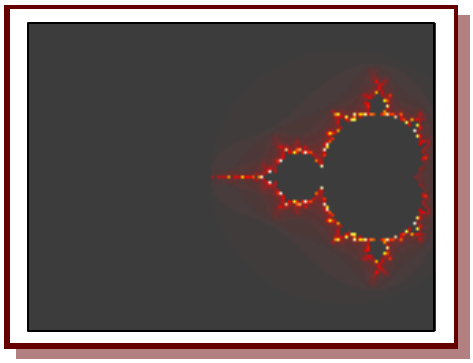
Angeles
INVESTMENT ADVISORS

SECOND QUARTER 2004

JULY 2004

Fractals

Euclid (pictured right) was undoubtedly the greatest mathematician in history. His mathematical formulae and proofs define all the familiar shapes in one-, two- and three-dimensions: point, line and plane. *Elements*, written 2,300 years ago, remains the basis of the standard geometry text, taught to every high school student around the world. Euclid stands alone in his influence across every material endeavor of man, from the construction of our homes to the trajectory of satellites.



There is but one small problem with Euclidean geometry: it explains nothing in the natural world. Points, lines and planes do not actually exist. Coastlines are not lines, mountains are not conical, lakes are not circular or cylindrical, so it is impossible to measure anything exactly.

Econometrics is the application of mathematical techniques to the study of economic data. Two (somewhat) familiar econometric applications are Gaussian distribution and Brownian motion (borrowed from molecular biology). The Gaussian, or *normal*, distribution is more popularly known as *the bell curve*, which illustrates the probabilities of potential outcomes. For example, market returns are likely to fall within a (relatively) narrow range, and extreme results (good or bad) are far less likely to occur. Brownian motion is more popularly called *random walk*, the notion that data patterns (stock prices, e.g.) follow a random sequence, hence are unpredictable.

All this would be academic, and unworthy of your attention, but for one fact: all of modern investing is based on these two assumptions: that market prices are normally distributed and fluctuate randomly. At one level, these appear to be reasonable assumptions, but upon closer examination, neither is true. Extreme events occur too frequently than predicted (resulting in "fatter tails" in a bell curve) and many data are distributed asymmetrically (making the curve lopsided).

Standard mathematics can discern no pattern in market prices; they do appear to move randomly. That is, until we were shown otherwise by the greatest mathematician of our time, whose work would come to supplant Euclidean geometry. He gave us a simple formula and a view into a world we could not imagine existed. That's fortunate for investors, for as we struggle to balance return objectives with acceptable levels of risk, we'll need new insights, both in how we define our goals, as well as how we can realize them.

INSIDE GRAPHS:

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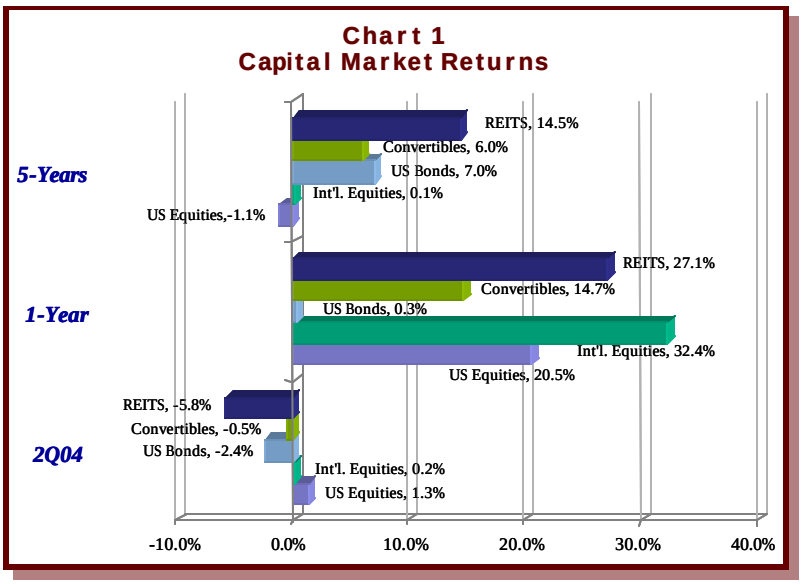
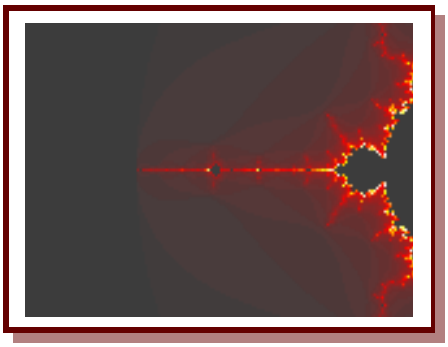


Returns for most major asset classes were uninspiring last quarter, but this masked some unusual events. April, in general, was a dismal month, with markets recovering in May and June. April was especially hard on the two heretofore stellar performers: emerging markets and real estate. Emerging markets lost nearly 10% in the quarter, although can still boast of a 33% return over the past year. REITS saw their worst month since the October 1987 crash, falling 20% in the first few weeks of April, but then trimming that to a 5.8% loss for the quarter. While not as dramatic, bonds too had an abysmal time, off 2.4%, the worst quarter in 14 years.

Economic data were strong throughout the quarter. Nearly a million net new jobs were added in the past three months, and industrial production saw its biggest monthly gain in nearly six years. Worrisome, though, was the sharp rise in inflation. CPI has grown 3.3% the past twelve months, more than twice the pace of a year ago, and at the end of June the Federal Reserve shifted to a tighter monetary policy for the first time in four years. Inflation is spooking the markets, unsure whether the Fed has a handle on it, or if we will see the 1970s-redux (W.I.N. buttons, gas lines, disco—generally a nadir across American society).



Monetary policy is tightening, but there is an unusual level of disagreement about how fast and how far it goes. Some see the recent rise in inflation as temporary and well-contained. They argue that much of the current spike is related to one-time factors that will either slow or reverse in time, such as the jump in energy and commodity prices. With weak job and income growth and excess capacity remaining, inflation will not likely rise much from here. The US economy is now more a service economy, less sensitive than in the past to rising commodity prices, since manufacturing is now just 12.7% of GDP compared with 23.1% in 1970.

Extreme levels of either high inflation or deflation are relatively rare as inflation has historically centered around 2-3% (see Chart 2 with 300-year data). Furthermore, spikes in inflation have almost always been coincident with wars (see Chart 3—Page 3).

While it is true that inflation "tends" to be moderate, it can be argued that we are at war, and

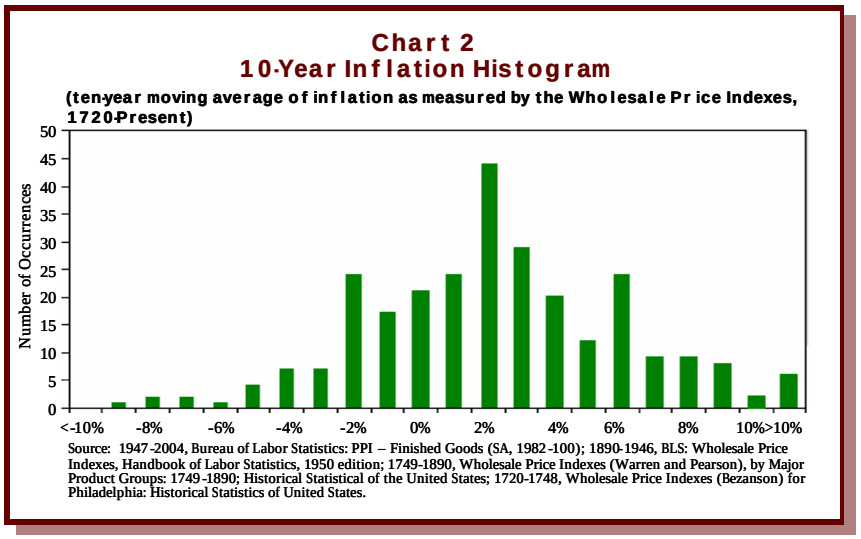
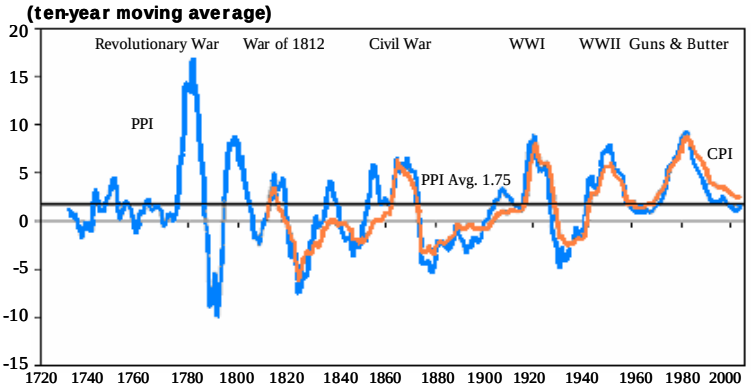


Chart courtesy Citigroup

like a generation ago, have chosen to finance it not with taxes or spending cuts but with debt. We remember, too, that inflation is not higher oil prices; inflation is a monetary phenomenon (as Milton Friedman famously noted). A year ago, all of Asia was suffering from deflation, and the rest of the world was at risk, so the Fed threw everything but the kitchen sink into that fight (and for good measure had its staff write a paper about how to throw the kitchen sink in too if necessary), bringing and holding real interest rates below zero. Well, it worked. Inflation is rising in Asia and in the US, world economic growth is accelerating, and we can now safely let the Fed bring rates back to neutral.

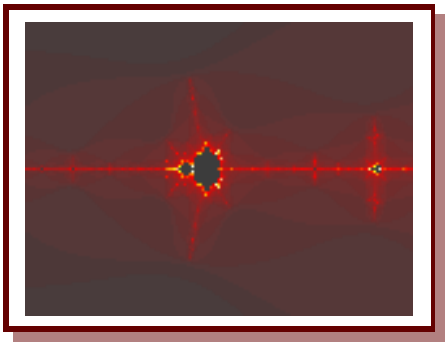
Chart 3
Inflation History



Source: PPI: Same as Figure 1 CPI: BLS

Graph Courtesy Citigroup

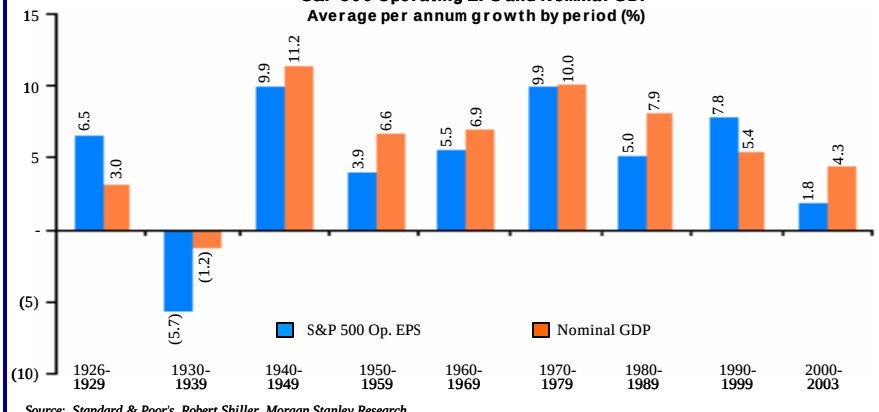
But a "neutral" monetary policy is best thought of as an area, not a point, and there is good reason to believe that the Fed may be slow to raise rates lest the economic recovery be jeopardized. We face three stiff economic headwinds. The savings rate is low (record low) and will have to rise. Debt levels, especially among households and the federal government, are high (record high), and the servicing burden will increase. Thirdly, the US current account deficit is large (record large) and, barring a significant decline in the value of the dollar, exports will not accelerate to boost the economy. These three factors suggest that the growth of the US economy will be moderate in the coming years. Consequently, the Fed may move cautiously to raise interest rates.



That caution risks allowing inflation to continue to rise, and this should worry investors. Inflation not only erodes the purchasing value of money, it results in lower returns on investment. From 1950 through June 2004, long-term government bonds returned 5.9% annually and the S&P 500 Index returned 12% annually. But during periods of rising inflation, the return on bonds was cut to just 1.7% and the return on stocks to just 5% (with a price return of just 1.2%). These data are in nominal terms; in real terms, results would be negative for both stocks and (especially) bonds.

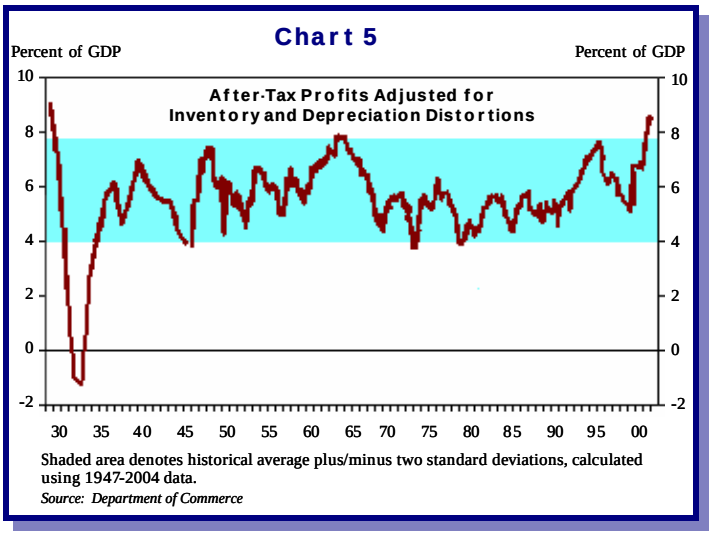
Reflected in these data is a compression of P/E multiples. As inflation and interest rates rise, equity multiples contract (and vice versa). In the 1990s, declining rates accounted for about 40% of the total return in equities (the 18.2% annualized return in the decade came from earnings growth of 7.8%,

Chart 4
S&P 500 Operating EPS and Nominal GDP
Average per annum growth by period (%)



Source: Standard & Poor's, Robert Shiller, Morgan Stanley Research

Graphs Courtesy Morgan Stanley

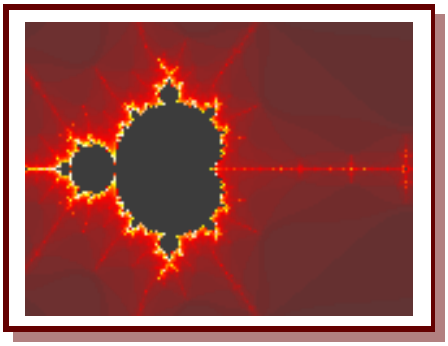


Graphs Courtesy Goldman Sachs

dividends of 2.6%, and multiple expansion of 6.9%).

Multiples are not likely to expand from here, with interest rates and inflation rising. Earnings generally track (or slightly trail) nominal GDP growth (see Chart 4, Page 3, the 1990s being the exception), and with profits as strong as they are likely to be (see Chart 5, Page 4), equity returns can be expected to be modest.

A change in monetary policy (however measured) carries risks, as Chart 6 illustrates. Financial crises tend to be coincident with tighter money.



If rising inflation is an immediate concern, a related issue is the path of productivity growth. Productivity is perhaps the single most important economic variable, affecting both inflation and economic output. Over time, productivity is the principal determinant of our standard of living. Roger Ferguson, vice chairman of the Federal Reserve, noted that knowing where productivity growth is heading is equivalent to knowing our economic destiny.

This is especially critical now because we are at an inflection point where the productivity growth trend will turn lower. But how much lower, and at what new equilibrium rate it settles, are the salient questions.

That there is a cyclical and a structural component of the growth trend can be seen in Chart 7 (Page 5). Cyclically, productivity generally falls during recessions and rises with the economic recovery.

Productivity has trended significantly higher since the mid-1990s, and this structural rise is a rare occurrence; only three times in the past 150 years have we seen periods where productivity growth has stepped up above the long term (1873-2004) trend of 2%. The latter part of the 19th century, the decade between World War One and the Depression, and post-World War Two till 1973 all saw productivity spurts. Each episode was characterized by the introduction of new technologies, but perhaps more importantly, by changes in business organization, investment and financing that enabled these new technologies to be applied in efficient ways (see Productivity Table, Page 5).

The 3% productivity growth over the past decade was twice the rate that occurred from 1973-1995, and 50% higher than the (very) long-term rate of 2%. Since the 2001 recession, productivity growth has averaged 5% per year, and was 5 ½ % last year. These are impressive numbers. With a 2% growth rate, productivity would double our standard of living in 37 years. Over the same period, at a 3% growth rate, our standard of living trebles, and at 5% growth, it rises six-fold. These small annualized differences lead to dramatically different outcomes over generations.

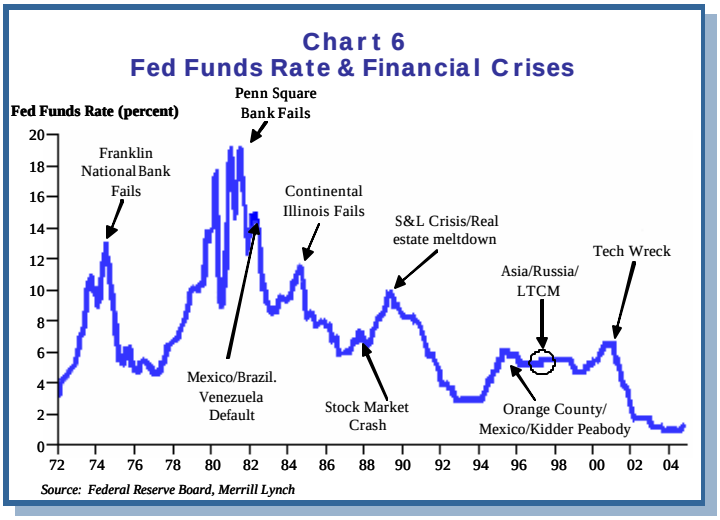
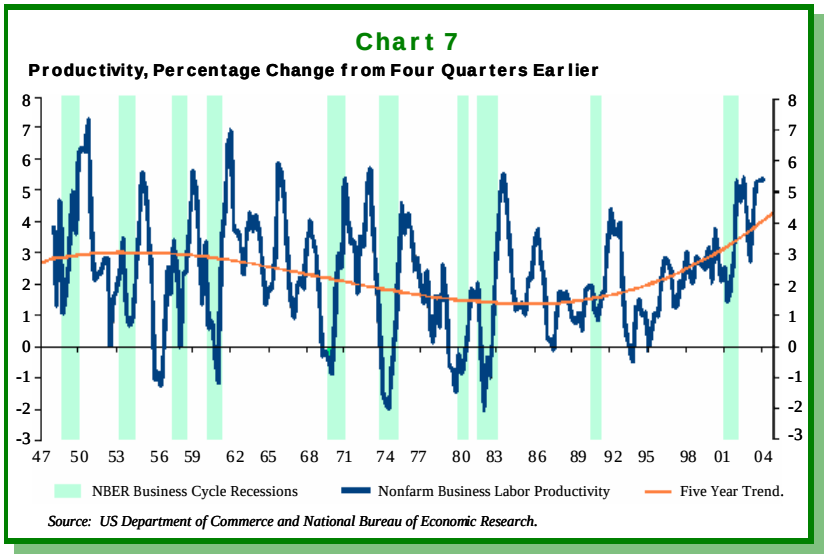


Chart courtesy Merrill Lynch

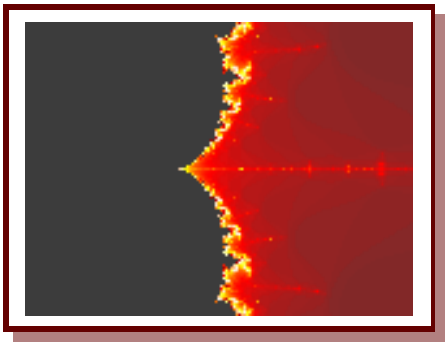


Graph Courtesy of J.P. Morgan

Can productivity growth remain above the long-term trend of 2%, or will it fall to or below that equilibrium? The optimistic view has been well-stated by Brad DeLong of UC-Berkeley, who notes that the continuing and rapid decline in technology prices indicates not just a fast pace of technological progress but also a greater efficiency in integrating technology into business processes. We continue to find better ways to utilize the recent introduction of fiber optics and wireless communications, and the work being done in biotechnology and nanotechnology promise significant breakthroughs affecting all aspects of our lives. Past deregulation should aid organizational flexibility, and financial innovations will continue to help allocate capital efficiently.

But productivity growth will slow as the cyclical components of the trend reverse. Profits are at record highs (Chart 5, Page 4) and will decline, energy prices are high, fiscal deficits are wide, and all these should bring the growth rate of productivity lower. Higher inflation usually accompanies lower productivity, a reason for investors to be concerned.

All these factors are well known and widely accepted. The real debate centers on the structural aspect of the productivity trend, and whether we can continue to sustain above-trend growth. There are several factors that will be critical to watch, because their positive contributions to productivity may be in jeopardy in the future. Trade liberalization engenders specialization and economies of scale, and thus higher productivity, but the backlash to globalization threatens further liberalization, and rising protectionism could roll back previous gains.



Imposition of new security measures could limit the flow of capital, goods and labor. These bear watching as the impact on productivity, and thus on inflation and economic growth, could be significant.

We look for signals and patterns to help guide us, but these are hard to spot, especially with our blunt tools. We do our best to model (predict) outcomes, or the probabilities of outcomes, but our standard errors could be as large as our assumptions (a fancy way of saying these "sophisticated" models are little better than poorly educated guesses). We have devoted a great amount of research effort to "alternative" investments, and even some of our money, but we know these investments do not conform to standard modeling, making any conclusions about outcomes and risk tentative, at best.

Productivity Table

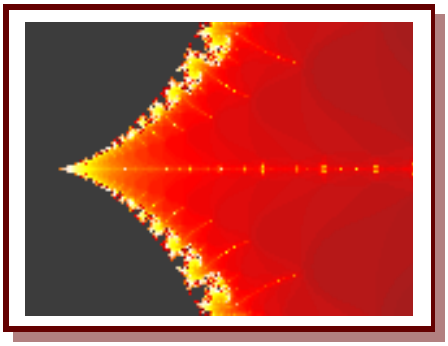
Period	Avg. Annual Productivity Growth	New Technologies	Organizational Developments
1873-1890	2.6%	Telegraph, railroad, steam engine	Economies of scale led to larger firms
1917-1927	3.8%	Telephone, electric motor, internal combustion engine	Vertical integration
1948-1973	2.9%	Transistor, petrochemicals, jet engine	Multinational and multiproduct companies
1995-2004	3.0%	Internet, wireless telecommunications	Outsourcing, inventory control

We really do need a different way of approaching, quantitatively, our analysis of asset classes. Fortunately, there are some very smart people (not me!) engaged in exactly this.

IBM was in 1958 (and to some extent is today) an unusual company. Its research center in Yorktown Heights, NY housed an extraordinary mix of scientists across myriad disciplines. The newest member of this cast in 1958 was perhaps its oddest, because he had no specific discipline. Born in 1924, his family sensed that being Jewish in Warsaw was not going to turn out well. An uncle, a noted mathematician, lived near Paris, so they sent the boy to him, where he survived the war years, although without any schooling. It was clear that the boy was a genius, although he never did learn the alphabet, and to this day cannot find a listing in the phone book. Nonetheless, IBM hired him, and gave him the task of trying to figure out why random errors were occurring in data transmission lines.

While he was working on that problem in 1960, a friend, Hendrik Houthakker, a distinguished professor of economics at Harvard, invited him to sit in on his lecture on income distributions in a population. Upon entering the classroom, he noticed hundreds of numbers on the blackboard, and became visibly shaken. The data turned out to be 50 years of cotton prices that Professor Houthakker was using as an example of randomness in statistics, but in that series was the answer to his data transmission problem. For in the randomness of those prices were consistencies, a strange sort of symmetry with respect to scale, an infinitely complex pattern that could be expressed with a simple, and thus the greatest geometric formula since Pythagoras:

$$Z = Z^2 + C$$



Benoit Mandelbrot never did learn the alphabet or algebra. He passed his university entrance exam and wrote his doctoral dissertation in France by converting algebraic equations to geometric pictures in his mind, and managed to hide this fact from his professors. Yet this "disability" allowed him to challenge a fundamental supposition of geometry, and thereby create an entirely new science. Like Albert Einstein, who asked, what if space can be curved, or that there could exist more than the three dimensions we see, Mandelbrot asked, what if shapes are defined not by solving an equation once, but by iterating (repeating) it in a feedback loop, as in the formula above? Mandelbrot saw (literally, one thinks) a symmetry of scale in those cotton prices on that blackboard, a time series that did not fit Gaussian distribution because there were frequent departures from "normal." Instead, he realized that departures from normality could be explained by using distribution functions with infinite variance.

The 23% drop in the stock market on 19 October 1987 was termed a 20-standard deviation event by econometricians using standard statistical tools. A 20-standard deviation event is, essentially, a statistical impossibility. But I was there; it really did happen. In Mandelbrot's world, this event was not only not impossible, it was expected.

Cotton prices, stock prices and many natural phenomena seem to conform to Mandelbrot's formula*. The bronchi of the lung are self-similar over 15 successive bifurcations. The receptive fields of the visual cortex in the brain seem to follow a hexagonal pattern of self-similarity. Fractal patterns explain the structure of snowflakes, the shape of tree bark, the path of the biliary duct in the liver and the fibers in the heart that carry electrical signals to muscles. The DNA molecule, the very essence of life itself, contains fractal structures

The formula can also be used to create "fractal art". The photo on Page 1 was created by plotting the pattern of thousands of iterations using Mandelbrot's formula. Color was then added to points that "escaped" the set based on the number of iterations it took the escape. Each subsequent image is a detail of the center of the preceding image.

that exist between randomness and predictability, and may account for how it is that DNA encodes the maximum amount of information while still being resilient to damage. *Fractal geometry explains nature*.

Henry Adams, the great historian, noted, "chaos often breeds life, while order breeds habit." We won't pretend that all (or any) of Mandelbrot's work is intuitive. There are many, far smarter people than us working on better applications of fractal geometry to economic data and market prices. We continue to look for patterns, not necessarily for clues to the future, as much as for what we can reasonably expect are the risks, and range of risks, we might face. Inflation and productivity are two of the important macroeconomic variables that will impact investors, but how we think about asset classes--why we own them, their role in our portfolios—will need to adjust too. But we're mindful of our limitations. As Winston Churchill observed, "It is a mistake to look too far ahead. Only one link in the chain of destiny can be handled at a time."

Benoit Mandelbrot is currently Sterling Professor of Mathematical Sciences at Yale University and Fellow Emeritus at the TJ Watson Research Center of IBM.

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