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Asset Price Bubbles: A Selective Survey

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Asset Price Bubbles: A Selective Survey [1]

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Abstract

Why do asset price bubbles continue to appear in various markets? This paper provides an overview of recent literature on bubbles, with significant attention given to behavioral models and rational models with frictions. Unlike the standard rational models, the new literature is able to model the common characteristics of historical bubble episodes and offer insights for how bubbles are initiated and sustained, the reasons they burst, and why arbitrage forces do not routinely step in to squash them. The latest U.S. real estate bubble is described in the context of this literature.

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I. INTRODUCTION

The persistent failure of present-value models to explain asset price levels led academic research to introduce the concept of bubbles as a tool to model price deviations from present-value relations. The early literature was dominated by models in which all agents were assumed to be rational and yet a bubble could exist. In many of the more recent papers, the perfect rationality assumption was relaxed, allowing the models to shift the focus to explaining how a bubble may be initiated, under which conditions it would burst, and why arbitrage forces may fail to ensure that prices reflect fundamentals at all times. In light of the recent U.S. real estate bubble, the question of why bubbles are so prevalent is once again a matter of concern of academics and policy makers. This paper surveys the recent literature on asset price bubbles, with significant attention given to behavioral models as well as rational models with incentive problems, market frictions, and non-traditional preferences. For surveys of the earlier literature, see, e.g., Camerer (1989) and Stiglitz (1990).

There are a number of ways to define a bubble. A very straightforward definition is that a bubble is a deviation of the market price from the asset's fundamental value. Value investors specialize in finding and investing in undervalued assets. In contrast, short sellers, who search the market for overvalued assets in order to sell them short, are routinely vilified by governments, the popular press, and, not surprisingly, by the overvalued firms themselves.[1] Trading against an overvaluation involves the additional costs and risks of maintaining a short position, such as the potentially unlimited loss, the risk that the borrowed asset will be called back prematurely, and a commonly charged fee that manifests itself as a low interest rate paid on the margin account; for this reason, a persistent overvaluation is more common than a persistent undervaluation.

A positive or negative mispricing may arise when initial news about a firm's fundamentals moves the stock price up or down and feedback traders buy or sell additional shares in response to past price movement without regard for current valuation, thus continuing the price

[1]England banned short selling for much of the 18th and 19th centuries, Napoleon declared short sellers to be enemies of the state, and many countries today either ban or severely restrict short selling. Short sellers make money precisely when other investors are losing it. Lamont (2004) describes a variety of tactics that firms employ against short sellers. On average, the firms in his sample that started various actions against short sellers ended up losing 42 percent of their market capitalization over the next three years, suggesting that they had indeed been overvalued, just as the short sellers suspected.

trend beyond the value justified by fundamentals.[2] However, because of the potentially nontrivial costs of short selling an overvaluation will be less readily eliminated, making positive bubbles more common. The paper will, therefore, focus predominately on positive price bubbles. We can define a positive bubble occurring when an asset's trading price exceeds the discounted value of expected future cash flows (CF):

$$P_t > E_t\left[\sum_{\tau=t+1}^{\infty}\frac{CF_\tau}{(1+r)^{\tau-t}}\right], \tag{1}$$

where r is the appropriate discount rate.[3] Since it may be difficult to estimate the required compensation for risk, an alternative definition may be used that replaces the discount rate with the risk-free rate, r_f:

$$P_t > E_t\left[\sum_{\tau=t+1}^{\infty}\frac{CF_\tau}{(1+r_f)^{\tau-t}}\right]. \tag{2}$$

When the asset's cash flows are positively correlated with market risk, as is the case for most firms, the required rate of return is strictly greater than the risk-free rate and the discounted-cash-flow formula represents an upper limit of the justifiable range of fair values. Likewise, when it is difficult to forecast future cash flows for a particular asset or firm, an upper bound of forecasted cash flows for other firms in the same industry or asset class may be used.

Over the years, the academic study of bubbles has expanded to explore the effects of perverse incentives and of bounded rationality. The new generation of rational models identifies the incentive to herd and the limited liability compensation structure as pervasive problems that encourage professional money managers to invest in bubbles. Another problem contributing to bubbles is that information intermediaries are not paid directly by investors, and their incentives are not always compatible with reporting negative information. And rather than merely trying to answer under what conditions bubbles may exist in asset prices, behavioral models offer new insights for how a bubble may be initiated, under which conditions it would burst, and why arbitrage forces may fail to ensure that prices reflect fundamentals at all times. Moreover, some models offer the explanation for why many bubble episodes are accompa-

[2] In addition to feedback traders, institutional restrictions may serve to amplify past price movements. For example, when it comes to downward prices movements, many institutions are forced to sell their shares of a stock once the firm's market capitalization falls below the institution's investible universe. This selling pressure, now unrelated to past news, causes a further price decline. In addition, a lower level of institutional ownership is likely to reduce the stock's liquidity, making it even less attractive to investors and forcing the price to drop even further.

[3] We will use the terms "discount rate" and "required rate of return" interchangeably.

nied by high trading volume. The behavioral view of bubbles finds support in experimental studies.

The paper proceeds as follows. After a cursory summary of the most famous bubble episodes and a brief description of the classic model, the paper reviews the new generation of rational and behavioral models of bubbles. The paper concludes with how the insights from these new models help understand the evolution of the recent subprime mortgage bubble.

II. Bubbles through History

This section provides, in chronological order, a brief overview of famous examples of bubbles observed throughout history. This list is, obviously, incomplete, and for a more complete description of bubbles through history the reader can refer to, for example, Kindleberger (2000). Perhaps the earliest known example is the tulip bubble in Holland that started in 1634 and burst in February 1637. Amid the general fascination with rare species of tulips among the Dutch, prices on rare tulip bulbs rose, attracting the attention of speculators. Since the supply of rare bulbs was severely limited in the short run, and demand sky-rocketed due to the influx of speculators, prices rose rapidly amid heavy trading. At the bubble's peak, a single tulip bulb sold for an equivalent of $60,000 today.

The South Sea bubble involved the market price of an English firm called the South Sea Company. This firm had no assets but told investors that it had come up with a strategy to earn enormous profits in the South Seas. During the first half of 1720 the company's stock price rose by over 700 percent, then fell during the second half of 1720 to about 50 percent above what it had been at the start of the year.

The Mississippi bubble refers to the rapid rise and fall in the share price of a company founded by John Law that was initially called Compagnie d'Occident and later renamed Compagnie des Indes, but was always popularly known as the Mississippi Company. The company was based in France and, at its founding in August 1717, was given control over trade between France and its Louisiana and Canadian colonies. In May 1719, John Law also obtained control over trade with China and the East Indies. In effect, the company controlled all trade between France and the rest of the world outside of Europe. Later, the company also purchased the right to mint new coins in France and the right to collect most French taxes. By January 1720, it had become Europe's most successful conglomerate and European investors, who knew little about the remote colony of Mississippi at the time, were excited about the possibility of finding gold and silver there. The company's expansion was financed by issuing shares, the price of which rose dramatically as the company's reach expanded. Share price rose from around 500 livres tournois in January 1719 to 10,000 livres in December 1719. The market became so active that even low-income individuals started buying the company's shares. The trend reversed and stock prices began to fall in January 1720 as investors started selling shares in order to turn capital gains into gold coins. Instead of paying off in gold coins, the company tried to get investors to accept paper money, agreeing to assume that the share price was 10,000 livres. The exchange of shares for paper money caused a runaway inflation that reached a monthly rate of 23 percent. Finally, Law devalued shares in the company in several stages during 1720; by September 1721, the price had dropped to its pre-bubble price of 500 livres.

The United States has experienced many bubbles and crashes, but the most devastating in the last century occurred when the period of fast economic expansion—often referred to as the Roaring Twenties—came to a sudden halt in October 1929.[4] The crash involved the collapse of both stock and real estate prices. As documented by Nicholas and Scherbina (forthcoming), using a hand-collected dataset of transaction prices, by the end of 1932 real estate prices in Manhattan had fallen by 67 percent from the third quarter of 1929 and, unlike stock prices, stayed down for the remainder of the decade. Mortgage lenders potentially suffered large losses, limiting future lending. Moreover, White (2009) argues that the collapse of the housing sector greatly depleted households' wealth, contributing to the severity of the Great Depression.

In the 1980s, Japan experienced a rapid run-up in equity and real estate prices. From 1980 to the peak in 1989, the Japanese stock market rose 373 percent in real terms but fell by 50 percent in the next three years. Land prices followed a similar pattern. They almost tripled in the second half of the 1980s, and at its peak in 1990, the market value of all the land in Japan was four times the land value in the United States. By the end of 1993, Japanese land prices had dropped by almost 50 percent. Some argue that the collapse of the bubble had a lasting effect, slowing down the rate of economic growth up until the present (e.g., Wood (2005)).

[4] Hoyt (1933) describes several cycles of land bubbles that occurred in Chicago before 1933.

The dot-com, or internet, bubble started around 1995. From that time until March 2000, when the bubble started to deflate, there was a rapid growth in the internet sector and related fields, fuelled by the supply of new internet IPOs. The mysterious nature of the new technology added to its allure. The internet-heavy NASDAQ Composite rose from 775.20 in January 1995 to 2,505.89 in January 1999 and more than doubled from this point to its peak of 5,048.62 on March 10, 2000, after which it started declining, reaching a low of 1,314.85 in August 2002. During the bubble period, investment banks responded to the high demand for internet shares by loosening their standards for the types of firms they typically took public. A large fraction of the new internet IPOs never generated any profit; the general thinking was that these firms would initially offer their services for free in order to capture market share and would start generating revenue later. Many of the new companies had the same business model and competed in the same market, ensuring that a large fraction of them would eventually fail.

Yu and Xiong (2011) document that in the 2005-2008 period of their study, bubbles were frequently observed in put warrants with long maturities, ranging between six months and two years, issued on 18 Chinese companies. These warrants were all but sure to expire worthless, yet they traded in high volumes and at inflated prices throughout the contract lives. What is remarkable about such bubbles is that they were observed on assets with finite maturities, which meant that investors knew with certainty that prices would converge to the warrants' fundamental prices by the contracts' expiration dates. Yu and Xiong (2011) argue that the combination of (a) differences of opinion about the potential trajectory of the underlying asset and (b) the legal ban on short selling any financial securities in China, including warrants, is to blame for the observed bubbles.

Reinhart and Rogoff (2009) detail many instances of bubbles that occurred in emerging markets. They point out that many bubbles are instigated by cheap credit. Consistent with the U.S. real estate experience during the Great Depression documented by Nicholas and Scherbina (forthcoming), Reinhart and Rogoff (2009) also observe that real estate prices around the world take longer to recover from a crash than equity prices.

These examples illustrate that bubbles can burst (as was the case with the stock market crash in October 1929)[5] or deflate gradually (as was the case with the dot-com bubble). Even then,

[5]Some studies dispute that there was a stock market bubble in the United States in the 1920s (e.g., Siegel (2003)).

evidence indicates that the period over which a bubble deflates is generally much shorter than the period of its build-up. Most likely, speculative attacks or regulatory changes lead to a quicker deflation than sentiment reversals, which are likely to be more gradual.

III. Rational Models

In this section, we will provide a brief overview of theoretical and empirical work on classic rational bubbles before moving on to the new generation of rational models that focus on the effect of perverse incentives and to behavioral models that assume bounded rationality for at least one group of agents.

The literature on rational bubbles derives conditions under which bubbles can occur when all agents are perfectly rational. One powerful conclusion is that when all agents are perfectly rational and all information is common knowledge, bubbles can exist for an infinitely-lived asset if the bubble's rate of growth is equal to the discount rate. To see this, suppose that the price of the asset, P_t, includes a bubble component, B_t, in addition to the fundamental (fair) value component, P_t^{fair}; that is, $P_t = P_t^{fair} + B_t$. Therefore, for an infinitely-lived asset, the total price is equal to the sum of the discounted cash flows (which represents the fair value) and the present value of the future bubble component:

$$P_t = E_t\left[\sum_{\tau=t+1}^{\infty}\frac{CF_\tau}{(1+r)^{\tau-t}}\right] + \lim_{T\to\infty} E_t\left[\frac{B_T}{(1+r)^{T-t}}\right]. \tag{3}$$

Let us assume that the bubble grows at a rate r_B, such that $B_T = B_t(1+r_B)^{T-t}$ and suppose further that this rate of growth is lower than the discount rate: $r_B < r$. Then the present value of the bubble is zero and it cannot exist. Now suppose that the bubble's rate of growth is higher than the discount rate: $r_B > r$. In this case, its present value is infinite and, again, the bubble cannot exist. The bubble component of the price can exist without bursting only if its expected rate of growth is exactly equal to the asset's required rate of return: $r_B = r$.[6] This condition allows us to eliminate many potential rational bubbles. In particular, it implies that bubbles cannot be present whenever there is an upper bound for the asset price. For example, there is an upper price limit for assets with close substitutes, since consumers will switch to

[6]Fiat money is an example of an infinitely-lived asset with a bubble, since the intrinsic value of fiat money is zero.

a substitute whenever the asset becomes too expensive. Also, if an asset's required rate of return is higher than the rate of growth of the economy, a bubble in this asset cannot exist since it would outgrow the aggregate wealth of the economy.

Now, suppose that an asset is *not* infinitely-lived. Then the bubble will surely burst at the end of the asset's life, T, when the asset is liquidated at its fair value. But if it is common knowledge among all agents that the bubble is sure to burst at time T, why would it not burst at time $T-1$, since at that time no one would be willing to buy the asset at an inflated price. By the same logic, the bubble cannot exist at time $T-2$, $T-3$, and so on, up until the present. This backward-induction argument leads to the conclusion that a bubble cannot exist for a finitely-lived asset.

Allen, Morris, and Postlewaite (1993), however, show that, when common knowledge is absent and short sale constraints bind, a bubble *can* exist for a finitely-lived asset. In their model, agents are asymmetrically informed about the terminal dividend on the asset and cannot sell the asset short. A bubble in this setting is defined as a state in which all agents know that the asset is overvalued, but they do not know that other agents know it as well (i.e., there is a lack of common knowledge that was assumed in the previous backward-induction reasoning). They cannot learn the other agents' private information from market prices, which, due to the complicated information structure, is not fully revealed until the final trading period. Agents are willing to hold an overvalued asset because they hope to resell it at an even higher price to another agent who may value the asset highly in certain states as a result of his particular information structure. By assuming that ex-ante asset allocations are inefficient, this model gets around the "no-trade theorem" of Milgrom and Stokey (1982), stating that agents will not trade, no matter what private information they might receive, if their ex-ante asset allocations are efficient (the "no trade theorem" will be described in more detail later).[7]

Let us now return to an infinitely-lived asset. If the asset's price contains a bubble component, then, as T goes to infinity, the bubble component of the price grows infinitely large and the price-to-cash-flow ratio approaches infinity ($\frac{B_T}{P_T} \to 1$ and $\frac{P_T}{CF_T} \to \infty$ as $T \to \infty$). Bothered by this implication of traditional bubble models, Froot and Obstfeld (1991) propose a special case of rational bubbles, in which a bubble is not a function of time but rather a function of the fundamentals. The rationale is that investors might be bad at forecasting the stream of

[7] Conlon (2004) is able to achieve an equilibrium in which bubbles can exist with a simpler setting and without assuming a lack of common knowledge.

future cash flows and, therefore, condition their valuations too much on the current realization of cash flows. The authors refer to this class of rational bubbles as "intrinsic bubbles" because they are deterministic functions of the fundamentals alone.

Re-labeling slightly the authors' notation and translating their formulas from continuous to discrete time in order to be consistent with our earlier exposition, the bubble component can be expressed as a function of the current cash flow:

$$B(CF_t) = cCF_t^{\lambda}, \tag{4}$$

where c and λ are constants. The exponential term λ needs to be set to satisfy the rational bubble requirement that the bubble component grows at the asset's required rate of return: $B_{t+1} = B_t(1+r)$. Assuming that the expected cash-flow growth rate is equal to g, next period's bubble component will, therefore, equal $B_{t+1} = cCF_{t+1}^{\lambda} = cCF_t(1+g)^{\lambda}$. Hence, the exponential term λ has to be set to satisfy the condition: $1+r = (1+g)^{\lambda}$.

Assuming a constant discount rate and a constant cash-flow growth rate, the fair-value component of the price can be expressed using the Gordon growth formula: $P_t^{fair} = \frac{CF_t(1+g)}{r-g}$. Therefore, the market price can be described as the sum of the fair value of the asset and the intrinsic bubble component:

$$P_t = \frac{CF_t(1+g)}{r-g} + cCF_t^{\lambda}. \tag{5}$$

Empirically, this specification can be tested with the following statistical model for the price-to-cash-flow ratio:

$$\frac{P_t}{CF_t} = c_0 + cCF_t^{\lambda-1} + \eta_t, \tag{6}$$

where the error term, η_t, could capture the fad component of prices—a shock to the demand for a stock that is unrelated to fundamentals. Under the assumption of no bubbles, the price-to-cash-flow ratio should be constant and, therefore, the last two terms should be zero. However, in the data, the price-to-cash-flow ratio is increasing in time. Using data for the S&P 500 index over the 1900-1988 time period and aggregate dividends in place of cash flows, Froot and Obstfeld (1991) estimate the intrinsic bubble component in prices (determined by both c and λ) to be significantly positive, thus rejecting the non-bubble hypothesis. Moreover, using dividends in place of cash flows, the authors estimate that, as of 1988, the non-bubble component of the S&P 500 price was just under 50 percent of the index value.[8]

[8]Extending the dataset to December 31, 2010 and using aggregate dividends in place of cash flows, we estimate the bubble to be 67.84 percent of the S&P 500 index price.

The intrinsic specification of a bubble offers an advantage in that a bubble does not have to explode relative to the fair value as time goes on. The bubble can even disappear entirely when the stochastic cash flow falls to zero, imitating a burst of the bubble. Overall, this modeling choice is more closely aligned with the empirical observations of bubbles and it also explains the seemingly puzzling empirical facts that (a) stock prices are more volatile than dividends and (b) prices overreact to dividend changes.

IV. The New Generation of Rational Models

The new generation of rational models investigate how incentives, market frictions, and non-standard preferences may play a role in creating and sustaining bubbles. The broad areas are non-standard preferences and incentive structures that cause agents to herd in their investment decisions; limited liability, which induces a preference for riding bubbles; and perverse incentives of key market players whose role is to disseminate correct information to market participants during bubble episodes.

(a) Herding. Herding in investment decisions by investors and money managers is shown to be an important mechanism for sustaining and propagating bubbles. A herding outcome can be achieved using a variety of settings.

DeMarzo, Kaniel, and Kremer (2008) introduce non-standard preferences to explain how bubbles can grow once formed. They consider a relative wealth model, in which an individual agent's utility depends not only on her absolute wealth but also on her relative wealth (i.e., the agents exhibit the so-called "keeping up with the Joneses" preferences). If that dependence is strong, agents will prefer to participate in bubbles as long as other agents do so in order not to fall too far behind their peers' wealth during the bubble's upside. The authors show that the relative wealth effects are necessary in order to sustain bubbles.

In the model of Scharfstein and Stein (1990), managers' herding behavior is a direct outcome of the imposed incentive structure. The model assumes that the managers' only incentive is to maximize their reputation in the labor market. Managers receive noisy signals about the value of an investment asset. The signals of "smart" managers are correlated with the truth, and, by this, with each other. The signals of "dumb" managers are pure noise. Yet, a smart manager may earn a low return acting on an informative signal because of the unpredictable component of the investment payoff, while dumb managers may outperform acting on a worthless signal because of luck. Therefore, the labor market updates its beliefs about a manager's skill not only based on his investment performance but also based on whether his investment choice was similar to that of other managers. The authors show that in the world with two managers, there exists an equilibrium in which the second mover always mimics the investment choice of the first mover regardless of his own private signal.[9]

Shiller (2002) provides another reason for why money managers would prefer to herd in their investment decisions. Due to limited time and resources, money managers cannot thoroughly investigate every potential investment. A money manager observing her peers investing in a particular asset may conclude that their decision is based on compelling private information and may then choose to add that asset to her portfolio.[10]

Betting against the herd is very costly while the bubble is on the rise; the managers who cannot keep up with their peers suffer fund outflows as investors reallocate funds to the more successful managers. As in the previously discussed model, reputational penalties are more severe when the manager is wrong at the time when the rest of the investment community is right than when everyone is wrong. Finally, being compensated based on relative performance is another powerful reason for mutual fund managers to mimic the others. These additional considerations further explain the decision to herd in investment decisions (e.g., Lux (1995)).[11]

According to evidence presented in Lamont and Frazzini (2008), mutual funds are, to a certain extent, forced by investors to invest in high-sentiment stocks and industries and thus perpetuate bubbles. The authors show that investors dynamically allocate money to funds that invest in high-sentiment stocks. For example, during the dot-com bubble, investors greatly favored funds that invested in high-tech stocks. As a result, sentiment-driven investors earn

[9] The herding incentive is relaxed if, in addition to caring about reputation, managers also care about their investment return.

[10] In a popular account of the recent U.S. real estate bubble, Lewis (2010) describes a few of the very small number of hedge fund managers who realized that mortgage-backed securities contained a bubble; these managers were all outsiders with respect to Wall Street's investment community, which provided them with sufficient separation to be able to think independently.

[11] See Hirshleifer and Teoh (2003) for a review of the literature on herding.

sub-par returns over the subsequent few years. The authors call this the “dumb money” phenomenon.

The role that popular media play in directing the attention of potential investors to a particular asset has not been extensively studied in the current literature, although it could be also important in perpetuating bubbles. News stories often focus on assets and industries with good past performance. Even if investors might be skeptical that this performance will continue, news stories signal the existence of others who have a positive outlook and thereby encourage investment in that asset class.

(b) Limited liability. Most market players enjoy limited liability. With limited downside, an agent benefits from a rising bubble but does not suffer to an equal extent when the bubble bursts.

Allen and Gorton (1993) consider the role of limited liability in the willingness of money managers to ride bubbles. They present a model with two types of managers—skilled and unskilled. Skilled managers can correctly identify undervalued investments and make a profit. Unskilled managers lack this ability and instead invest in bubbles, hoping that they can make money while the price is still rising and sell it before the crash. However, even if the fund suffers losses in the crash, the limited liability structure limits the downside. As long as unskilled managers make a profit, they can pool with the skilled managers in equilibrium and acquire money to manage.

In the model of Allen and Gale (2000), limited liability induces bubbles in risky assets. Borrowers obtain investment capital from banks. Because of limited liability, the borrowers’ downside risk is limited, but they get to keep the upside of their investment. This convex payoff structure generates a preference for risk and for riding bubbles. The borrowers’ preference for risky assets initiates a bubble, and the magnitude of the bubble increases with the riskiness of the asset.

(c) Perverse incentives. Every crisis brings to light misaligned incentives of important market players, whose role would be to supply truthful information and to sound an alarm about a bubble. However, equity analysts hold back negative views about the firms they cover, rating agencies are reluctant to issue low bond ratings, and accounting auditors overlook questionable reporting choices. Furthermore, when a bubble arises, many market players see an increase in profits due to higher trading volume, larger investment banking proceeds on the increased IPO and SEO activity, and the investment profits generated on the bubble upside. The downside risk is limited by limited liability of equity holders, firm executives, and the implicit government guarantees to bail out the financial sector in the event of a large-scale collapse.

Equity analysts' incentives are not perfectly aligned with telling the truth. In the aftermath of the collapse of the dot-com bubble, it was revealed that analysts frequently issued "strong buy" recommendations while privately holding pessimistic views about the firm. The reasons are threefold. First, analysts fear that, by being negative about a firm, they may lose favor with its management and be shut out of future communication.[12] Second, despite the so-called "Chinese Wall," which is supposed to separate the corporate-advisory and trading arms of a firm, analysts stand to profit from the investment banking business they help generate by issuing favorable stock recommendations. Third, because sell-side analysts are paid a fraction of the trading commissions that their analysis brings to their employers' trading desks—and due to the widespread reluctance to sell short—it is easier to generate trade by issuing "buy" rather than "sell" recommendations. Analysts with negative views may prefer to keep quiet or drop coverage altogether. Consistently, Scherbina (2008) shows that when a large fraction of analysts keeps quiet, future returns are low.

Rating agencies and accounting auditors are paid by firms rather than by investors and are understandably reluctant to cause trouble for their clients and risk losing business. An agency's choice of whether or not to perform its duties honestly is determined by the trade-off between near-term profits and the long-term payoff of preserving its own reputation. Many firms choose the short-term approach to profits; rating agencies often assign overly positive bond ratings and auditors overlook accounting irregularities. Even if it may be in the best interest of firms' shareholders to adopt a long-term approach, the executives are typically more short-term-oriented due to compensation schemes that reward current profits. Better corporate governance mechanisms are essential for reducing the wedge between the interests of firms' shareholders and executives.

[12]Regulation Fair Disclosure, adopted in 2000 in response to analyst scandals in the United States, is designed to prevent selective information disclosure but has not been entirely effective.

V. Behavioral Models

In this section, we provide a brief overview of more recent models that depart from the assumption of perfect rationality. The unifying feature behind this class of models is that at least one group of agents is assumed to be irrational. Behavioral models capable of generating bubbles can be roughly classified into four categories.

(a) Model 1: Differences of opinion and short sale constraints. This class of models considers a setting with investor disagreement and short sale constraints. These models show that if optimistic investors are boundedly rational, or simply dogmatic about their beliefs, they will fail to take into account that other agents in the economy may have more pessimistic views about an asset but cannot sell it due to short sale constraints. The resulting market price of the asset will be too high relative to the fair value, which is probably in between the two sets of beliefs. The price will adjust down to the fundamental value either when the uncertainty about the asset's value is resolved and investors' beliefs converge to a common view or when the short sale constraints are relaxed, allowing pessimistic investors to sell the overvalued asset. Miller (1977) provides a simple static model for overvaluation generated by disagreement and short sale constraints. Scheinkman and Xiong (2003), building on the previously mentioned model of Harrison and Kreps (1978), present a dynamic continuous time model that incorporates Miller's intuition. The dynamic setting allows this model to achieve even higher levels of overpricing because agents will choose to pay a premium over their valuations today in hope of reselling the asset at an even higher price tomorrow.

A number of empirical studies confirm the validity of this model. For example, using dispersion in analyst earnings forecasts as a proxy for disagreement, Diether, Malloy, and Scherbina (2002) show that stocks with high forecast dispersion seem to be overpriced—they underperform otherwise similar stocks in the future. In another test of the model, Chen, Hong, and Stein (2001) use the breadth of mutual fund ownership as a proxy for disagreement, conjecturing that when a stock is owned by a large cross-section of mutual funds, the disagreement about the stock value is lower than when a stock is owned by just a few funds. The authors find that stocks owned by few mutual funds are overvalued, confirming the model.

(b) Model 2: Feedback trading. This class of models generates bubbles by assuming that a group of traders base their trading demands solely on past price movements. Feedback trading mechanisms are chronicled in many accounts of asset price bubbles as well as in a large number of theoretical models; these mechanisms allow bubbles to grow for a period of time before the eventual collapse. A simple description is as follows: In response to positive news, an asset experiences a high initial return. This is noticed by a group of feedback traders who assume that the high return will continue and, therefore, buy the asset, pushing prices above fundamentals. The further price increase attracts additional feedback traders, who also buy the asset and push prices even higher, thereby attracting subsequent feedback traders, and so on. The price will keep rising as long as more capital is being invested. Once the rate of new capital inflow slows down, so does the rate of price growth; at this point, capital might start flowing out, causing the bubble to deflate.

Shiller (2002) argues that news media attention amplifies feedback-trading tendencies in the market. As more investors become interested in an asset, news media expand coverage, attracting attention from more potential investors. These then buy the asset and drive up prices, thereby attracting more news media attention, and so on. Consistent with Shiller's hypothesis, Bhattacharya and others (2009) show that news media paid disproportionately more attention to internet stocks than non-internet stocks during the internet-bubble period. The news stories were generally positive, but, following the bubble collapse, turned negative.

Feedback models give bubbles the flavor of a Ponzi scheme: The growth of a bubble is sustained by the inflow of new money and the investors who get in on the bubble early and get out before it deflates stand to profit at the expense of the latecomers. An example of a model that contains feedback traders is Hong and Stein (1999). The model includes two groups of traders—news watchers and momentum traders (another label for feedback traders). Neither group is completely rational. News watchers observe private signals about the asset fundamentals but do not condition on past prices. Momentum traders do not observe the signals about the fundamentals and condition their trading decisions entirely on past price changes. New information diffuses slowly across the population of news watchers, and, therefore, prices react gradually to new information. Since prices initially underreact to news, the strategy of conditioning trades on past price changes could be profitable in expectation. However, because news watchers cannot tell whether they are trading early or late in the news cycle, prices end up overshooting fundamentals.

The model of DeLong and others (1990) is slightly different in that it considers what would happen if rational speculators are introduced into a similar setup. The model contains three types of traders: positive feedback traders, who, like the momentum traders in the previous model, base their trading demands exclusively on past price changes; passive investors, whose demand depends only on an asset's price relative to its fundamental value; and informed rational speculators, who trade in response to news about fundamentals and in anticipation of future price movements. A frequent argument against behavioral models is that the presence of rational investors in the market should stabilize prices. Remarkably, in this model, introducing rational speculators destabilizes prices and causes them to overshoot the assets' fundamental values. Speculators know that feedback traders will base their future demands on the magnitude of the past price change. In order to generate a larger price change, the speculators form higher trading demands in response to a private signal than they would in the absence of feedback traders. When feedback traders enter the market in the next period, the speculators reverse their trades, earning a profit at the feedback traders' expense.[13] This model produces a troubling prediction that rational traders will not trade *against* the anticipated future mispricing that is sure to occur as a result of feedback traders' overreaction to past price changes; instead, rational traders will trade *with* the mispricing, buying more of the asset today in order to resell it at inflated prices tomorrow. (The tendency of rational arbitrageurs to jump on the bandwagon rather than trade against mispricing will be discussed again in the context of the model of Abreu and Brunnermeier (2003).)

(c) Model 3: Biased self-attribution. In this model, a representative investor suffers from *biased self-attribution*. A phenomenon extensively documented in psychology research, biased self-attribution leads people to take into account signals that confirm their beliefs and dismiss as noise signals that contradict their beliefs. The model, introduced by Daniel, Hirshleifer, and Subrahmanyam (1998), is set up in the following way.[14] Investors form their initial beliefs by receiving a noisy private signal about the value of a security. They may have arrived at this private signal, for example, by researching the security. Subsequently, investors receive a noisy public signal, which, for the ease of exposition, is assumed to be almost pure noise and therefore should be ignored. However, since investors suffer from biased self-

[13]In contrast to the model of Hong and Stein (1999), in this model, feedback traders always lose money. The other difference is that due to the short horizon of the model, prices do not overshoot their fundamentals in the absence of speculators, but they would if the number of periods were larger because feedback traders would continue to trade on past price movements, pushing prices past their fair values.

[14]To simply the calculations, the set of investors who suffer from biased self-attribution are assumed to be risk-neutral; therefore, they set the equilibrium price.

attribution, they grow overconfident in their belief after the public signal confirms their private information and further revise their valuation in the direction of their private signal. When the public signal contradicts the investors' private information, it is appropriately ignored and the price remains unchanged. Therefore, public signals, in expectation, lead to price movements in the same direction as the initial price response to the private signal. These subsequent price moves are not justified by fundamentals and represent a bubble. The bubble starts to deflate after the accumulated public signals force investors to eventually grow less confident in their private signal.

(d) Model 4: Representativeness heuristic. The fourth model combines two behavioral phenomena, the *representativeness heuristic* and the *conservatism bias*. Both phenomena were previously documented in psychology and represent deviations from optimal Bayesian information processing. Representativeness heuristic leads investors to put too much weight on attention-grabbing ("strong") news, which causes overreaction. In contrast, conservatism bias captures investors' tendency to be too slow to revise their models, such that they underweight relevant but non-attention-grabbing (routine) evidence, which causes underreaction. Barberis, Shleifer, and Vishny (1998) formulate a parsimonious model loosely based on these two distinct psychological biases. They assume that earnings follow a random walk process, and, therefore, the best forecast for the future earnings stream is the most recent earnings realization. Instead of using a random walk model, investors mistakenly assume that the earnings process is captured by either a mean-reversion model or by a trending model. The first model assumes that earnings innovations will be reversed, the second model assumes that future earnings innovations will be of the same sign as the past innovations (e.g., a growth company will continue to grow in the future). The investors further assume that there is a small probability that the earnings process can switch between trending and mean-reversing. In this setting, the salient signal that leads investors to adopt the trending rather than the mean-reversion model of earnings is the repeated realization of earnings innovations of the same sign over several consecutive periods. The repeated realization of earnings surprises of the same sign occur purely by chance and have no relevance for the future earnings forecast. However, investors mistakenly see a pattern and extrapolate it into the future, thus overreacting to the information contained in the past sequence of earnings.[15] In the future, after the predicted earnings trend fails to materialize, the investors are forced to abandon their

[15] In contrast, investors operating with a particular model in mind, typically underreact to the information contained in the most recent earnings realization.

model, and prices revert to fundamentals.[16] In this setting, a positive bubble will arise purely by chance, for example, if a series of unexpected good outcomes have occurred, causing investors to over-extrapolate from the past trend. Investors make a mistake by ignoring the low unconditional probability that any company can grow or shrink for long periods of time. The mispricing will persist until an accumulation of signals forces investors to switch from the trending to the mean-reverting model of earnings.

While model 1 can generate only positive bubbles, models 2-4 can also generate negative bubbles. The difference between models 3 and 4 is that, while the initial positive autocorrelation in returns always represents an overreaction in model 3, depending on the parameters, it may represent an initial underreaction followed by an overreaction in model 4. Models 1, 3, and 4 imply that bubbles are more likely to arise in hard-to-value assets, for which judgement is important in forming valuations.

Unlike traditional models that place the emphasis on explaining how a bubble can exist when all investors are perfectly rational, behavioral models use the freedom of departing from perfect rationality to shed light on the conditions that cause bubbles to rise and deflate. Despite departing from perfect rationality, behavioral models aim to be disciplined in basing their assumptions on empirical facts and evidence documented in psychology. They also attempt to be comprehensive in their approach by trying to capture other known return anomalies. For example, models 2-4 offer an explanation for why prices may overreact to news about fundamentals and are able to replicate the short-term return continuation of Jegadeesh and Titman (1993) and the long-run return reversal of DeBondt and Thaler (1985). Moreover, models 2-4 can explain the post-announcement price drift.

The behavioral view of bubbles finds support in experimental studies. These studies set up artificial markets with finitely-lived assets and observe that price bubbles arise frequently. The presence of bubbles is often attributed to the lack of common knowledge of rationality among traders. Traders expect bubbles to arise because they believe that other traders may be irrational. Consequently, optimistic media stories and analyst reports may help create bubbles not because investors believe these views but because the optimistic stories may indicate the existence of other investors who do, destroying the common knowledge of rationality.

[16]When the mean-reversion model is used, investors instead underreact to the information in the current earnings realization, mistakenly thinking that the recent earnings innovation will be reversed in the future.

A. How are Bubbles Initiated?

Diba and Grossman (1987) point out that in traditional rational models, which were discussed earlier, a bubble cannot be created but must already be present when the asset starts trading (again, consider the case of fiat money, where the intrinsic value of the asset is zero but it trades at a strictly positive price). In the behavioral models, a bubble may arise when prices overreact to a potentially informative signal about fundamentals.

Historically, most bubbles have a compelling and sensible story behind them. For example, the dot-com bubble fed on the argument that the new technology would bring great improvements in productivity; similar lines of reasoning were offered during the past railroad and electricity booms. Land-price bubbles were often justified by the logic that an ever-growing population combined with a limited supply of land is sure to make land scarce. During the recent U.S. real estate bubble, the frequently heard argument was that real estate prices would permanently increase because securitization would allow to diversify the idiosyncratic risk of real estate.

An initial positive shock to the fundamentals may be further amplified in asset prices via the "financial accelerator" mechanism described by Bernanke, Gertler, and Gilchrist (1999). The authors propose a model with credit market frictions, in which higher-valued firms that can post a larger collateral will borrow at a lower cost. Hence, any value-increasing development, such as, for example, a technological breakthrough, would reduce firms' cost of borrowing. This will stimulate investment spending, and the increase in investment may, in turn, lead to further increases in cash flows and asset prices, inducing an additional feedback effect on investment, and so forth.

Brunnermeier and Julliard (2008) argue that house price run-ups are frequently initiated by "money illusion." This term was coined by John Maynard Keynes and refers to investors' tendency to think of money in nominal rather than real terms. Agents suffering from money illusion make their rent-versus-buy decision by comparing the current monthly rent with a fixed-nominal-interest-rate monthly mortgage payment, failing to take into account that rents will increase with inflation while mortgage payments will remain constant for the duration of the loan. Consider, for example, a scenario in which inflation is expected to be high for the duration of the mortgage loan. The schedule of nominal mortgage payments will take into account the high expected inflation, making the initial mortgage payment higher than the initial rent payment for a comparable property. However, an agent prone to money illusion will fail to foresee that rent payments will increase over the time-span of the mortgage in order to keep up with inflation. She would, therefore, choose renting over buying, which would push house prices down. On the other hand, when inflation expectations fall, the relative attractiveness of buying will increase, pushing house prices up.

Put formally, the current house price, P_t, should be equal to the discounted value of future *real* rent payments for a comparable property, $Rent_\tau$:

$$V_t = E_t\left[\sum_{\tau=t+1}^{\infty} \frac{Rent_\tau}{\left(1+r_\tau^{real}\right)^\tau}\right], \tag{7}$$

where r_τ^{real} is the expected real discount rate.[17] Assuming that real rent payments and the real discount rate are constant over time, the price-to-rent ratio should equal the inverse of the real discount rate: $V/Rent = \frac{1}{r^{real}}$. If agents suffer from money illusion, they will mistakenly discount the stream of future rent payments with the *nominal* rather than the *real* rate, which would imply that the price-to-rent ratio will equal the inverse of the nominal discount rate: $V/Rent = \frac{1}{r^{nom}}$. Since $r^{nom} = r^{real} + inflation$, the observed price-to-rent ratio will be decreasing in expected inflation. Consequently, an unexpected decrease in inflation expectations will lead to an initial increase in house prices.

The data seem to support the money illusion hypothesis for real estate markets: Brunnermeier and Julliard (2008) show that changes in price-to-rent ratios are negatively related to changes in expected inflation but not to changes in real interest rates. Attracted by the initial price increase, feedback traders may continue purchasing and re-selling housing assets, leading to a continuation of price increases.[18] Indeed, Case and Shiller (1989) document price momentum (or the continuation of past returns) in real estate prices, indicating a departure from market efficiency.

Hong, Scheinkman, and Xiong (2008) present a theory for how bubbles may arise in new technologies. It has been previously discussed that one type of behavioral setting that generates bubbles is investor disagreement in the presence of short sale constraints. The authors set out to model how investor disagreement could arise, initiating a bubble. Their model includes

[17] This formula ignores real estate taxes, depreciation, maintenance costs, and the tax benefit of ownership, which could be easily added in.

[18] Consistently, Hayunga and Lung (2011) show that high house price-to-rent ratios are associated with high turnover, measured as the number of house sales to total housing inventory.

two sets of advisors who make stock recommendations to uninformed investors. The first set of advisors are those who understand the revolutionary effect of a new technology and assign it a higher valuation than do the second set of advisors, who fail to understand the potential of the new technology. Advisors in the first set purposely exaggerate the extent of their optimism in order to differentiate themselves from the second set of advisors who try to mimic them. When at least some investors fail to take into account the incentives of the advisors in the first set to inflate their assessments, a pricing bubble arises.

In emerging markets, expansion of credit, frequently set off by financial liberalization, is another frequent starting point of bubbles. Many instances of such bubbles are described in Reinhart and Rogoff (2009).

B. Why do Bubbles Burst or Deflate?

Model 1 predicts that a bubble will burst when the uncertainty about the asset value is resolved or when short sale constraints become less binding. Consistently, Scherbina (2008) shows that, for stocks with high levels of analyst disagreement about future earnings, the largest price declines are observed around earnings announcements, when much of the uncertainty about future cash flows is resolved. Additional corroborating evidence is offered by Ofek and Richardson (2003), who trace the end of the internet bubble to the expiration of the lock-up provisions on many of the internet IPOs.[19] The authors point out that the internet bubble was largely driven by an overvaluation of many internet IPOs during the bubble period.

Between 80 percent and 85 percent of the shares of these new internet IPOs were held by insiders, venture capitalists, and angel investors[20] who were restricted from selling their holdings by lock-up provisions. Besides severely limiting the number of shares potentially available to be borrowed and sold short, these restrictions also prevented firm insiders, who were likely better informed, from selling their shares and correcting the overvaluation. The authors show that many of the lock-up provisions expired between October 1999 and April 2000,

[19]Underwriters generally require that existing stockholders do not sell their shares for a certain time period after the IPO (with 180 days being standard). The stated purpose of this restriction is to prevent flooding the market with additional shares before the shares issued during the IPO are absorbed.
[20]An angel investor is a wealthy individual who provides capital in the early stages of a start-up.

such that an amount of almost $300 billion in shares was unlocked in a short period. The sudden increase in the number of unlocked shares coincided with the fall of the Morgan Stanley internet index from 1,030 on March 1, 2000, to 430 on April 30, 2000.

According to model 2, a bubble will deflate when the supply of new capital is exhausted. In order to keep growing, a bubble needs an inflow of new investment capital. As the inflow of new capital slows down, prices begin to flatten out and, as a result, the initially optimistic sentiment eventually reverses, causing the bubble to deflate. Of course, it is difficult to predict the reversal of sentiment. If it is linked to the slowing of the bubble's growth, it will coincide with the exhaustion of the supply of new investors. Indeed, there is some evidence that bubbles burst soon after a large fraction of non-sophisticated market participants —such as households—start investing in the overpriced asset. Historical accounts indicate that the end of the tulip, South Sea, and Mississippi bubbles were marked by a widespread participation of poor households. Continuing with this logic, bubbles caused by a sudden expansion of credit will deflate when credit tightens, which happened in Japan in 1990, precipitating the collapse in the Japanese equity and real estate markets. Governments may tighten credit for policy reasons—for example, by limiting the inflow of foreign capital—or with the direct intent to burst a bubble. Other ways that governments have tried to burst bubbles are, for instance, by increasing capital gains taxes or imposing transactions taxes. These measures will decrease trading and help deflate bubbles. For example, on May 30, 2007, China tripled the security transactions tax, resulting in lower market prices.

Models 1 and 2 both imply that bubbles will deflate when a sufficient supply of the bubble asset is added to the market (via new housing construction, IPOs, SEO, etc.). For that reason, Glaeser, Gyourko, and Saiz (2008) argue that real estate bubbles will be shorter-lived in areas with more elastic new housing supply.[21]

In models 3 and 4, a bubble will deflate when the positive sentiment is reversed. Moreover, in model 4, a bubble could burst following a "strong" negative signal. For example, Nicholas and Scherbina (forthcoming) show that real estate prices started to decline in the third quarter of 1929, roughly coinciding with the stock market crash. Even though the stock market crash is likely not directly relevant for real estate valuations, it may have served as a "strong" signal against the positive sentiment about investments in any asset class.

[21] See also the model of Hong, Scheinkman, and Xiong (2008) relating the size of equity bubbles to the supply of tradeable shares.

Bubbles on finitely-lived assets are sure to burst before the asset's final trading day. For example, in the case of the Chinese warrants bubbles, the warrants' expiration dates were known in advance and it was common knowledge that the bubbles would deflate on or before that date. Yu and Xiong (2011) observe that the bubbles did not burst suddenly on the last day of trading, but deflated gradually, with price decreases accelerating six days before the option expiration; this period was also characterized by heavy trading.

Finally, a bubble will burst if arbitrageurs attack it by selling short a sufficient amount of the overvalued asset.

C. Trading Volume

Bubbles are frequently accompanied by abnormally high trading volume.[22] Traditional asset pricing models have trouble explaining not only abnormally high trading volume but the existence of trading in general. The "no-trade theorem" of Milgrom and Stokey (1982) states that, in the absence of portfolio rebalancing needs, there will be no trading, since if someone wants to trade, other agents will rationally assume that the decision is prompted by private information and will therefore refuse to take the other side of the trade. In order to explain trading, rational models introduce liquidity traders who need to trade due to exogenous shocks. These traders, on average, lose money to the informed traders. Similarly, a decision to trade can be modeled by ex-ante inefficient asset allocations. However, even with these additional assumptions, traditional models are unable to explain the changing patterns of trading volume associated with the different stages of a bubble's life cycle.

High trading volume is a natural outcome of model 2. According to the model, trading volume evolves as follows. In the early stage of a bubble that precedes the speculative frenzy, trading volume is relatively low. It drastically increases during the middle stage of a bubble's life cycle, as the past price increases begin to be noticed by a wide cross-section of investors who then engage in speculative or feedback trading. The demand for the asset at this time is very high. In order to meet this demand, additional supply is often provided by means of

[22] For example, during the dot-com bubble, the price run-up of internet stocks was accompanied by heavy trading. Hong and Stein (2007) document that monthly turnover of internet stocks exceeded 50 percent in 12 out of 24 months preceding the internet index peak in February 2000, while the average turnover for non-internet stocks was in the range of only 10-15 percent. After the internet index decline, the turnover of internet stocks dropped to the average market level.

IPOs, secondary equity offerings (SEOs), new start-ups, and, in the case of real estate bubbles, by construction of new housing. As the rate of inflow of new capital starts to drop, the speed of the bubble's growth decreases, potentially leading to a decrease in trading volume. In the later stages of a bubble, fraud is more frequent as investors try to get rid of the overvalued asset by preserving an illusion of rising prices.[23] Subsequently, the bubble starts to deflate. The interaction of returns and trading volume may, thus, offer information about the life-cycle stage of a bubble. Although it does not specifically focus on bubbles, a study by Lee and Swaminathan (2000) empirically documents the interaction between trading volume, price momentum, and return reversals.

While the static version of model 1 offers no relation between bubbles and trading volume, Baker and Stein (2004) extend the model to have stock market bubbles coincide with high liquidity and trading volume. They assume that the irrational investors in the model, besides being dogmatic about their beliefs, underreact to the information contained in the order flow. When irrational investors are pessimistic about the stock market, the short sale constraint keeps them out of trading. At these times, valuation levels are relatively low, and so are liquidity and trading volume. At the times when the irrational investors are optimistic, they trade frequently and bid up stock market valuation levels. Since the irrational investors underreact to the order flow information, liquidity, and, hence, trading volume are high at the times when the market is overvalued. The model thus argues that trading volume and liquidity can proxy for investor sentiment about the stock market.[24]

The aforementioned extension of the static version of model 1 into a dynamic setting by Scheinkman and Xiong (2003) shows that bubbles should coincide with active trading. The model contains two groups of agents, who each receive signals about the unobservable asset fundamentals. Each set of agents is overconfident about their own signal, overestimating its precision. The authors derive an equilibrium price process, which at any point of time is equal to the expected present value of future dividends from the viewpoint of the current owner plus the value of the option to resell the asset in the future to the other group of traders at a higher price. The value of the resale option represents a bubble in this setting. The bubble increases in the degree of the agents' overconfidence and in how quickly opinions can evolve but decreases in trading costs. The latter property predicts that, across markets, the size of

[23] For example, Hoyt (1933) writes about how, in the later stages of the 1920s real estate bubble in Chicago, an illusion of rising prices was created by arms-length transactions in which properties were exchanged at inflated prices between related parties.

[24] Baker and Wurgler (2007) combine a number of market indicators to construct a measure of investor sentiment.

the bubble will be positively related to trading volume. The literature on the relation between overconfidence, bubbles, and trading volume is reviewed in detail in Scheinkman and Xiong (2004).

While models 1 and 2 rely on heterogeneous agent settings, in models 3 and 4, behavioral biases can be aggregated to the level of the representative agent. Hence, in these models, trading volume is not an identifying feature of a bubble.

D. Why are Bubbles not Arbitraged Away?

In response to a frequent critique of behavioral models that competitive arbitrage forces will promptly eliminate all mispricing, the models of DeLong and others (1990) and Abreu and Brunnermeier (2003) show that under certain conditions rational arbitrageurs may amplify rather than eliminate the mispricing.

The literature points out a number of reasons why bubbles are not arbitraged away. First, there is always a risk that, instead of collapsing, the bubble will continue to grow and arbitrageurs will have to close or scale back their bets in order to meet margin calls for the short positions in the overvalued asset (e.g., Shleifer and Vishny (1997), Xiong (2001)), and Gromb and Vayanos (2002). Another source of risk is that an asset's fundamentals may change such that the asset is no longer overvalued. This risk is especially worth considering when the overvalued asset lacks another closely correlated asset in the economy that is not overvalued such that this risk could be hedged away with a long-short bet.

Remarkably, it turns out that costs of arbitrage tend to be nontrivial at the same time that the risk of potential mispricing is high, making it very costly to eliminate some types of mispricing. The reason is that mispricing arises when new information about a firm or an asset is difficult to interpret. Some agents, due to their particular skill or knowledge, may be better positioned to assess the impact of the new information, which creates potentially large informational asymmetries between them and everyone else. When informational asymmetries are high, trading costs will also be high and will increase with the size of trade, reflecting the risk that the traders that place large orders possess a considerable informational advantage. Given that arbitrageurs typically trade large quantities, increased trading costs will either greatly reduce or completely eliminate their potential profits, turning the arbitrageurs away from the trade (e.g., Sadka and Scherbina (2010)).

If each arbitrageur is relatively small, it takes a coordinated effort of many arbitrageurs to burst a bubble; otherwise, the bubble will persist. In the model of Abreu and Brunnermeier (2003), a bubble develops when a new technology asset's price, which has been initially growing at an appropriately high rate, g, fails to revert to a slower steady-state growth rate, r, at time t_0 because investors incorrectly believe that there has been a "paradigm shift" leading to a "new economy" with permanently higher growth rates. Hence, the asset becomes overvalued starting at time t_0. If the fair value of the asset at time t_0 is P_0, then the fair value, P_t^{fair}, at time $t > t_0$ is $P_t^{fair} = P_0(1+r)^{t-t_0}$. Yet, if the market price instead continues to grow at the high growth rate, g, past time t_0, then at time $t > t_0$ the price will equal $P_t = P_0(1+g)^{t-t_0}$. Therefore, the bubble component, which is the difference between the market price and the fair value, will be $B_t = P_0\left[(1+g)^{t-t_0} - (1+r)^{t-t_0}\right]$. The formula indicates that the bubble grows with time and increases with the difference between g and r.

Abreu and Brunnermeier (2003) further assume that arbitrageurs can short sell only a limited amount of the asset and it takes a fraction k of arbitrageurs selling short the asset to crash the bubble. Another key assumption is that arbitrageurs become aware of a bubble's existence only sequentially and therefore cannot coordinate their attack on the bubble. The *sequential awareness* eliminates the perfect competition among arbitrageurs assumed in rational models. The common knowledge of the bubble's existence (i.e., I know that there is a bubble, I know that others know that there is a bubble, others know that I know that others know, and so on), which is usually assumed in rational models, is at all times absent in this setting due to sequential awareness. In order to induce arbitrageurs to trade against the bubble, the model assumes that the bubble will burst for exogenous reasons at time $t_0 + \overline{\tau}$. Yet, since arbitrageurs do not know exactly when t_0 was, they do not know when the bubble will burst. The striking conclusion of this model is that—much as in DeLong and others (1990)—upon becoming aware of the bubble, arbitrageurs will optimally choose not to short sell the overvalued asset but rather to ride the bubble for a period of time.

The arbitrageurs' choice to ride a bubble represents a challenge to the view that rational investors always exert a correcting pressure on prices. Here, arbitrageurs choose to participate in the mispricing over a period of time, ultimately increasing their profits at the expense of the irrational investors. The lack of common knowledge about the bubble's existence allows for the bubble to persist. The lack of a synchronization mechanism among arbitrageurs is ultimately to their advantage, allowing them to ride the bubble for some time before eventually attacking it. The time that the arbitrageurs will wait before attacking the bubble increases with (a) the disagreement among the arbitrageurs about when the bubble started, (b) the fraction of arbitrageurs, k, required to succeed in the attack, and (c) the "excess" growth rate of the bubble, $g - r$. If these values are sufficiently large, the time of the speculative attack may be deferred up until the time that the bubble bursts for exogenous reasons, allowing the arbitrageurs who found out about the bubble early on to reap maximum profits. Consistently with the prediction of this model and that of DeLong and others (1990), Brunnermeier and Nagel (2004) show that, during the dot-com bubble, hedge funds followed the optimal strategy of riding the bubble rather than attacking it before selling out of their positions before the bubble started to deflate.[25]

E. Bubbles in Experimental Settings

A large number of experimental studies have consistently replicated the bubble phenomenon. The experiments tested the assumptions behind theoretical models, specifically, whether lack of experience, lack of common knowledge of rationality, and short sale constraints play a role in the emergence of bubbles.

[25]Of course, a completely different reason for why bubbles are not arbitraged away is that they are not bubbles to begin with; several studies argue that the observed patterns of rapid price increases followed by crashes do not have to be attributed to bubbles. For example, Zeira (1999) models a setting in which such price patterns are frequently observed, when a market expands to a new capacity, which is unknown until it is reached. In the transition phase, before the new capacity is reached, prices increase rapidly. However, right after the new capacity is reached, prices crash. The reason is that the last price before the crash was based on the growth rate forecast extrapolated from the recently high growth rates. Therefore, even though just before the crash the price was too high, it was the correct price given the information known at that time and the crash could not have been anticipated with ex-ante-known information. Similarly, Pástor and Veronesi (2003) argue that patterns of rapidly rising and then falling prices need not reflect mispricing; they also attribute such price trajectories to technological revolutions, during which the productivity of the new technology is subject to learning. During the adoption period of the new technology, positive cash flow news push prices up, but as the technology becomes a larger part of the economy, its risk gradually changes from idiosyncratic to systematic, leading to a higher discount rate. The higher discount rate effect eventually starts to dominate the positive cash flow effect and pushes prices down. In both models, even though the price experiences a fast increase followed by a decrease, prices do not drop all the way down to the starting level. Finally, Pástor and Veronesi (2006) argue that there was no dot-com bubble. Rather, the high valuations at the peak could have been justified by the uncertainty about the future growth rate, increasing expected firm values through Jensen's inequality, and the subsequent price drop by the downward revisions in investors' expectations, as described in the model of Zeira (1999).

Many of these studies have built on the experimental design of Smith, Suchanek, and Williams (1988). The experiment in that paper is conducted in the following way: The market consists of traders who are, at the beginning of the experiment, endowed with the asset and cash. They are free to trade the asset over the course of the experiment, which consists of 15 (or 30) trading periods, each lasting a maximum of 240 seconds. At the end of each trading period, the asset pays an uncertain dividend derived from a known probability distribution. All information is common knowledge among traders by virtue of it being verbally announced to all traders in the room at the beginning of each trading period. All traders who wish to buy or sell one unit of the asset can type their bid or ask prices on the computer screen and only the highest bid and the lowest sell offers are displayed to the entire market. In order to accept an offer, a trader needs to confirm this by touching the computer screen, and the trade is recorded at the accepted price. After the trade, the new highest bid and lowest offer prices are displayed. The traders' cash endowments are at all times adjusted by the accumulated capital gains and losses generated from trading as well as the accumulated dividends. Traders can continue to purchase asset units as long as they have sufficient cash to cover the purchase price. Short selling is not allowed. At the close of the market, a trader's endowment is equal to the sum of the capital gains and losses from trading and the dividends earned.

The experiment revealed that price bubbles appear frequently (a bubble is observed in 14 out of 22 experiments) and more so when subjects are less experienced. Furthermore, the mean price in the first trading period is always below the expected value of future dividends, consistent with traders exhibiting risk aversion. The initially low price might help create an expectation of the future capital gain, possibly giving rise to a bubble. The collapse of the bubble is preceded by a decline in the number of "buy" relative to "sell" offers made by traders, and is accompanied by a lower trading volume than the bubble's rise.

This experiment informed future experimental studies by highlighting that it is not necessary to provide traders with divergent dividend expectations in order to induce trade. Even in the presence of common knowledge and common priors, trades are motivated by the differing price expectations that arise because of the uncertainty regarding the actions of other traders and by the diversity in risk attitudes.

Dufwenberg, Lindqvist, and Moore (2005) set out to see whether traders' experience helps prevent bubbles from appearing in experimental markets. The setup was very similar to that of Smith, Suchanek, and Williams (1988), but a subset of traders had the experience of having previously participated in three rounds of the game. The authors found that mixing together experienced and inexperienced traders, even when the fraction of the experienced traders was only one-third, eliminated or substantially reduced the incidences of bubbles. Given that, in real markets, the fraction of experienced traders is substantially greater than one-third and that their experience is more substantial, the authors questioned whether bubbles can be realistically attributed to the prevalence of inexperienced traders in real markets. The authors further pointed out that, consistent with the outcome of their experiment, the real market is relatively free of bubbles most of the time and is only once in a while swept up by a bubble craze.

Some follow-up experimental studies relaxed short sale constraints with varying consequences. For example, Ackert, Church, and Deaves (2002) found that allowing short selling made experimental markets more efficient and moved trading prices closer to the fundamentals. In contrast, Naruvy and Noussair (2006) found that permitting short selling did not make markets more efficient. Their experimental markets retained many of the properties associated with positive or negative asset bubbles: high transaction volume, large swings in price relative to the fundamentals, and sustained trading at prices different from the fundamentals.

VI. The Subprime Mortgage Bubble

The origins of the recent real estate bubble can be traced to the low-interest-rate environment that followed the collapse of the dot-com bubble and a number of financial innovations and policies that made housing investment seem more attractive than an investment in stocks and bonds.[26] In particular, a newly popular two-tier securitization process, which involved pooling mortgage loans into mortgage-backed securities (MBSs) and subsequently pooling MBSs into collateralized debt obligations (CDOs), allowed investors to diversify away the idiosyncratic risk of regional real estate price movements, further lowering mortgage rates. These developments are some of the reasons behind the initial rise in house prices that was subsequently amplified by further capital inflows into the housing market, consistent with feedback trading models.[27]

[26] A number of studies review the causes of the subprime mortgage crisis (e.g., Brunnermeier (2009), International Monetary Fund (2011)).

[27] Large inflows of foreign capital into U.S. Treasury and agency bonds also contributed to low mortgage rates as these rates are linked to U.S. government bonds.

As in the limited liability models, the securitization process had the unfortunate side effect of creating a moral hazard problem for lending institutions, since they no longer held the loans on their books.[28] The institutions' primary objective became to increase the number of loans made, which was done at the expense of loan quality. The competition among lenders for new loans led to a proliferation of the types of loans designed to attract subprime borrowers with few assets and low income. These loans (the most widespread being adjustable-rate mortgages) required little or no money down and low initial payments that were scheduled to increase to prevailing market rates in a few years.[29] The would-be feedback traders who could not previously obtain a mortgage loan now could. Those who were especially optimistic about the prospects of the housing market frequently owned several properties, hoping to resell them.

The borrowers faced their own moral hazard problem. Many existing home owners were remortgaging their homes by taking loans against their home equity, and a large fraction of new home owners never accumulated home equity to begin with because banks no longer required them to make a reasonable down payment when taking out a loan. Having little home equity created an incentive for the borrowers to walk away from the house in the event that mortgage payments exceeded the cost of renting elsewhere. This set the stage for a potentially quick collapse of the bubble, because a small initial downward price movement could be quickly amplified.

Just like securities analysts during the dot-com crisis, bond rating agencies failed to sound the alarm. This could have been the result of both incentive problems and a series of faulty assumptions in their risk models. For example, the models relied heavily on recent house-price data that showed consistent price increases. The implication was that, in the event of a borrower's default, the loan value could be recovered by repossessing the house. Of course, this assumption was violated when house prices started to decline. The models also overstated the benefits of cross-regional diversification; while the assumed correlation in housing returns across regions was as low as 30 percent, the actual correlation turned out to be close to 100 percent at the time when house prices started to fall. Further aggravating the problem, investment banks routinely gamed the rating algorithms by delivering loan pools at the very bottom

[28] Some mortgage originators were required to keep a portion of the loans on their books in order to reduce the moral hazard problem; however, the high demand for new loans at the time overshadowed concerns about the increase in risk exposure. As a result, many lending banks suffered large losses and went bankrupt after the housing market collapse (see International Monetary Fund (2009)).

[29] For example, the average down payment made by Alt A borrowers (a category between prime and subprime) fell from 14 percent in 2000 to only 2.7 percent in 2006.

of the desired rating grade. Additionally, the delivered loan pools combined borrowers with high and low FICO scores but were rated based on the average FICO score, potentially not reflecting their true riskiness. Rating agencies, fearful of losing business to competitors, did not press for detailed information on the individual loans. As a result, many highly risky subprime loans received investment-grade ratings. Investors, blindly trusting these ratings, did not demand a high enough rate of return to be properly compensated for their risk exposure (see, e.g., International Monetary Fund (2010)).[30]

In this environment, highly risky loans were made at low mortgage rates, which led to even further price increases. Speculation in the housing market was abundant and the investment strategy of "flipping" properties was promoted by the success stories reported in news media. As in previous bubble periods, the market was dominated by the optimistic investors. If there were pessimists who would have liked to short the housing market or the mortgage-backed securities, they lacked the means to do so until the introduction of the CDS contracts on MBS and the ABX index and related instruments.

As during the Roaring Twenties, the rise in housing prices was accompanied by a construction boom. Many new houses were built to supply the market with additional units of the overvalued asset, especially in the areas that experienced significant price increases. When the prices eventually began to fall, the unsold inventory of new housing was supplemented by the staggering number of foreclosures, exacerbating the fall in house prices. If the Great Depression is any indication, house prices are likely to remain low for a long time, until the housing demand finally catches up with the existing housing supply.

Between 2004 and 2006, the Fed raised interest rates 17 times, from 1 percent to 5.25 percent. Around that time, many of the initially low teaser-rate mortgages were being adjusted up to market interest rates and subprime home owners who could not afford the high interest

[30]Credit ratings are based on an estimate of the underlying debt security's expected payoff. Coval, Jurek, and Stafford (2009) show that expected payoffs of CDOs (and even more so, the so-called CDO^2's, which are made up of lower tranches of straight CDOs) are highly sensitive to the correlations between payoffs of the underlying debt securities, as well as to the underlying securities' default probabilities and their default recovery rates. Credit rating agencies made overly optimistic assumptions about all these inputs in their rating models. Correlations between underlying mortgage-backed securities turned out to be higher than expected as these mortgages were originated at similar times and in similar geographic areas. Default probabilities exceeded the expectations and recovery rates fell below expectations due to lower than expected borrower quality. The authors further argue that investors failed to take into account that senior tranches of CDO securities had a much higher exposure to systematic risk than similarly rated corporate bonds and, as a result, did not demand sufficient compensation for their exposure to systematic risk.

payments were unable to refinance with lower-rate mortgages. Many borrowers had zero equity in their homes and chose to default and walk away. Increased interest rates thus had the effect of lowering housing prices. The largest decline in house prices occurred in 2008.[31]

Prices of mortgage-backed securities also collapsed, but with a delay. Fostel and Geanakoplos (2012) argue that the price drop of mortgage-backed securities can be traced to the introduction of credit default swaps (CDSs).[32] A CDS is a derivative contract on an underlying bond that ensures the buyer against the bond's default. Since many of the mortgage-backed securities were traded over the counter but not on exchanges, they were impossible to sell short; buying CDS contracts offered the closest alternative. If not pursuing a hedging strategy, a CDS buyer takes a bet that the underlying bond will default and the seller takes a bet that it will not. Holding a long position in a CDS contract can be costly: It requires both posting a collateral, which can be large, and making agreed-upon quarterly spread payments, which can be thought of as insurance premia. Nonetheless, as predicted by models with disagreement and short sale constraints, the introduction of CDS contracts implicitly relaxed the short sale constraint in the mortgage-backed securities market, bringing prices down to fundamentals.

Whether or not they understood that the rising real estate prices were a bubble, many sophisticated money managers initially took long positions in the housing market by holding MBS and CDOs and selling CDS contracts. As was predicted by the models of DeLong and others (1990) and Abreu and Brunnermeier (2003), sophisticated investors, such as Goldman Sachs and its hedge funds, successfully rode the bubble and switched to betting against it just in time before it crashed. Goldman Sachs may have been either lucky with its timing or may have simply waited to reprice the mortgage-backed securities in which it made markets until after it had switched its bet. Other investment banks followed, switching to the short bet, but because of the delay, they were already exposed to losses on their long positions.

The Financial Crisis Inquiry Commission recently determined that the crisis could have been avoided if the U.S. government had paid more attention to the warning signs: an explosion in risky subprime mortgage lending, an unsustainable rise in house prices, widespread unscrupulous lending practices, steep increases in homeowners' mortgage debt, and a spike in investment banks' trading activities, especially in mortgage-backed financial products. Financial firms were blamed for a combination of poor risk management and poor governance that

[31] In that year, the Case-Shiller 20-city index fell by 18.61 percent. In 2007, it fell by 9.03 percent.
[32] See also the model of Hong and Sraer (2011).

enabled individual traders to take on too much risk with very little exposure to the downside (Financial Crisis Inquiry Commission (2011)). In the aftermath of the crisis, policy makers introduced the Dodd-Frank Wall Street Reform and Consumer Protection Act, which aims to improve the monitoring and incentives of Wall Street players as well as to strengthen investor protection.

VII. Conclusion

Back in 1923, Edwin Lefèvre, an American writer and journalist, wrote: "Nowhere does history indulge in repetitions so often or so uniformly as in Wall Street. When you read contemporary accounts of booms or panics, the one thing that strikes you most forcibly is how little either stock speculation or stock speculators today differ from yesterday. The game does not change and neither does human nature." (*Reminiscences of a Stock Operator*, 1923, p. 180). In almost 90 years that have since passed, we have had a chance to observe many other instances of booms and crashes in a variety of asset markets around the world. Much academic effort has been devoted to understanding this puzzling and persistent phenomenon. More recently, the literature moved away from simply modeling the conditions under which bubbles could exist in perfectly rational markets to trying to model the observed dynamics of a bubble, in the process often abandoning the assumption of perfect rationality.

Behavioral models of bubbles can be subdivided into four types. The first type of behavioral models incorporates the influence of short sale constraints in the presence of diverging investor beliefs about the fair value of the asset. The second type of models incorporate feedback traders; these traders form trading demands based on the assumption that the most recent price trends are going to continue, thereby ensuring that they do indeed continue. The third type assumes that investors suffer from the self-attribution bias, paying attention to public signals that confirm their priors and ignoring those that do not, which leads to an overreaction in prices. Finally, the fourth type assumes that investors use the representativeness heuristic that leads them to overreact to potentially uninformative but attention-catching news, leading to an overreaction; at the same time, they also exhibit conservatism bias such that they are too slow to update their faulty models of the world based on relevant signals.

The experimental literature on bubbles shows that in artificial markets bubbles arise frequently. Directly testing the assumptions behind behavioral models, the experimental literature indeed finds that the rise of bubbles is accompanied by high trading volume, a feature observed in real markets and explicitly captured in models with feedback trading. Consistently with the second type of behavioral models, imposing short sale restrictions and having many inexperienced traders participate in the experiment increases the likelihood of a bubble. Importantly, the experimental setting confirms that one of the key reasons for why bubbles arise is the lack of common knowledge of rationality on the part of all traders.

The contribution of the recent theoretical literature is to show that the presence of rational investors does not necessarily help eliminate bubbles. The new models introduce very realistic innovations, such as departing from the assumption of common knowledge of a bubble's existence, introducing feedback traders, or imparting limited liability for key agents, and show that these new assumptions can each lead to an outcome where rational traders do not trade *against* the bubble, which would contribute to its collapse, but trade *with* the bubble, aggravating the mispricing, at least for some time.

While the question of whether governments should intervene once a bubble is already under way is still open, the literature makes several suggestions on how to help prevent future bubbles. One suggestion is to, whenever possible, remove short sale restrictions. Another suggestion is to provide better financial education in order to reduce the adverse influence of investor irrationality. Finally, the literature suggests the need to mitigate the limited liability incentive structure and expose all agents to the downside risk of a bubble.

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