picture of the movements of many financial markets' variables, providing an idea of how they are expected to relate to each other in the hypothesized unusual situation. One way to generate a scenario is to use history. We can look back to an unusual financial situation like the Russian debt crisis/Long Term Capital Management disruption in the fall of 1998. We can retrieve the behavior of interest rates, stock markets, commodity prices, and other variables during this period, and then investigate what would happen to a proposed client portfolio under such conditions. Of course we don't expect an exact replay of the fall of 1998, but we may decide that the ability to withstand such a historical scenario will help our portfolio in different future circumstances. Or we may try to think through a hypothetical future scenario such as global deflation and economic slowdown.

Scenario analysis combines qualitative and quantitative methods. Once we have used intuition to decide which scenario to focus on and how it might unfold, we translate that intuition into numbers measuring the relevant financial variables and apply quantitative analysis to see what would happen to our clients' portfolios.

Thus our layered approach to investment risk management starts with a discipline to estimate the numbers we need to perform a Knightian Risk calculation. Following the Keynes/Pascal argument that we must make a bet, we try to embody our best thinking about volatilities and relationships in our portfolios in a projection of future portfolio volatility. This allows us to make an estimate of the probabilities of various outcomes using the probabilistic disciplines articulated above.

But we can't stop there; remember, ***Investing is not a game***. The arrangements that humans make with each other are not physical laws like $E=mc^2$; human arrangements break down. There can be wholesale disruptions in society—changes in laws, or outright suspension of the rule of law. There can be feedback loops in the market caused by crowded trades and other procyclical behaviors that cause markets to depart from their roles as efficient allocators of capital. We must apply a combination of qualitative and quantitative thinking embodied in scenarios that try to anticipate an uncertain future.

The combination of these two approaches—precise estimates of probabilities and qualitative generation of scenarios—gives investment managers a powerful combination of techniques that are effective in all market conditions. This combination also helps us calibrate our portfolios to client risk preferences; client portfolios designed to be extremely concerned about downside risk will focus more on stress and scenario analyses. For example, for money market funds, the ability to withstand a battery of stress tests is a far more important risk management technique than is estimation of volatilities and correlations. For opportunistic funds, the reverse may be true.

Principle 3: Clarity is Imperative

3.1 Division of Labor

There is a division of labor between investment managers and their clients. The client decides on a mandate for the investment manager, instructing the manager to expose the client's capital to items including the following:

- A capital market, such as Japanese equity market;
- A segment of a capital market, such as European high-yield corporate bonds;
- Specific combinations of markets, such as equity/bonds/cash;
- Customized time varying exposures, such as those indicated by a pension fund's or an individual's liability stream, and
- A strategy, such as capital structure arbitrage.

For example, if a client invests in a global inflation-linked (I/L) bond mutual fund, it probably means that the client has decided to task the fund's manager with the job of exposing that portion of the client's capital to the global I/L market. The manager should not contravene this decision by taking that money and investing it entirely in European high-yield corporates. If global I/L bonds as an asset class do well versus other asset classes, it isn't because the manager was a genius, nor was the manager dumb if this asset class underperforms. The responsibility for the decision to invest in the asset class belongs to the client.

Any type of managed portfolio has a strategic center that represents the exposures the client is instructing the portfolio manager to take on. The strategic center is expressed as a *benchmark*, which may be as simple as a widely used index like Barclays Global Inflation Linked Index, or may be a complex time varying set of exposures. We'll discuss benchmarks in more detail below.

If the investment manager provides no additional services other than following the client's instructions as literally as possible, the manager is said to be *passive*. A passive manager generally tries to replicate the returns on the benchmark. However many managers are *active*, meaning that they apply skill and discretion to add value over the basic service of providing client-directed exposures. Active managers try to outperform the benchmark.

In this division of labor, the performance of the benchmark versus other opportunities is the client's responsibility. The differential (active) exposures taken on to outperform the benchmark are the investment manager's responsibility. These differential exposures might include taking risks on factors such as the shape of the rate curve; on the level of breakeven inflation; on swap spreads; on particular credits or sovereigns; on currencies; on placement in the capital structure; on credit quality; or on any other factor the client allows the manager to use to add value.

Suppose a portfolio is always, through all market conditions, at least two years long duration compared to its benchmark. In this case the manager would be delivering a strategy that is further out the yield curve than the client expected, since the client's strategic expectations are expressed in the benchmark. A permanent active exposure is a misunderstanding about the benchmark, not a part of active management. On the other hand a portfolio that is sometimes two years long duration; sometimes neutral; and sometimes short duration is using this exposure as a technique to deliver added value over the benchmark.

If there is a misunderstanding between the client and the manager, then key decisions will not be properly thought through. Have you ever seen two doubles tennis players miss a ball that was hit between the two of them? Each expects that the other will handle it, so neither does.

An investment manager of, say, a global I/L mutual fund may be under the impression that the mutual fund clients are looking to the Barclays Global Inflation Linked Index as a benchmark. Even if the manager feels that global I/L will do poorly versus European high-yield bonds, the manager will not cash the portfolio entirely out of global I/L bonds and buy only European high-yield bonds. The manager may have great expertise within the global I/L market, but may not have any expertise in moving between markets (or at least may believe that the client wished to retain control over this function and has not hired the manager to exercise it).

Meanwhile, the client may be under the impression that the investment manager is keeping an eye on the relative attractiveness of global I/L bonds, and that the manager will exercise discretion to exit the asset class when appropriate. In that case, the Barclays Global Inflation Linked Index is not an appropriate benchmark. A benchmark that has a greater range of possibilities—perhaps a blend of the permitted asset classes, or one following a mechanical rule for switching between them—could express the understanding between manager and client more precisely.[15] Without such clarity, the decision to switch asset classes (and many other key decisions) may fall between the cracks. ***Clarity is imperative***: all parties stewarding the client's capital must have precise definitions of their responsibilities so they can move quickly and decisively.

3.2 Benchmarks

A widely used list of the characteristics of a good benchmark was put forward by Bailey, Richards and Tierney (Bailey, Richards and Tierney, 2009). This list has been adopted by the CFA Institute in their standard teaching materials:

- **Unambiguous.** There should be a clear rule or set of rules so that anyone knowing the rules can form the benchmark.

– **Measurable.** It should be possible to calculate the benchmark's performance on a reasonably frequent basis.

– **Investable.** The option is available to forego active management and simply hold the benchmark.

– **Appropriate.** The benchmark is consistent with the portfolio manager's investment style or biases. For example, a US small-cap equity portfolio should not be benchmarked to Asian distressed debt.

– **Specified in advance.** The benchmark is fully specified prior to the start of an evaluation period.

– **Reflective of current investment opinion.** The manager has current investment knowledge (be it positive, negative, or neutral) of all of the securities and themes in the benchmark.

– **Owned.** Both the investment manager and the client accept and acknowledge the benchmark as the appropriate accountability standard.

In some cases, market participants confuse performance targets with benchmarks. A client may tell an investment manager to aim for a yield that is at least 2 percentage points above the UST 10-year rate. This violates the "Investable" criterion above—there is no passive investment that returns exactly 2% above the UST 10-year rate in every period.[16] Since risk has to be taken in order to generate the extra 2%, the fate of the client's funds is unclear.

Peer groups are sometimes suggested as benchmarks. For example, the average performance of all the mutual funds competing in a particular investment style might be used to judge performance. Peer groups violate the "Specified in advance" criterion: there is no way to know what investments competitors are making until well after they have been made. An investment manager cannot wait until this information becomes available before making a decision about which risks to take to generate active returns. One method of addressing this problem is to construct a dynamic combination of securities and indices that is specified in advance and that is intended to mimic the expected behavior of the peers (Ben Dor 2008).

The most common kind of benchmark that complies with the criteria above is an index specified by a well-known index provider, such as the Barclays Global Aggregate.[17] Sometimes simple combinations of indexes are taken (50% Global Agg, 50% Corporate). Unfortunately there are many problems with indices. For example, in some fixed income indices, the largest debtors are the largest components of the index, which seems to reward fiscal profligacy.

There are methods to address benchmark problems: for example, issuer percentages can be capped. More complex formulations can be used, such as mechanically screening a universe for securities with certain properties. Dynamic benchmarks can also be created—for example, a benchmark consisting of the S&P 500 and the Barclays Aggregate in proportions determined by the average dividend yield of the S&P 500 compared to the average yield on the Barclays Aggregate.

No benchmark is ever perfect, but their imperfections pale beside the necessity for client and investment manager to specify a carefully chosen benchmark that will embody the division of labor between client and investment manager. Otherwise there is a lack of clarity that can subject the client's funds to unexpected hazards.

We can write:

$$\text{Portfolio} = \text{Benchmark} + \text{Skill} \tag{1}$$

The Benchmark portion is free or low-cost as it is formed based on public information. All private information—the investment manager's skill—is in the residual portion of the portfolio after the benchmark is subtracted. In the financial industry, the kinds of factors that move the Benchmark are referred to as "betas" and the factors that move the Skill portion are referred to as "alphas," although this division can be overly simplistic. For example a time varying beta can be an alpha.

Expression 1 is simple but powerful. For one thing, along with our understanding of the division of labor and the benchmark characteristics enumerated above, Expression 1 tells us that permanent exposures to market factors cannot reside in the Skill portion. Suppose for example that the benchmark is the Barclays US Treasury Index, but the portfolio is always the Barclays US Credit Index. The Skill portion would have a permanent exposure to credit, which violates the Appropriate criterion for benchmarks.

If there are no permanent systematic factors in the Skill portion, then we certainly can't have any of the Benchmark's permanent systematic factors showing up in Skill. This tells us that Skill has to be uncorrelated with the Benchmark over full market cycles. For more technical readers, we can put this observation in an equation as follows:

$$\text{Covariance (Skill, Benchmark)} = 0 \tag{2}$$

Together with (1) this means that

$$\text{Covariance (Portfolio, Benchmark)} = \text{Variance (Benchmark)} \tag{3}$$

Dividing both sides by the variance of the benchmark tells us that:

$$\text{Beta (Portfolio, Benchmark)} = \frac{\text{Covariance (Portfolio, Benchmark)}}{\text{Variance (Benchmark)}} = 1 \tag{4}$$

This says that the beta defined in Expression 4—a statistical term not to be confused with the betas and alphas cited above—of the portfolio to the benchmark must be one. This calculation is intended to hold over full market cycles, so there may be temporary tactical deviations away from it. But over the long term, if the beta does not equal "one" then there is a permanent strategic tilt in the portfolio away from the benchmark, so the benchmark has not appropriately captured the systematic behavior of the portfolio. If the portfolio levers the original investment 2 to 1, then the benchmark needs to have 2 to 1 leverage as well. Otherwise there will be predictable systematic relative behavior: the portfolio will have a strong tendency to outperform in up markets and underperform in down markets.

We have expressed qualitative principles as part of our general ***Clarity is imperative*** directive: a clear division of labor; the use of benchmarks; and the CFA Institute criteria for benchmarks. These qualitative principles give rise to specific quantitative guidance such as Expression 4. Skill, the residual portfolio after subtracting out the Benchmark, must be unrelated to the Benchmark over the full cycle. As a result, the systematic risk of the portfolio relative to its benchmark (the portfolio/benchmark beta) must equal 1 over the full cycle. The kinds of risks the manager takes to deliver Skill must be different than the kinds of risks that reside in the benchmark.[18]

3.3 Clarity, Risk and Skill

A client hires an active investment manager to make certain decisions affecting a portion of the client's capital. With a properly specified benchmark, the two parties can understand which decisions the investment manager is allowed to make, and those for which the client is responsible. This avoids the missed-tennis-ball problem where neither party makes a crucial decision. This level of clarity is especially important in extreme market environments, where the consequences of a missed decision can be disastrous.

In addition to helping clarify the client's expectations, this division of labor helps clarify the types and amounts of risks the client wants the investment manager to take. As we've noted above, there are many ways to characterize risk. One common way to estimate risk is *tracking error* to a benchmark. Tracking error is the estimated volatility of the difference between portfolio returns and benchmark returns. It's a number that describes how much the portfolio is expected to differ from its benchmark—that is, how much active risk is being taken.

In order to generate active performance over a benchmark, an investment manager must subject the client's portfolio to risk and uncertainty. This generates volatility (tracking error) in active returns. For example, it would not be unusual that a portfolio aiming for 100 bps (1%) of active annual performance would have a year where it underperformed by 100 bps. Over time, a skilled manager can generate the targeted outperformance, but not on a straight upward line and only by taking on the appropriate level of risk.

In many mutual funds, the typical client experience is worse than the officially computed rate of return on the fund. This is because the rate of return on the fund is computed as if money was invested and left in the fund for the entire evaluation period. Clients in many mutual funds withdraw their money when recent performance is relatively poor, thereby locking in the losses they have experienced.

A client who is clear on what types and levels of risk are being taken by the investment manager is in a better position to judge the manger's skill, avoiding unnecessary movements of capital and revealing necessary ones. ***Clarity is imperative***.

Conclusions

In this paper we have articulated three principles that guide investment risk managers.

The first principle, ***Prediction is very difficult***, leads us to consider disciplined ways to categorize possible future outcomes and their probabilities. We know that perfect prediction of the future is impossible, so we must follow this discipline to avoid undesirable outcomes like the lottery ticket payoff pattern of Exhibit 1. With the proper use of risk management techniques, we can harness manager skill in a way that provides desirable outcomes for investment management clients.

The second principle, ***Investing is not a game***, revealed a new level of complexity in assessing the future of investments. While the discipline developed as a result of the first principle is a powerful and useful approach, there are times when its efficacy breaks down. The rules governing financial markets can be strained, changed, or abandoned altogether. The behaviors of financial market participants can cause outcomes not seen in simple games. To deal with these uncertainties we need to expect more unusual behavior than normal, and we need to apply qualitative thinking to developing scenario analysis that anticipates uncertain futures.

The third principle, ***Clarity is imperative***, arises from thinking through the division of labor between an investment manager and the manager's client. An investment manager using a properly specified benchmark has a precise understanding of what types and amounts of risks are allowed in pursuit of active returns. The client also has a better understanding of what to expect from the manager and when action is or is not necessary.

Together these three principles guide us in the design of investment risk management techniques that work in all environments.

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Footnotes

[1] Variously attributed to Yogi Berra, Niels Bohr, and Mark Twain.

[2] For probability theory purists, "casino bankruptcy" is not an event in the one-turn-roulette-wheel probability space we have previously sketched. We would widen out our set of outcomes to include multiple turns of the roulette wheel and betting amounts.

[3] This isn't quite true. An attempt to predict the destination of the roulette ball using its speed, friction, etc. with the assistance of wearable computers was chronicled in Thomas Bass, *The Eudaemonic Pie,* 1985 (Houghton Mifflin). Sadly, casinos tend to frown upon this sort of thing, so it's generally either not possible or at least highly impractical to predict where the roulette ball will land in a real casino.

[4] 14% over three months is obtained by raising the single-period success probability to the third power. The single-period success probability is 55% times (1-.0526), the latter factor representing transaction costs. By importing the roulette analogy to investment management, we have assumed what in most cases would be an unrealistically high friction penalty, but we seek here merely to illustrate some points, and not to produce a realistic simulation.

[5] An early form of the Central Limit Theorem is credited to French mathematician Abraham de Moivre in 1733. A more precise and powerful version widely used today is due to Finnish Mathematician Jarl Lindeberg in 1922.

[6] The very large bar in the middle is partly due to round-off—the Federal Reserve publishes rates to two decimal places, so if there is a daily change less than half a basis point, it is published as zero.

[7] The observation that certain financial outcomes might be characterized by a normal distribution is due to Louis Bachelier, *Théorie de la speculation*, (PhD Thesis, Universite de Paris, 1900).

[8] *http://wordnetweb.princeton.edu/perl/webwn?s=risk*

[9] A reference to English philosopher Jeremy Bentham, who in 1789 proposed a "felicific calculus" to determine the amount of pleasure or pain an action might cause by carefully listing its components.

[10] Blaise Pascal, "Pensees sur le pari, le jeu et le divertissement," #233, circa 1662. This is known as "Pascal's Wager," and is part of a religious argument that has been debated for centuries.

[11] For the statistical reader, the excess kurtosis of this distribution of daily changes is 9.6. The skewness is a mild -.28, for a Jarque-Bera statistic of 46,074. The p-value (probability) that this is a normal distribution is zero.

[12] This work was later summarized in *The Misbehavior of Markets* (Mandlebrot and Hudson, Basic Books, 2004).

[13] This is an oversimplification. A normal distribution assigns a nonzero probability to extreme events, as does Mandlebrot's model (which is technically called a Levy alpha-stable distribution). So it is not completely impossible for extreme events to happen in either model. However the probabilities in the normal distribution drop so dramatically that at some point they indicate that extreme events will occur less than once in the age of the universe, which makes them for all practical purposes impossible. Mandlebrot's model indicates that extreme events are less likely than routine events, but not so much less likely that they can't plausibly occur in (say) a human lifetime.

[14] See for example Paul Embrechts, ed., *Extremes and Integrated Risk Management*. Risk Waters Group, 2000.

[15] It is not uncommon to see clients who expect investment managers to deliver both good relative performance (beating a benchmark) and good absolute performance (beating cash). This gives the client a *benchmark switch option*, where the client holds the manager responsible for beating whichever is doing better (benchmark or cash). While it's not impossible to aim at such a dual goal, the dual benchmark must reflect the Black-Scholes cost of the benchmark switch option to realistically reflect the manager's task.

[16] If there were, there would be a risk-free arbitrage: investors would buy such an investment and short US Treasury 10-year futures, generating free money.

[17] Generally indexes assume no frictions – such as no costs of instantly reinvesting dividends or coupons—and no transaction costs. Thus there is often a bias in favor of indexes when they are used to measure portfolio performance. If the index is well constructed, this bias is small, but certain indexes—especially fixed income indexes—are not always as investable as the criterion requires. Managers and clients should be careful to create benchmarks whose returns can be realized in practice.

[18] This doesn't mean that an investment manager can't touch anything present in the benchmark to deliver skill. For example, if the benchmark has exposures to interest rates in it, an investment manager can certainly use interest rate strategies—long duration, short duration, curve steepeners or flatteners, for example—to generate active returns. But as we previously noted, if the manager's interest rate tilt is always predictably different than the benchmark's tilt then the benchmark is misspecified.