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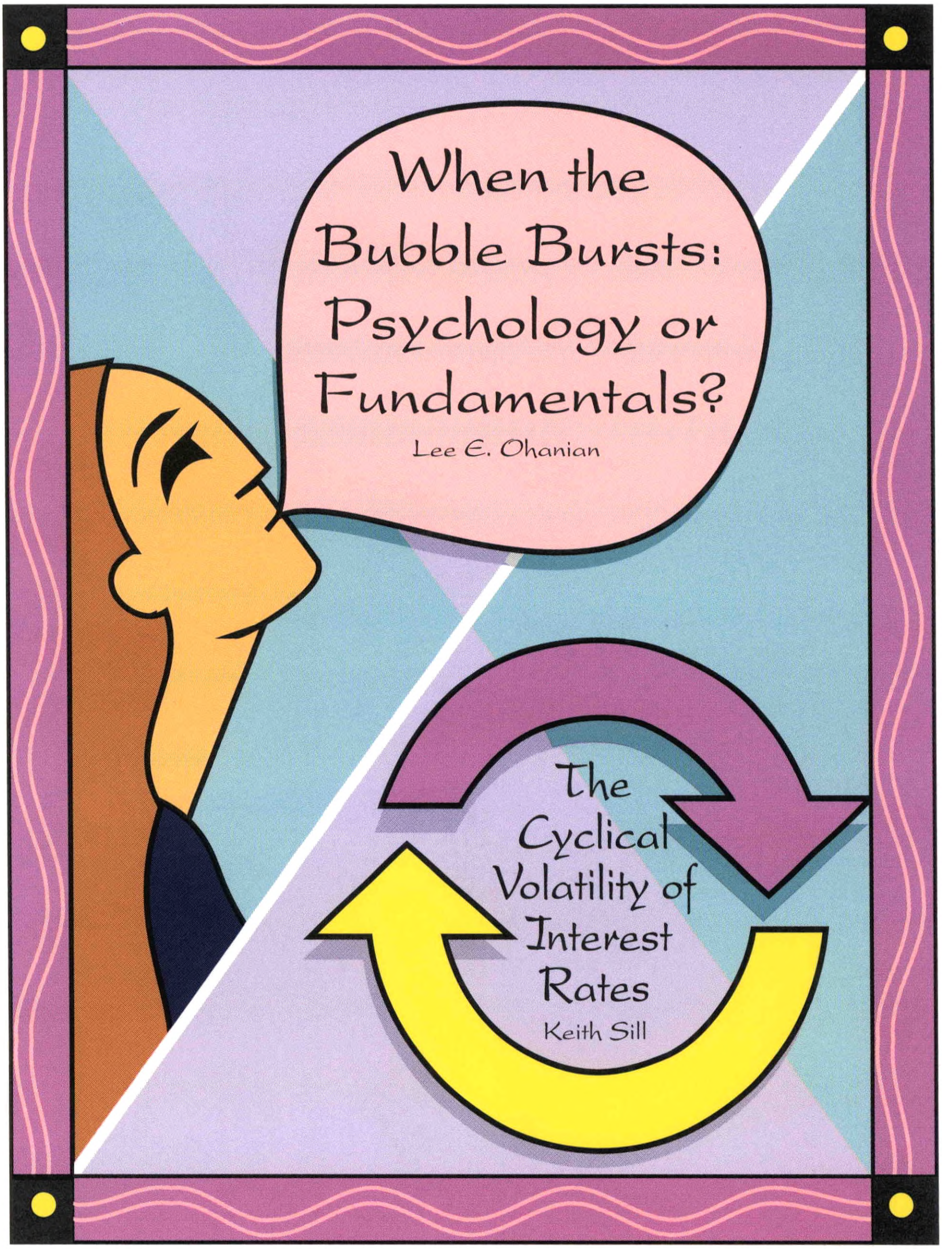

Business Review

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When the Bubble Bursts: Psychology or Fundamentals?

*Lee E. Ohanian**

Prices for stocks, bonds, foreign exchange, and other assets frequently exhibit large fluctuations on a daily and long-term basis. Perhaps the best known example of asset-price volatility was the 500-point decline in the Dow Jones Industrial Average on October 19, 1987. The 23 percent drop coincided with similar declines in the Tokyo, London, and Hong Kong stock exchanges and was nearly twice the magnitude of the October 1929 crash that ushered in the Great Depression.

October 19, 1987, was not the only turbulent day on the New York Stock Exchange in recent history. Since 1987, there have been 16 trading sessions in which the Dow moved at least 90 points. Extreme price volatility is not confined to the stock market, nor is it strictly a short-term feature of the market. High variability has characterized foreign exchange rates since currencies were allowed to float in the early 1970s. The U.S. dollar, which rose 20 percent between February 1984 and February 1985, fell

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25 percent over the following year. Price volatility has also characterized the markets for corporate and U.S. government debt in recent years. Once the haven of conservative investors, the bond market now frequently displays fluctuations equal to those in the stock and foreign exchange markets. For example, the price of the 30-year U.S. Treasury bond rose more than 40 percent between October 1985 and July 1986 and fell nearly 20 percent during the first half of 1987.

These price fluctuations have important economic implications. Recent empirical studies suggest that asset prices have predictive power for the business cycle. In particular, low bond prices (high interest rates) tend to precede recessions, and high bond prices (low interest rates) tend to precede expansions.

There are also potentially important economic costs associated with asset-price volatility. In particular, substantial price volatility will tend to increase the volatility of returns on assets. Since investors typically dislike risk, high volatility will tend to increase the average rate of return on capital demanded by investors; that may lead to lower investment, a smaller capital stock, and a lower standard of living.

This article presents an analysis of the volatility of security prices. The objective is to discuss issues associated with whether movements in asset prices reflect changes in the fundamental value of the asset or whether these extreme price changes might be associated with changes in market psychology that may not be related to business conditions.

MARKET FUNDAMENTALS

There is an old debate associated with whether asset prices correspond closely to their fundamental values or whether market psychology and extraneous factors can cause prices to deviate substantially from an asset's fundamental value. This debate has focused on the interpretation of changes in security prices and their volatility. Many academic economists have argued that security prices efficiently reflect current and past information and that market prices are a good approximation of a security's *fundamental* value. Fundamental values are often referred to as *market fundamentals.*

The fundamental value of an asset is defined as the present value of the expected payoff from that asset. For example, consider a hypothetical asset that yields $1 per year for five years. The fundamental value of this asset would be the sum of the five yearly payoffs, discounted by the relevant interest rate. (Discounting a future cash flow by an interest rate is required because a $1 payoff in the future is not equivalent to a $1 payoff today.) One can use the same logic to determine the fundamental value of a stock. Since the payoff from a stock is the dividend, one measure of the fundamental value of a stock is the sum of all (expected) discounted future dividend payments.

Market fundamentals, combined with the efficient markets theory, provide a simple tool for interpreting fluctuations in security prices. According to the efficient markets theory, security prices fluctuate only as investors respond to new information concerning changes in market fundamentals (the discounted sum of future cash flows).[1] For example, suppose a pharmaceutical manufacturer announces that it has developed and tested a new product that successfully combats cancer. The efficient markets theory predicts that the price of the company's stock would jump immediately as investors re-evaluate the security in light of the new information. The extent of the price increase reflects how the new information alters market fundamentals. An increase of 15 percent in the stock price indicates that the dis-

[1]For a readable discussion of security prices and the efficient markets theory, see Burton Malkiel's book.

counted sum of expected future dividends is 15 percent higher, according to the theory.

A popular version of the efficient markets theory states that security prices will follow a "martingale."[2] The basic idea behind the martingale model for security prices is that the difference between a stock's price today and a stock's discounted price tomorrow is completely unpredictable.[3] Thus, the main implication of this model is that the best forecast for tomorrow's stock price will simply be today's price. Moreover, the efficient markets theory implies that whatever change occurs in the stock price tomorrow will be completely accounted for by new information on market fundamentals.

This theory makes a number of predictions for the behavior of asset prices. One important implication of the martingale model is that trading strategies designed to "beat the market" cannot be systematically successful. This follows from the fact that for the martingale model, the probability that the price of a stock will rise in value tomorrow is the same as the probability that the price will fall. Moreover, this theory predicts that stocks cannot be identified as under- or overvalued, nor are there particularly good or bad times to purchase stocks. Another strong implication of this theory is that the dominant investment strategy is a very simple one: buy and hold a diversified portfolio of assets.

This theory has been widely applied to understanding movements in asset prices. Its popularity likely reflects the fact that it provides a simple way of using basic economic theory to evaluate security prices. Also, an important implication of the theory—that changes in asset prices are unpredictable—seems to be fairly well supported by a large body of data. However, some of the strong assumptions embodied in the theory, such as the risk neutrality of investors, and the fact that some other features of the data are difficult to reconcile with the theory have led to criticisms of this model.

Some critics of the efficient markets theory point out that the volatility of security prices seems much too high to be justified by changes in market fundamentals. Market traders and many financial analysts claim that new information about market fundamentals provides only a partial explanation of observed price fluctuations. While they acknowledge that long-term movements in securities prices correspond to changes in fundamentals, they argue that short-term fluctuations are caused by shifts in market psychology or perhaps even by events that have no direct bearing on business prospects or economic conditions.

BUBBLES

A bubble is defined as any deviation of an asset's price from its fundamental value. We can think of an asset's price as consisting of two components: one associated with market fundamentals and the other representing the bubble. The bubble theory suggests that securities may go through periods of under- and overvaluation relative to fair-market values. One reason for this may be investor overreaction. In the pharmaceutical example described above, investors may be overly optimistic in evaluating the increase in the firm's profits. Of course, investors have strong incentives to correctly evaluate how product developments affect firm profitability. This reasoning suggests that it's unlikely that investors will consistently overreact to news about firms' profitability.

Bubbles may also reflect investors' reactions to factors unrelated to fundamental eco-

[2]The martingale model of security prices, which has also been called the random-walk model, comes from an assumption that investors care only about the expected rate of return on an asset, not the variability of the return.

[3]Technically, this implication is for the change in price plus any dividend amount.

nomic and business conditions. Hypothetically, individual investors may rush into the stock market because they believe everyone else is making money in the market. In this case, they prefer to buy stocks immediately rather than miss an excellent buying opportunity. As a result, the anticipation of rising prices becomes a self-fulfilling prophecy, and market participants enjoy profits that may not necessarily reflect favorable business prospects.

For example, investors know that the outcome of the Super Bowl played each January has had a good track record in predicting the course of that year's stock-market performance. When a National Football Conference team has won, the stock market has frequently increased considerably over the year, while a win for an American Football Conference team often presages a lower stock market. Even though the outcome of a football game has little, if any, effect on overall business conditions, the business press and investor publications often cite this correspondence. As long as some investors are perceived to act on this statistic, others also may buy in anticipation of this higher demand and rising prices. If enough investors behave this way, prices rise and expectations become self-fulfilling.

Certain types of bubbles can be difficult to explain in a sensible way. They are similar to Ponzi schemes and chain letters in that participants will benefit from the game as long as others can be found who are eager to play the game. Of course, Ponzi schemes crash as soon as individuals believe it will be difficult to find others willing to participate. Similarly, some types of bubbles imply that dramatic declines in security prices are the result of investors finally realizing that rising prices may never be justified on economic grounds. At that point, investors try to sell their assets and prices drop: the bubble bursts.

While certain types of bubbles seem to be inconsistent with rational behavior, there is a class of bubbles called *rational bubbles*.[4] A rational bubble reflects a self-fulfilling belief among rational investors that an asset's price depends on variables unrelated to market fundamentals. In this context, a rational investor is an individual who efficiently uses relevant information for assessing the value of a security. Within the bubbles framework, the fact that investors are rational means that while bubbles can exist, obvious profit opportunities cannot. This simply means that if an easy profit opportunity were available, a rational investor would exploit it and quickly eliminate the opportunity. In other words, for simple types of bubbles, the expected rate of return on a security must be the same whether or not the price includes a bubble.

This means that one key feature of a rational bubble is that the evolution of the bubble over time is restricted to rule out easy profit opportunities. For example, a situation in which all investors expect a security to double in price between today and tomorrow, but fall back to its original value the following day would not constitute a rational bubble. In this case, everyone would rationally want to sell the security tomorrow, so that the price would fall before the following day. Alternatively, an asset could be overpriced 20 percent relative to its fundamental value and, thus, could exhibit a rational bubble, as long as both the fundamental value and the bubble component are expected to grow at the same rate. For example, suppose that market fundamentals for a security were expected to grow at 5 percent per year forever. The price of this security would have a rational bubble if the bubble component also grew at 5 percent per year. In this case, the rate of return on the security with the bubble component

[4]A large literature has analyzed rational bubbles. This review provides an analysis of some very simple examples. For an extensive review of this literature, see the *Journal of Economic Perspectives*, Spring 1990, Symposium on Bubbles, pp. 13-102.

would be identical to the rate of return on the security without a bubble.

Bubble interpretations have been popular with professional investors and the financial press for many years. In his introduction to Charles Mackay's *Memoirs of Extraordinary Popular Delusions and the Madness of Crowds*, the noted investor Bernard Baruch wrote, "All economic movements, by their very nature, are motivated by crowd psychology...Men think in herds; it will be seen that they go mad in herds, while they only recover their senses slowly, and one by one."

HISTORICAL EPISODES OF DRAMATIC PRICE MOVEMENTS

A number of historical episodes of extreme price movements have been interpreted as bubbles. While these episodes and the circumstances surrounding them bear little resemblance to modern financial markets, they are interesting to analyze, since they may be helpful in understanding current experience.

Perhaps the most famous episode occurred in 17th century Holland with an unlikely asset: diseased tulip bulbs. Tulipmania, as it is often called, began quietly when a nonfatal virus, known as a mosaic, attacked tulip bulbs. The effect of the virus was to produce a variegated flower of brilliant stripes and colors. The virus affected only a relatively small number of bulbs, and these bulbs became highly prized by collectors.

As the prices of the mosaic bulbs began to rise rapidly, investors as well as horticulturists began acquiring them. The increased demand for the bulbs resulted in even higher bulb prices and large profits for existing owners. Charles Mackay, who described this episode in his book, noted that "nobles, citizens, farmers, mechanics, seamen, footmen, maid-servants, even chimney sweeps and old clotheswomen dabbled in bulbs."

By 1635, tulipmania had engulfed the country. Futures markets sprang up in local taverns, where trades were made without margin limits and, presumably, the flow of spirits facilitated transactions. Interestingly, speculation apparently spread to common bulbs unaffected by the mosaic virus. In the first week of February 1637, prices peaked, and common bulb prices rose 20-fold in one month. Then, prices fell dramatically. While historical data from this period are sketchy at best, Peter Garber of Brown University has estimated that common bulb prices lost about 95 percent of their peak values just three months after the crash. A century later, the bulbs were virtually worthless. The strikingly colored Semper Augustus bulb, which traded for about $60,000 (in current dollars) in February 1637, commanded just 50 cents in 1739.

Tulipmania was a costly lesson for the Dutch. Unfortunately, the British did not learn from this episode. In 1711, some holders of short-term British government war debt agreed to exchange that debt for equity shares in a new government-chartered, joint-stock company called the South Sea Company. In return, the company received a perpetual annuity paying 6 percent annually on the same face value of debt that had been exchanged. The South Sea Company was also given a monopoly on all trade to the South Seas. Although initial trading was fraught with mistakes and a war with Spain shut off most trading opportunities, the price of the stock rose modestly. By 1719, it appeared that peace with Spain was at hand, and as a result, prospects for the South Sea Company looked better than ever.

In 1720, many additional holders of government debt traded the debt to the South Sea Company in exchange for new stock. The company was expected to consolidate the debt and receive a steady stream of interest payments on the government obligation. At this point, the stock's price rose from 130 pounds to 300 pounds per share. After Parliament approved this plan, a new stock offering at 300 pounds quickly shot up to 340. Fights among investors eager to buy the offering were common. The next offering came out at 400, and the next at 500, with an option to buy at just 10 percent margin. When the stock hit 800, half of the members of the House of Lords and the House of Commons plunged in. Soon the price hit 1000 pounds per share. At this point, the directors of the company began selling, which resulted in rapid liquidation of South Sea shares.

Parliament ultimately passed the Bubble Act, which prohibited the issuing of stock certificates by companies. So strong was the British aversion to a repeat bubble that this law was in force for the next century: British companies were not allowed to issue stock until 1825.[5]

PLEASE DON'T EAT THE TULIPS!

In his book, Charles Mackay relates an anecdote that shows just how seriously the Dutch took their tulips. Mackay describes an incident in which a young sailor notified a merchant of the arrival of a shipment of new goods. For bringing the news, the sailor was summarily rewarded with a breakfast of herring. It so happened that the sailor noticed the ideal condiment for his herring, an onion, perched on the merchant's counter and helped himself to it. To the merchant's—and ultimately the sailor's—distress, the "onion" was actually a prized Semper Augustus bulb. The merchant pressed charges, and the unwitting felon spent several months in prison.

Of course, who knows how much—if any—of this story is true. Peter Garber, for one, points out that an astute merchant would hardly leave such a valuable object lying around, especially within easy reach of a random guest. Nonetheless, it underlines the frenzy created by the speculation in tulip bulbs in 17th century Holland.

BUBBLES VS. MARKET FUNDAMENTALS: EVIDENCE FROM MODERN TIMES

Although not accepted universally, many economists agree that prices during these historical periods reflect some bubble component. Are bubble explanations of extreme price movements confined to just a few historical episodes, or might bubbles be relevant for today's financial markets?

Critics of the efficient markets theory point out that the theory cannot account for observed volatility in security prices. Nevertheless, the implication of the theory that changes in asset prices are unpredictable has received a fair amount of empirical support. For example, a number of experiments have been conducted in which stock portfolios picked by Wall Street's leading money managers were compared over time against a portfolio chosen by throwing darts at a stock page from the *Wall Street Journal.* The martingale model predicts that portfolios chosen at random should perform, on average, about the same as those chosen by portfolio managers. In many of these experiments, random picks do just as well as many of Wall Street's leading traders.

Moreover, critics of the bubble theory point out that technical analysis, which is the practice of trying to identify systematic patterns in security price movements, should be useful in choosing securities if bubbles are present. The basic idea is to plot security prices over time and use past price behavior to predict future prices. Patterns often considered important for predicting future price movements include the "inverted head and shoulders," "triple top double bottoms," and "piercing necklines." In

[5]See Charles Kindleberger's book for a more in-depth treatment of the South Sea bubble.

general, these approaches have not significantly outperformed randomly chosen strategies or buy-and-hold strategies.

Nevertheless, several observations from the stock market do challenge efficient markets explanations. One of the best known patterns is the January effect, which refers to the first two weeks of January when stock returns tend to be unusually high. This is also a period when stocks of smaller companies, such as those that tend to trade on the over-the-counter market, outperform larger, well-known issues. While selling stocks because of end-of-the-year tax considerations may play a role in explaining the January effect, it cannot completely account for the anomaly. The January effect was present in the United States even before income taxes.

Some economists have made another observation that challenges the market fundamentals theory: the underpricing of initial public offerings (IPOs). An IPO is the initial sale of equity shares in a company that was privately held. Brokers allocate the initial offerings of shares to customers, and after the initial offering, these shares are traded on public exchanges. For many IPOs, the initial rate of return is enormous.[6] In a 1988 paper, Roger Ibbotson, Jody Sindelar, and Jay Ritter reported that between 1977 and 1987, the average initial return, which is defined as the percentage increase from the offering price to the end-of-first-day bid price, is over 20 percent. On an annualized basis, this rate of return would be in the neighborhood of over 1000 percent.

These enormous returns suggest to some observers that the shares are initially underpriced. There does not appear to be a generally accepted theory of this observation, and it is somewhat puzzling as to why issuing firms would agree to deal with underwriters who underprice the security.[7]

TESTING FOR BUBBLES AND EXCESS VOLATILITY IN ASSET MARKETS

The tulipmania and the South Sea bubbles are striking examples of how prices may diverge from fundamental values. Many economists think it unlikely that similar episodes could occur today. If there are bubble or nonfundamental components in asset prices, chances are they will be much less dramatic and harder to distinguish from market fundamentals.

Until recently, claims that prices were out of line with market fundamentals were conjectures, substantiated by little more than anecdotal evidence. However, recently developed statistical tests may help shed some light on the debate. A number of tests have been developed, and two widely used tests will be discussed here.

Robert Shiller of Yale University developed and implemented one popular test that has been used to evaluate whether prices are consistent with market fundamentals. Shiller constructed an economic model of the fundamental price of an asset. The test compares the volatility of the observed security price with the volatility of the fundamental price. These tests are typically called variance bounds tests, since the basic idea is to determine whether the observed variability of market price is consistent with the observed variability of market fundamentals.

For stocks, the model assumes that the price an investor would be willing to pay today depends on the total return (the dividend and price appreciation) he expects to receive from

[6]For example, in August 1995, Netscape, a company that produces software for the Internet, had an IPO with an offering price of $28 on Tuesday and closed at $58.25 on Wednesday.

[7]For additional discussion of asset market anomalies, see Richard Thaler's 1992 book.

the stock tomorrow. In turn, the price in the following period depends on the dividend and price appreciation he expects to receive two periods from now, and so forth. This logic implies that the fundamental price of a stock today will depend on all expected future dividends adjusted by an appropriate discount rate (interest rate). This analysis suggests that today's share price is a predictor of future returns. If the market price is consistent with market fundamentals, the share price should equal market fundamentals. In this case, the volatility of predicted cash flows (the market fundamentals price) cannot exceed the volatility of actual cash flows (the returns). Using data on dividends and prices, we can compare the historical volatility of the predicted cash flows to the actual cash flows.

A constructed series represents the sum of discounted dividends from stocks listed in the Standard & Poor's 500 graphed against the price of the S&P 500 since 1871 (Figure 1). Clearly, stock prices are many times more volatile than the present value of discounted dividends. Given the relatively stable history of dividends over the last century, market fundamentals, constructed this way, clearly cannot account for the extreme volatility of asset prices. One interpretation is that stock prices are too volatile relative to observed changes in cash flows and that some factor unrelated to business conditions is responsible for the bulk of asset price fluctuations.

However, there are some important caveats associated with interpreting these tests. First, there is no unique way to determine how investors discount future cash flows. The typical procedure carried out in these tests (and in Figure 1) is to assume that the discount factor (interest rate) is constant, which may not be true. Second, we cannot observe people's expectations of future dividends directly, so we must infer them. It is common to simply assume that today's stock price is exactly equal to the future discounted sum of dividends. But this practice leads to difficulties in evaluating whether market fundamentals are consistent with price data. Instead, Robert Flood, Robert Hodrick, and Paul Kaplan, in a 1986 paper, suggested that apparent violations of variance bounds tests reflect errors in the model. That is, the test depends on the underlying economic model being correct. Of course, this is a very strong assumption, and test results may simply reflect misspecification of the economic model. While there may be bubble components to asset prices, this type of test will not likely resolve the debate.

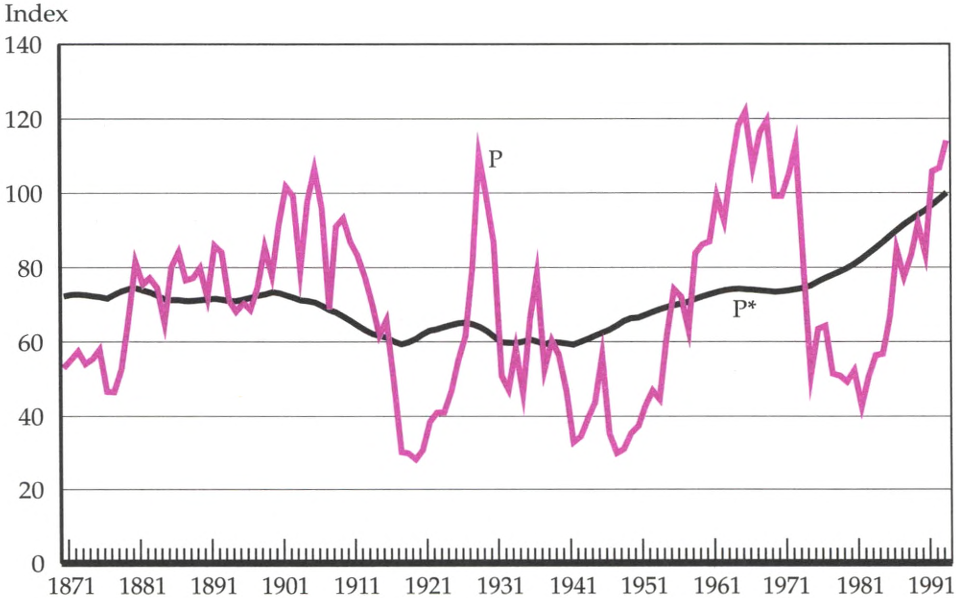
An alternative approach for testing whether variations in security prices are consistent with variations in market fundamentals is to determine whether the trend rate of growth in the asset price is similar to that in market fundamentals. Specifically, if market fundamentals are growing at a slower rate than the price of the corresponding asset, we may reasonably conclude that prices include a particular type of bubble component. This procedure can be used to detect the presence of bubbles that grow continuously over time.

In 1985, James Hamilton and Charles Whiteman, and in 1988, Behzad Diba and Herschel Grossman conducted tests along these lines. To determine whether market prices grow at a faster rate than market fundamentals, we must evaluate the trends in the data. First, we test the data on annual stock prices and annual dividends to see if there are trends. If both series have trends, the series are "differenced." For example, to calculate the differenced data for market prices, subtract the price of the asset last year from its price this year.

The differenced data for market prices and dividends are then tested for trends. If both of these differenced series have trends, the series are differenced again, and the trend tests are repeated. This process of successively differencing the data continues until the transformed data do not have trends. If market

FIGURE 1

Detrended Stock Prices and the Present Value of Detrended Dividends 1871 - 1994



P is the real Standard & Poor's Composite Stock Price Index, detrended by a long-run exponential growth factor. P* is the discounted present value of real dividends, detrended by the long-run exponential growth factor. Real values are calculated by dividing nominal values by the wholesale price index.

Source: Shiller, *Market Volatility*, Figure 5.1, updated by author.

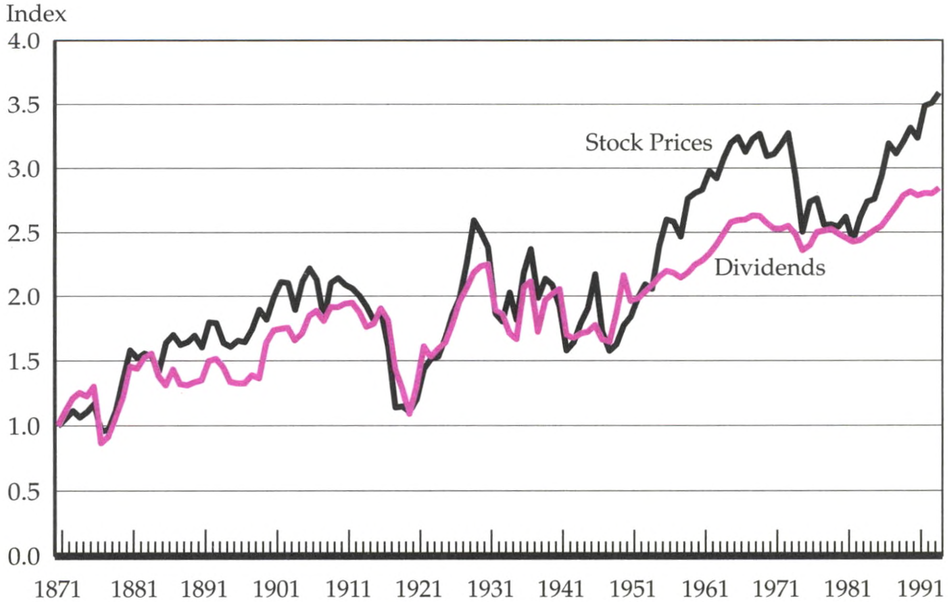
prices must be differenced more times than market fundamentals, we may reasonably conclude that a bubble is present in market prices.

This analysis for dividends and stock price data, which appears in Figure 2, offers evidence that both prices and dividends have trends, but when differenced once, both do not. This implies that prices over this period have not grown consistently faster than dividends and provides evidence against the notion that stock prices have included a growing bubble component.

Although the analysis presented here was conducted with data only from the stock market, these same tests can be used to evaluate data from the bond and foreign exchange markets. Briefly, the nature of these data are quite similar to data from the stock market. Like stocks, the variability of bond prices and exchange rates seems to be high relative to mar-

FIGURE 2

Stock Prices and Dividends 1871 - 1994



"Stock prices" is a logarithmic index of the real Standard & Poor's Composite Stock Price Index. "Dividends" is a logarithmic index of the real dividends on the real Standard & Poor's Composite Stock Price Index. Real values are calculated by dividing nominal values by the wholesale price index.

Source: Author's calculations from data in Standard & Poor's *Security Price Index Record*.

ket fundamentals. Moreover, there don't appear to be any differences in the trend behavior of market fundamentals and prices for either bonds or foreign exchange.

CONCLUSION

The extreme volatility of security prices has been a source of considerable interest since financial assets have traded in organized markets. It is important to distinguish between market fundamentals and bubbles when analyzing the volatility of any security. If there are dramatic changes in fundamental economic factors, we would expect to see highly volatile security prices. If the volatility of security prices is considerably greater than the volatility of underlying business conditions, or if asset prices tend to grow much faster than the asset's associated cash flows, price movements may reflect a bubble component.

The episodes of Dutch tulipmania and the British South Sea bubble provide dramatic examples of how prices may have deviated from fundamental values. Anecdotal evidence from recent periods provides no clear answer to the question of whether price movements may be due to bubbles. A number of statistical procedures have been developed to investigate these questions directly, and these tests have been applied to stock market data. Unfortunately, these tests often rely on assumptions that make interpretation of results very difficult. Test results that show differences between security prices and market fundamentals may be due to bubble components, but they may also reflect errors in the model for market fundamentals. That is, a researcher may find evidence in favor of bubbles, but this may simply be due to the fact that the model for market fundamentals is wrong.

Since market fundamentals are generically unobservable, it will always be difficult, if not impossible, to analyze data on asset prices and determine whether price movements can be entirely reconciled with movements in market fundamentals. We are left with the interesting observation that there are historical variations in asset prices that, at least, do not appear to be consistent with variations in underlying business conditions.

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The Cyclical Volatility of Interest Rates

*Keith Sill**

The variability of short-term and long-term interest rates is a prominent feature of the economy. Interest rates change in response to a variety of economic events, such as changes in Fed policy, crises in domestic and international financial markets, and changes in the prospects for long-term economic growth and inflation. However, economic events such as these tend to be irregular. There is a more regular variability of interest rates associated with the business cycle, the expansions and contractions that the economy experiences over time. For example, short-term interest rates rise in expansions and fall in recessions. Long-term interest rates do not appear to co-vary much with the level of economic output.

The term *cyclical volatility of interest rates* refers to the variability of interest rates over periods that correspond to the length of the typical business cycle. In this article, we will examine some facts and theory about the cyclical volatility of short-term and long-term interest rates. Why should we care about interest rate volatility? How do short-term and long-

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term interest rates behave over the business cycle? What determines the cyclical volatility of interest rates associated with different maturities of government bonds? These questions are important to ask and answer as we seek a fuller understanding of the dynamics of the business cycle in market economies.

WHY DOES INTEREST RATE VOLATILITY MATTER?

The variability of interest rates affects decisions about how to save and invest. Investors differ in their willingness to hold risky assets such as stocks and bonds. When the returns to holding stocks and bonds are highly volatile, investors who rely on these assets to provide for their consumption face a relatively large chance of having low consumption at any given time. For example, before retirement, people receive a steady stream of income that helps to buffer the changes in wealth associated with changes in the returns on their investment portfolios. This steady return from working helps them maintain a relatively steady level of consumption. After retirement, people no longer have the steady stream of income from working (though it will, in part, be replaced by pension income and Social Security), so a less volatile investment portfolio is called for. The lower volatility of investment returns allows retirees to maintain a relatively even level of consumption over time. Young investors, who are saving for retirement, are better able to absorb the risks of holding assets with highly volatile prices and returns. They can weight their portfolio more heavily toward risky stocks and bonds because they are receiving a steady return from working. For holding these riskier assets, the young investor will be rewarded with a higher average return on the investment.

Just as individuals care about managing risk in their investment portfolios, so do firms. To manage risk, firms must pay attention to interest rate volatility and the composition of their portfolios. Many business firms hold portfolios containing large numbers of assets and, thus, are interested in quantifying the risk of losing large sums of money. As risks in the economy change, the expected gains and losses from the investment portfolio change. Measuring this risk involves knowing how volatile prices of and returns on assets are, as well as how the returns on different assets change together over time. The volatility of interest rates is likely to be an important component in quantifying risk and guiding the investment decisions of these institutions.

Interest rate volatility also has implications for how the prices of certain types of assets are determined. Options are assets that give investors the right, but not the obligation, to buy (call options) or sell (put options) other assets (such as stocks or bonds) at a prespecified price at or before some prespecified time in the future. For options purchased on interest-bearing securities, modern finance theory demonstrates that the option price depends on the volatility of returns on the underlying asset. The volatility of interest rates is related to the volatility of returns on these assets.

Thus, interest rates and their volatility have important implications for how both individuals and firms make investment decisions. These investment decisions are part of the process whereby resources are allocated in the economy. To begin, we'll briefly discuss how bond prices, interest rates, and maturities of bonds are related and how interest rates can be determined from bond prices.

INTEREST RATES, BOND PRICES, AND THE TERM STRUCTURE

There is a very close connection between bond prices and interest rates. We will focus on interest rates calculated from prices of traded U.S. government securities and show how the interest rate on a particularly simple type of security can be derived solely from its price. We focus on yields derived from U.S. government securities because these assets are backed by the full faith and credit of the government and, therefore, have virtually no default risk.

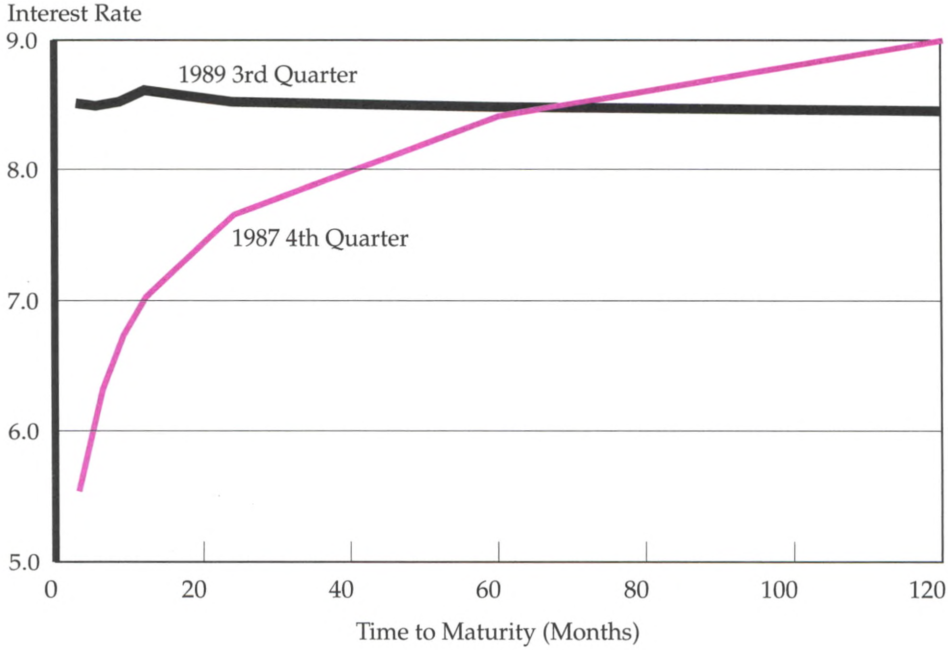
The U.S. government issues securities of many different maturities: the maturity is the length of time until the final payment on the security is made by the issuer. Treasury bonds are fixed-coupon securities with initial maturities of more than 10 years. Treasury notes are fixed-coupon securities with initial maturities of from two to 10 years. Treasury bills are securities that are sold at a discount from face value and have initial maturities of a year or less.

If we know a bond's current price and the payments that the bondholder will receive over the course of the bond's life, we can calculate the implied interest rate on the bond. This interest rate, called yield-to-maturity, equates the current price of the bond to the present value of the bond's payment stream.[1] The relationship between the maturity of bonds and the interest rates implied by bond prices is called the term structure of interest rates. A plot of the relationship between interest rates and bond maturity, called the yield curve, can take a variety of shapes (Figure 1). Typically, interest rates on short-term bonds are lower than interest rates on long-term bonds, in which case the yield curve is upward sloping, as shown in the figure for the fourth quarter 1987. But sometimes the yield curve inverts, in which case interest rates on short-term bonds are

[1]For more detail on how yield-to-maturity is calculated, see my article in the July/August 1994 *Business Review*.

FIGURE 1

Term Structure of Interest Rates



higher than interest rates on long-term bonds, as shown in the figure for the third quarter 1989.

The shape of the typical yield curve shows that interest rates often vary with maturity. We might also suspect that the volatility of interest rates varies with maturity. But before we turn to how volatility is measured and how volatility is related to maturity, let's clarify the relationship between interest rates and the price of a particularly simple type of bond.

Interest Rates and Bond Prices. Interest rates on certain types of bonds can be derived solely from the bonds' price and maturity. Let's look at a particular type of bond called a discount, or zero-coupon, bond. A discount bond sells at a discount from its face value and makes no interest payments over its lifetime. When the bond matures, the bondholder receives the bond's face value. For example, a one-year Treasury bill with a face value of $10,000 is a discount bond that promises to pay the holder $10,000 in one year's time. Such a bond may sell for a current price of $9434, in which case the implied interest rate on the bond is 6 percent (($10,000-$9434)/$9434 = .06). Clearly, as the current price of the bond changes, the implied interest rate will change. For example, suppose the current price of the bond falls to $9009. Then the implied interest rate on the bond is 11 percent (($10,000-$9009)/$9009 = .11). So, as the price of the bond falls, the interest rate rises; as the price rises, the interest rate falls.[2]

The U.S. Treasury does not issue discount bonds with maturities greater than one year. However, financial market participants create pure discount bonds from long-term, coupon-paying Treasury bonds by "stripping" the coupon (semiannual interest) payments from the principal payment and selling the components as separate discount securities. In February 1985, the Treasury announced the STRIPS (separate trading of registered interest and principal of securities) program, which facilitated the "stripping" of long-term Treasury bonds. Under the STRIPS program, all newly issued Treasury bonds and notes with maturities of 10 years or longer are eligible for stripping. The prices of these pure discount bonds can be found in publications such as the *Wall Street Journal.*

Since there is a clearly defined relationship between interest rates and prices for discount bonds, we need to refer to only one of these elements, not both. When we consider discount bond prices, we can easily derive the implied interest rates. Similarly, when we talk about the volatility of discount bond prices, we will easily be able to make inferences about the volatility of interest rates.

Trends and Cycles in Interest Rates. We can plot the interest rate on discount bonds with a 10-year maturity from 1959 to 1990 (Figure 2).[3] Notice that, overall, the interest rate tended to rise from 1959 to the early 1980s, after which it generally declined.

From Figure 2 we can discern two types of variability in interest rates and hence in discount bond prices: long term and short term. Long-term variability refers to broad trends in interest rates, such as the upward trend until the early 1980s and the downward trend since then. Short-term variability refers to how interest rates vary *around* these long-term swings. Since our focus is on the business-cycle volatility of interest rates, we would like to remove

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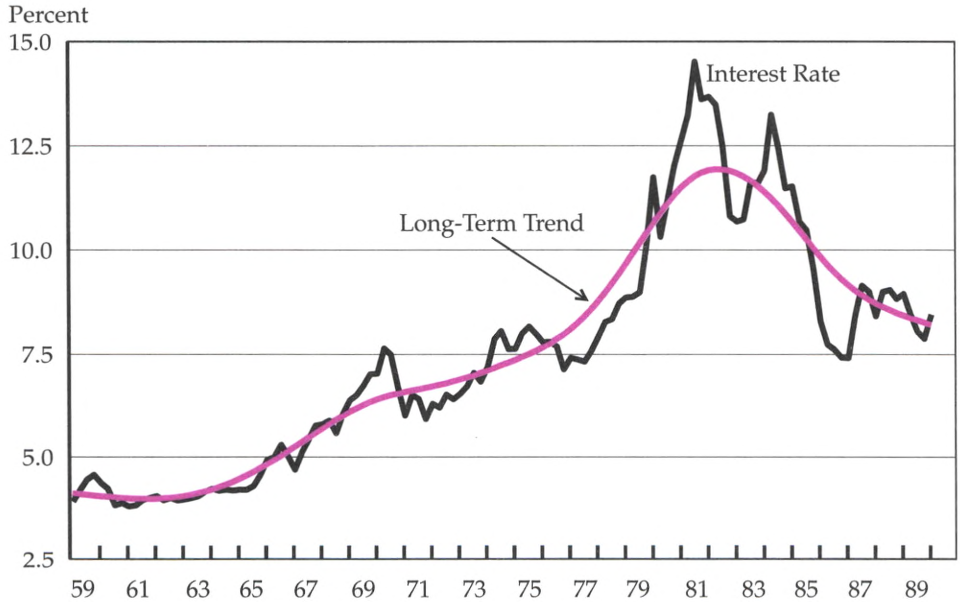
[2]There is a simple relationship between the interest rate on a discount bond and the price of the bond. Suppose the price today of a bond that pays off $100 in five years is $75. The five-year interest rate on the bond is 33.3 percent [(100-75)/75 = .333]. The average annual interest rate on the bond is 5.9 percent since [$75 x (1.059)5 = $100]. Generalizing this idea, if the interest rate is r on a bond paying $1 in j years, the current price of the bond is $\$1/(1+r)^j$.

[3]The data plotted in Figure 2 are yields on discount bonds from the dataset compiled by McCulloch and Kwon.

FIGURE 2

Ten-Year Interest Rate and Long-Term Trend



that part of interest rate volatility associated with swings of longer duration than the typical business cycle.

The National Bureau of Economic Research defines minor cycles as recurrent fluctuations lasting from two to four years and major cycles as recurrent fluctuations lasting about eight years. Figure 2 clearly shows long-term trends in interest rates that are of greater duration than typical business-cycle lengths. In Figure 2 we've plotted a long-run trend that is fitted to the interest rate data. This long-term trend is chosen in such a way that it removes the swings in interest rates associated with periods longer than about eight years.[4] The remaining short-run variability then corresponds more closely to variability that is part of the business-cycle movement in interest rates. We will define the difference between the actual interest rate and the long-run trend as the cyclical component of the interest rate (Figure 3). The long swings in interest rates have been taken out, and all the variability in interest rates is around zero because this figure plots deviations from the long-term trend. When the interest rate is zero in Figure 3, we are on the long-term trend line in Figure 2. Henceforth, when we refer to interest rate volatility, we will be referring to the variability of this short-run component.

MEASURING THE VOLATILITY OF INTEREST RATES

We will measure interest rate volatility using a statistic called the standard deviation.

[4]The fitted trend is calculated using the Hodrick-Prescott filter. More details on how this filter works are provided in the paper by Robert King and Sergio Rebelo.

FIGURE 3

Cyclical Component of Ten-Year Interest Rate

The standard deviation measures how dispersed a variable is around its average value. If the standard deviation is high, observations on a variable tend to be far away from the variable's average value. If the standard deviation is low, observations on the variable tend to be clustered around the average value. Therefore, as the standard deviation increases, there is a greater chance that we will see large changes in the value of the variable.[5]

The volatility of interest rates can be calculated over the entire term structure of interest rates: we simply use historical data to calculate the standard deviation of interest rates for each maturity. Table 1 presents the relationship between interest rate volatility and the maturity of bonds as well as the standard deviation of the associated prices for discount bonds.[6] The table shows that short-term interest rates are more volatile than long-term interest rates and that long-term discount bond

[5]The standard deviation is calculated as the square root of the variance of a variable. Suppose we have n observations on a variable $\{X_1, X_2, \ldots X_n\}$. Denote the average value of X by $\overline{X}$. The variance of X is then the average of the squared deviations of X from its mean: $V(x) = [(X_1-\overline{X})^2 + (X_2-\overline{X})^2 + \ldots (X_n-\overline{X})^2]/n$. The standard deviation of X is the positive square root of V(x).

[6]More specifically, we calculate the standard deviation of detrended yields and logarithms of bond prices using quarterly data over the period 1959:Q1 to 1990:Q1. We use the logarithm of the discount bond price because it is proportional to the yield-to-maturity of the bond, with the factor of proportionality equal to the maturity of the bond. The interest rates and bond prices are detrended using the Hodrick-Prescott filter.

prices are more volatile than short-term discount bond prices.[7]

In describing the cyclical volatility of interest rates we would like to know not just how much interest rates vary but also how they vary with the state of the economy. During recessions, real output is declining; during expansions, it's rising. We can get an idea of the behavior of interest rates over the business cycle by evaluating how interest rates and the level of real output co-vary over the business cycle. The correlation coefficient is a measure of the strength of the co-variation between two variables, and it can take on values between minus one and one. When the correlation coefficient between two variables is positive and close to one, the two variables track each other closely and move in the same direction: when one variable is high, the other variable is very likely to be high. If the correlation coefficient is negative and close to one, the two variables track each other closely but move in opposite directions: when one variable is high, the other is likely to be low. When the correlation coefficient is zero, the two variables do not track each other closely in either direction.

The cyclical component of short-term interest rates has a positive contemporaneous correlation with the cyclical component of real output. So when current output falls, short-term interest rates tend to fall, and when current real output rises, short-term interest rates tend to rise (Table 2). The strength of this correlation between output and interest rates tends to decline as the maturity of the bonds increases. By the time we get to bonds with 10-

[7]There is a direct relationship between bond-price volatility and the volatility of the interest rate on the bond. Using the relationship between bond prices and interest rates in footnote 2, it can be shown that the standard deviation of the interest rate on a j-period bond is approximately equal to the standard deviation of the logarithm of the j-period bond price divided by j.

TABLE 1

Interest Rate and Bond-Price Volatility 1959:Q1 - 1990:Q1

Time to Maturity	Standard Deviation of Detrended Interest Rate	Standard Deviation of Detrended Discount Bond Price
1 quarter	.0032	.0032
2 quarters	.0031	.0063
3 quarters	.0030	.0092
1 year	.0029	.0117
2 years	.0025	.0205
5 years	.0021	.0426
10 years	.0018	.0735

Standard deviations are calculated from the term structure data in McCulloch and Kwon (1993). Standard deviation is of the logarithm of discount bond prices (see footnote 5).

TABLE 2

Correlations of Interest Rates and Real GDP 1959:Q1 - 1990:Q1

	Correlation of Detrended Interest Rate in Period t with Detrended Output in Period:		
Time to Maturity	t-1	t	t+1
1 quarter	.42	.35	.11
2 quarters	.41	.34	.09
3 quarters	.40	.32	.08
1 year	.37	.29	.05
2 years	.27	.20	-.02
5 years	.11	.04	-.15
10 years	.02	-.05	-.21

Output is measured as the logarithm of real GDP. Interest rate data are from the term structure data in McCulloch and Kwon (1993).

year maturity, the contemporaneous correlation is negative, though quite small. This implies that there is little co-variation between the cyclical movements in current real output and the cyclical movements in long-term interest rates. These facts can be expressed by saying that short-term interest rates are procyclical and long-term interest rates are acyclical. The results in Table 2 suggest significant business-cycle variability in short-term interest rates but relatively little business-cycle variability in long-term interest rates.

The last column of Table 2 shows that the correlation between current interest rates and real output one quarter into the future is positive for short-term and negative for long-term interest rates. This fact suggests that upward movements in short-term interest rates are associated with upward movements in near-term output, but that higher long-term interest rates forecast lower near-term output. The first column of Table 2 shows the correlation between current interest rates and the level of real output one quarter in the past. These correlations suggest that increases in current output are associated with increases in future interest rates.

We can also make some deductions about the shape of the yield curve over the business cycle using the data in Table 2. We have seen that short-term interest rates tend to move up when output moves up but that the correlation tends to decline as the maturity of the bond increases. Thus, when current output rises, the yield curve tends to flatten, since short-term interest rates tend to rise and long-term interest rates move relatively little. Similarly, when current output declines, the yield curve tends to steepen, since short-term interest rates tend to fall with output and long-term interest rates tend to remain about the same.

We have seen how the volatility of interest rates changes with maturity and how interest rates move in relation to real output over the business cycle. But how are interest rates on bonds of different maturities related to each other? In general, interest rates on bonds of different maturities are highly correlated with each other, with the highest correlations occurring between bonds of similar maturities (Table 3). Let's take the case of the interest rate on a security with one-quarter maturity. We see that the one-quarter interest rate is most highly correlated with the interest rate on a bond with two-quarter maturity, and that the correlation declines, though remains strong, as we compare bonds with increasingly different maturities. These correlations suggest a tendency for the entire yield curve to shift up and down, while allowing for the possibility that the shape of the yield curve can change.

Finally, if we re-examine Figure 3, we might suspect that the measured volatility of interest rates depends on the period we're looking at. Since the late 1970s, long-term interest rates appear to have shown more short-run variability, and the deviations of the interest rate on 10-year bonds from the trend line have been large and persistent.

In fact, the results in Table 4 show that interest rates at all maturities may have been more variable since that time. The table shows the standard deviation of interest rates using the same data, but the sample is divided into two subsamples: from first quarter 1959 to first quarter 1979 and from second quarter 1979 to first quarter 1990. We see that interest rates at all maturities have been more volatile since 1979. This result suggests the possibility that some structural change in the economy has affected the variability of interest rates and bond prices.[8]

[8]For short-term interest rates in particular, higher volatility after 1979 may reflect a change in the way that the Federal Reserve implements monetary policy. After late 1979, and especially between late 1979 and late 1982, monetary policy placed less emphasis on smoothing short-term interest rates. Thus, after 1979, short-term interest rates were more likely to reflect changes in the state of the economy.

TABLE 3

Cross Correlations of Detrended Interest Rates 1959:Q1 - 1990:Q1

Maturity	1 qtr	2 qtr	3 qtr	1 year	2 years	5 years	10 years
1 quarter	1.0						
2 quarters	.99	1.0					
3 quarters	.97	.99	1.0				
1 year	.96	.99	.99	1.0			
2 years	.90	.94	.96	.98	1.0		
5 years	.79	.84	.87	.90	.96	1.0	
10 years	.69	.75	.78	.81	.90	.98	1.0

Interest rate data are from McCulloch and Kwon (1993).

TABLE 4

Interest Rate and Bond-Price Volatility

Time to Maturity	Standard Deviation of Detrended Interest Rate		Standard Deviation of Detrended Discount Bond Price	
	59:1-79:1	79:2-90:1	59:1-79:1	79:2-90:1
1 quarter	.0026	.0040	.0026	.0040
2 quarters	.0026	.0040	.0051	.0079
3 quarters	.0025	.0039	.0075	.0116
1 year	.0024	.0037	.0094	.0148
2 years	.0019	.0034	.0151	.0275
5 years	.0014	.0030	.0278	.0608
10 years	.0011	.0027	.0442	.1080

Standard deviations are calculated from the term structure data in McCulloch and Kwon (1993). Logarithms of discount bond prices are taken before the standard deviation is calculated (see footnote 5).

WHAT DETERMINES INTEREST RATE VOLATILITY?

The postwar data imply that prices of long-term discount bonds are more variable than those of short-term discount bonds and that long-term interest rates, measured by yield-to-maturity, are less volatile than short-term rates. In addition, we find that short-term interest rates are procyclical, while long-term interest rates vary little with current output. What economic factors influence interest rate variability? If we can isolate some economic determinants of the levels of interest rates and bond prices, we will be well on our way to finding determinants of this variability.

Determination of Short-Term Interest Rates. A standard economic model will help us think about how the interest rate on short-term discount bonds is determined. Let's consider the case of a discount bond that will pay off $100 with certainty in one year. Suppose a prospective bond buyer expects her real income over the coming year to be higher than usual (real income refers to income adjusted for any change in the general level of prices over time). In that case, she has less of an incentive to increase her savings by purchasing a bond today. In fact, she may well decide to borrow against some of her expected increase in income. If all prospective bond purchasers expect higher real income over the coming year, demand for current one-year bonds will fall, and their prices will fall as well, which means that the one-year interest rate will rise. On the other hand, investors may decide to hedge against the risk of lower future income by purchasing bonds today that provide a guaranteed future payoff.

If current real output (and thus aggregate real income) is low, investors may expect future output to be low, because there is some persistence to output movements. Hence, a downward movement in current output is consistent with a downward movement in current short-term interest rates if people expect output and income in the near future to be low as well. This theory is consistent with procyclical movement in short-term interest rates.

The yield curve tends to flatten when output is high and tends to steepen when output is low. Suppose we are currently in a boom, but people expect a recession in one year. Investors may buy one-year bonds to hedge the risk of low future income, and they may pay for these bonds, in part, by cashing in their shorter-term assets. This portfolio reallocation tends to lower one-year interest rates and raise shorter-term interest rates, thus leading to a flatter yield curve. Empirical studies have found that the shape of the yield curve does help predict recessions and expansions.[9]

Expected inflation is also a determinant of interest rates. Consider again the case of a discount bond that pays $100 with certainty in one year. Suppose now that prospective bond purchasers expect inflation to rise over the coming year. When inflation rises, the current price of one-year bonds will fall because investors realize that their dollars buy less when prices rise. For example, if the price of a cup of coffee one year from now is $1, bondholders can buy 100 cups of coffee with the $100 that the bond pays off. But if the price of a cup of coffee is expected to rise to $1.05, bondholders will be able to buy only 95 cups of coffee. To be compensated for the loss in purchasing power, investors must get a higher dollar return on their investments. Thus, bond prices will fall and interest rates will rise when expected inflation rises.

This model suggests that when expected income or expected inflation rises, bond prices will fall. This fall in bond prices translates into higher interest rates. So, when we think about how short-term interest rates are determined, we want to think about people's forecasts for real income growth and inflation. Any current economic variables that help to predict real income growth and inflation will help to determine current short-term bond prices and interest rates.

Determination of Long-Term Interest Rates. Long-term interest rates can be linked to short-term interest rates by the expectations theory of the term structure. This theory says that long-term interest rates are equal to an average of expected short-term interest rates plus a risk premium.[10] The risk premium accounts for the co-variation over time of variables like income growth and inflation that could influence the level of interest rates.

The logic of the expectations theory of bond prices is most clearly seen in an example in which we ignore the risk premium. Take the case of an investor who has a two-year investment horizon. The investor can purchase a two-year bond, or he can purchase a one-year bond today and, when that bond matures, purchase another one-year bond. The expected return on these alternative investment strategies should be equal. Since there is a direct relationship between interest rates on bonds and bond prices, the expectations theory also links long-term discount bond prices to expected short-term discount bond prices over the life of the long-term bond.

In terms of expected future short-term bond prices, the same variables that affect short-term bond prices basically determine long-term bond prices and interest rates. Thus, expected future income growth and expected inflation are also determinants of long-term bond prices, but now the forecasts of income growth and inflation are for further in the future. It is still the case that if, over the life of

[9]See the article by Campbell R. Harvey.

[10]For more detail on the expectations theory and risk premiums, see my article in the July/August 1994 *Business Review.*

the bond, expected future income growth or expected future inflation rises, long-term interest rates will rise. Including a risk premium does not alter these basic conclusions about the determinants of interest rates. However, the risk premium can be an additional source of variability for interest rates because it picks up some indirect effects of income growth and inflation on interest rates, as well as other risk factors.

This model helps us think about why long-term interest rates co-vary less with current output than do short-term interest rates. Current movements in real output are much more closely correlated with output movements in the near future than they are with output movements in the far future. Since the payment stream on a long-term bond extends further out into the future than that on a short-term bond, long-term interest rates are less likely to have a strong co-variation with current output movements.

Determinants of Interest Rate Volatility. The same basic economic factors that determine interest rates and the prices of bonds also determine the volatilities of interest rates and bond prices. This economic model suggests that expected real income growth and expected inflation determine bond prices and interest rates. It follows then that the volatility of expected real income growth and the volatility of expected inflation, as well as the correlation between the two, determine the volatility of interest rates and bond prices.

The reasoning behind this conclusion is straightforward. Take the case of real income growth. We saw above that if real income growth is expected to be high, current bond prices will fall and interest rates will rise. The higher real income growth is expected to be, the higher interest rates will be. Thus, large changes in expected real income growth are associated with large changes in interest rates. When real income growth has high volatility, large changes in real income growth occur more frequently, and hence large changes in current bond prices and interest rates occur more frequently. When large changes in interest rates occur more often, interest rates are more volatile. Similar reasoning holds for the case of inflation. When large changes in expected inflation occur, large changes in current bond prices and interest rates occur also. So, more volatile inflation translates into more volatile bond prices and interest rates.[11]

What determines how volatile income growth and inflation will be? One factor is monetary policy. Take the case of monetary policy and inflation. Economists generally believe that a persistent inflation has its root causes in monetary policy, in particular, how fast the money supply grows relative to real income growth. If growth of the money supply is excessive, inflation is likely to be high. If we take growth of the money supply as the primary determinant of inflation, highly volatile growth in the money supply can lead to volatile inflation. This does not mean that every change in the money supply necessarily leads to a change in inflation. Rather, if, on average, money supply growth becomes more volatile, inflation can become more volatile as well. As we have seen, the model then suggests that bond prices and interest rates will also be more volatile.

Monetary policy could also have an effect on real income, although economists disagree on the mechanism by which this occurs. One theory is that workers write contracts with their employers that fix a nominal wage rate over the contract period. Workers and firms

[11]Higher volatility of income growth and inflation suggests that price volatilities for both short-term and long-term bonds will increase. Long-term volatility remains higher than short-term volatility because investors who buy long-term bonds have to make forecasts about future variables that are not relevant for determining the prices of short-term bonds.

negotiate the contracted wage based, in part, on their expectations of what inflation will be over the contract period. Since monetary policy affects inflation, this requires workers and firms to forecast what monetary policy will be over this same period. If monetary policy and the price level turn out to be different from what workers and firms expected when they wrote the contract, employment and output could be affected because firms' demand for workers depends on the real wage rate that must be paid. If nominal wages are fixed by a contract and prices rise unexpectedly, real wages fall, and firms demand more workers and produce more output. If prices fall unexpectedly, real wages rise, firms lay off workers, and output falls. Thus, variability of the money supply, through its impact on prices, could have an impact on the variability of real income.

We can point to many other factors, besides monetary policy, as potentially influencing the volatility of output and inflation. For example, variability in weather can affect agricultural output as well as production in the economy. Changes in productivity due to the introduction of new technologies can influence the variability of output and inflation as well. A whole class of economic models, called real-business-cycle models, attempts to account for output volatility over the business cycle. These models assume that shocks to productivity are the main cause of business cycles.[12] Shocks to current productivity affect peoples' forecasts of the future course of the economy and thereby affect their expectations about economic variables like real income growth and inflation. The more persistent productivity shocks are, the greater their effect on long-term interest rates will be, since output and inflation far into the future will be affected.

[12]See the article by Satyajit Chatterjee in the September/October 1995 *Business Review*.

Economic Models and Interest Rate Volatility. This economic model for determining bond prices and interest rates suggests that investors' expectations of future real income growth and inflation are the primary determinants of current bond prices and interest rates. There are, of course, other determinants of interest rates and interest rate volatility in the economy. But we can try to assess how well this view of interest rate determination explains the interest rate volatility that we observe in the actual economy.

One approach to assessing how well a model performs is to use the model to simulate interest rates and then compare the properties of the simulated interest rates to the properties of actual interest rates. For example, we can set up models and use them to simulate price data on discount bonds of various maturities. We can then calculate the standard deviation of these simulated data and compare it to the standard deviation of discount bond prices implied from the interest rates we observe in the economy. We can also examine how the simulated bond prices and interest rates covary with simulated output and compare the correlations to the correlations we find in the actual data. In this way, we can assess the ability of the model to account for the cyclical volatility of interest rates.

SIMULATION RESULTS

In my 1994 working paper, I present an exercise similar to the one following. Briefly, in the model, expected real income growth and expected money growth determine current discount bond prices and yields. Expected money growth is assumed to be the primary determinant of inflation. The model also requires some input on investor characteristics, such as how willing investors are to undertake risky investments. Table 5 shows the variability of the bond prices and yields simulated by one particular version of the model and reproduces the variability of bond prices and yields

TABLE 5

Yield and Bond-Price Volatility From Model Simulations

Time to Maturity	Standard Deviation of Detrended Interest Rate		Standard Deviation of Detrended Discount Bond Price	
	Simulated	Actual	Simulated	Actual
1 quarter	.00362	.00322	.00362	.00322
2 quarters	.00332	.00315	.00663	.00629
3 quarters	.00303	.00308	.00909	.00923
1 year	.00278	.00293	.01112	.01172
2 years	.00202	.00256	.01619	.02051
5 years	.00100	.00213	.02005	.04265
10 years	.00051	.00184	.02045	.07348

Standard deviations are of the yields and logarithms of discount bond prices (see footnote 5). Actual discount bond prices are calculated from the term structure data in McCulloch and Kwon (1993).

derived from actual interest rate data for comparison.[13]

The model generates data in which volatility of interest rates falls but bond price volatility rises with the maturity of the bond. Out to a maturity of about one year, the variability of the simulated bond yields and prices matches the variability of the data fairly closely. At a maturity of three months, the model overpredicts the volatility of bond prices and yields about 12 percent. At a maturity of one year, the model underpredicts the volatility of bond prices and yields about 5 percent. These results suggest that the variability of income growth and money growth account for a substantial portion of the variability of short-term discount bond prices and hence of short-term interest rates.

For longer maturities, the variability of simulated bond prices and yields underpredicts the volatility of actual yields and implied prices of discount bonds by a progressively larger amount. When we look at the historical data, the variability of implied prices for a discount bond with 10-year maturity is about 23 times larger than the variability of short-term discount bond prices. But in the simulated data, the variability of 10-year discount bond prices is only about five times greater than the variability of short-term bond prices.

Many reasons might explain why the growth of the money supply and the growth of real income do not account for much of the vari-

[13]The model also replicates some of the correlations between discount bond prices and output as well as some features of the correlation patterns of bond prices.

ability of long-term bond prices and yields. The basic model is designed to highlight the business-cycle variability of interest rates, and as we have seen, long-term interest rates do not appear to have a large business-cycle component. In addition, the model is very simple, and so it is missing some important elements found in actual economies. For example, the model does not account for the fact that different people have different beliefs about the future course of the economy or that people are continually learning about the economic environment. Changes in fiscal and monetary policies may induce greater volatility in interest rates than the simple economic model accounts for. The expectations theory may be an inadequate model of the term structure of interest rates. Despite difficulties such as this, the model's implication that real income growth and money supply growth are factors that help to determine the volatilities of interest rates and discount bond prices does find some support, especially for shorter maturities, when we compare the model with actual data.

CONCLUSION

We have seen that the volatility of interest rates depends on the maturity of the underlying bond: long-term interest rates are less variable than short-term interest rates. Short-term interest rates are procyclical while long-term interest rates co-vary little with movements in output over the business cycle. Economic theory suggests that both the level and volatility of interest rates should be tied to economic variables such as income growth and inflation. Simulation results suggest that the volatility of both income growth and money growth accounts for a large portion of the volatility of short-term discount bond prices. However, these same economic variables by themselves are able to account for only a small fraction of the volatility of long-term discount bond prices.

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