Rational Asset-Price Movements Without News

By DAVID ROMER*

This paper argues that an important part of movements in asset prices may be caused by neither external news nor irrationality, but by the revelation of information by the trading process itself. Two models are developed that illustrate this general idea. One model is based on investor uncertainty about the quality of other investors' information; the other is based on widespread dispersion of information and small costs to trading. The analysis is used to suggest a possible rational explanation of the October 1987 crash. (*JEL* G14, G12)

In seeking to understand movements in the value of the aggregate stock market, there are two standard reference points. The first is an efficient-markets view in which asset prices are rational assessments of expected future payoffs. In this view, changes in prices reflect the arrival of external news about future payoffs and interest rates—news about the economy, firms' profits, and so on. The second reference point is a "fads," "noise," or "bubbles" view in which there is a component of prices that is not tied to fundamentals, and in which changes in asset prices can therefore reflect changes in the nonfundamental component as well as changes in fundamentals.

Large parts of day-to-day movements in the stock market do not fit comfortably with the first of these views. Outside observers very often cannot identify any news that could plausibly have been the source of observed changes in stock prices. The stock-market crash of October 1987 is a striking example: stock prices fell by 20 percent in a single day without any news of obvious importance. The crash is simply an extreme instance of a general phenomenon. David M. Cutler et al. (1989) examine the 50 largest daily changes in aggregate stock prices over the period 1946–1987; they find that in the majority of the cases there was no external news that was clearly responsible for the change and that in many cases contemporary analysts were unable to suggest any fundamentals-based explanation at all. Richard Roll (1988) reports a similar finding about firm-specific stock price changes: the variance of firm-specific price movements for a particular firm is only very slightly lower on days when no news about the firm is reported in the financial press than it is on days when such news is reported. Kenneth R. French and Roll (1986) provide very different evidence that supports the same conclusion: they show that market volatility is much larger over periods when the market remains open than over otherwise similar periods that include times when the market is closed.

Thus if the discussion of movements in the stock market is cast as a debate between the view that the movements reflect rational responses to outside news and the view that the movements have a substantial irrational component, the evidence provided by day-to-day movements appears to weigh decisively in favor of irrationality. Essentially, defenders of rationality are reduced to arguing that there are subtle but very important items of news whose significance can be discerned by market participants but not by

*Department of Economics, University of California, Berkeley, CA 94720. I am grateful to Gil Mehrez for research assistance, to Fischer Black, Robert Shiller, the referees, and seminar participants at Berkeley, Chicago, Stanford, and the NBER for helpful comments, and to the National Science Foundation and the Sloan Foundation for financial support.

economists and other outside observers.[1] Indeed, this was precisely the approach taken by supporters of market rationality immediately after the 1987 crash.

This paper proposes a "middle way" between these two polar views of asset-price movements. Investors possess diverse useful information about fundamentals. Aggregating this information is a difficult task. Although there are specific conditions under which market prices successfully aggregate all relevant information, there is no presumption that they always do. The possibility of imperfect aggregation implies an alternative to external news and irrationality as a potential source of asset-price movements: some price changes may be caused by "internal" news. That is, asset prices can change because initially the market does an imperfect job of revealing the relevant information possessed by different investors and because developments *within the market* can then somehow cause more of that information to be revealed.

If each investor recognizes that others possess objectively useful information about value that is not reflected in prices, then changes in the investor's opinion of what others' opinions are will cause the investor to change his or her own estimate of value. Thus Keynes's famous "beauty contest" interpretation of the stock market, in which market participants are more interested in others' beliefs than in their own estimates of fundamentals, applies even when investors are holding stocks for their fundamental payoffs rather than in the hopes of selling to someone else at a higher price.

This paper demonstrates that there can indeed be rational changes in the market's assessment of fundamentals without the arrival of outside news. Sections I and II present two different models of rational price movements arising from "internal" rather than "external" news.

A model of rational movements in asset prices arising from the trading process must have two properties. The first is that the market's initial reaction to news does not fully reflect investors' assessments of the news's implications for fundamentals. The second is that further trading reveals additional information about those assessments. The two specific models that I present incorporate these two central components in different ways.

The model developed in Section I is based on information of heterogeneous quality and uncertainty about the quality of others' information. Uncertainty about the quality of others' information can cause investors who in fact possess the best available information to place some weight incorrectly (but rationally) on the market price and little weight on their own information in attempting to estimate value; alternatively, it can cause investors who have inferior information to place excessive weight on that information. As market developments (e.g., market responses to buy and sell orders arising from liquidity needs) reveal information about others' uncertainty, it becomes clearer whose information is superior. The best available information therefore becomes reflected more fully in asset prices.

The central feature of Section II's model, in contrast, is dispersion of information among a large number of investors. If the knowledge that is helpful in evaluating the implications of a piece of news for future payouts and discount factors is widely dispersed, the incentives for any single investor to trade on the basis of his or her knowledge may be small. If there are costs to trading, investors possessing relevant information may therefore choose not to trade immediately. As other considerations cause these investors to trade, however, their information will affect their asset demands and therefore be partially incorporated in

[1]Given the magnitude of many of the price changes that occur without apparent news and the range of stocks they affect, it appears unlikely that they could be caused either by the contemporaneous arrival of private information or by strategic trading based on previously acquired private information. For example, it is difficult to imagine what private information could have caused the October 1987 crash. Similarly, the absence of negative serial correlation in daily stock-market returns suggests that the price changes are not caused by short-run changes in liquidity.

prices. With many such investors, the resulting price movements may be substantial. I present some simple examples in which investors collectively possess information implying that the market is initially mispriced by an average of 5–10 percent but in which the expected gain to any single individual from trading is only a few dollars.

The two models are not mutually exclusive. One possibility is that the mechanism described in Section I is central to large price movements without significant outside news (such as the 1987 crash) while the mechanism illustrated in Section II is more relevant to smaller day-to-day variations in prices that occur without apparent news. Indeed, I argue at the end of Section I that a variation on the model presented there provides a possible explanation of the 1987 crash.

In presenting my particular models, I do not intend to argue that the specific mechanisms they illustrate are the only important channels through which trading can reveal information; nor do I wish to argue that all changes in stock prices are fully rational.[2] My goals are more limited: I want to show that it is possible for there to be rational changes in asset prices without external news and to describe some mechanisms through which this could occur. At a broader level, my goal is to argue that the fact that changes in stock prices are often unaccompanied by evident news is a major puzzle and that theories that attribute this fact to the revelation of information by the trading process offer a promising route to understanding it.

[2]This paper is one of a number of recent (and largely independent) papers concerned with the possibility of rational reassessments of fundamentals without the arrival of outside news. These papers suggest a variety of mechanisms other than those presented here through which such rational reassessments can occur: self-fulfilling expectations (Leonard J. Mirman and Haim Reisman, 1988; Bruce D. Grundy and Maureen McNichols, 1989), imperfect information about the market's ability to bear risk (Alan Kraus and Maxwell Smith, 1989), dependence of the implications of news received by one investor on news received by another (James Dow and Gary Gorton, 1991), strategic interactions among a small number of traders (Jeremy Bulow and Paul Klemperer, 1991), and fixed costs that prevent any of a large number of similarly informed investors from acting until there has been a large shift in fundamentals (Andrew Caplin and John Leahy, 1991, 1992). In addition, in Subsection I-D, I discuss the related analyses of the 1987 crash by Sanford J. Grossman (1988), Gerard Genotte and Hayne Leland (1990), and Charles J. Jacklin et al. (1992) which argue that the crash may have represented a rational reassessment of fundamentals in response to market developments.

I. Uncertainty About the Quality of Others' Information

This section presents a simple model that formalizes the idea that heterogeneous information quality and uncertainty about the quality of others' information can give rise to rational revisions in estimates of fundamentals without external news. It also describes how such a revision might have played an important role in the 1987 crash.

A. *The Model*

There is a perfectly inelastic supply of Q units of the economy's single risky asset. The asset's payoff, α, is distributed normally with mean μ and variance V_α; μ is assumed to be sufficiently large that the probability of a negative realization is negligible. In addition, there is a perfectly elastic supply of a riskless asset yielding a zero rate of return.

There are many investors, each with identical constant absolute risk-aversion utility, $U_i = -e^{-\rho C_i}$. Investor i's consumption, C_i, is given by $x_i\alpha + y_i$, where x_i and y_i are the investor's holdings of the risky and safe asset, respectively.

Each investor receives some private information about the payoff to the risky asset. There are three potential signals: $s_j = \alpha + \varepsilon_j$ ($j = 1,2,3$), where ε_j is distributed normally with mean zero and variance V_j. The disturbance ε_2 is given by $\varepsilon_1 + \delta_2$; ε_3 equals $\varepsilon_2 + \delta_3$; and α, ε_1, δ_2, and δ_3 are independent. Thus if s_2 is known, s_3 provides no information about α. Similarly, s_2 provides no information about α if s_1 is known.

There are two possible distributions of signals, each occurring with probability $\frac{1}{2}$. In the first, half of the investors receive signal

s_1, and half receive s_2; in the second distribution, half receive s_2, and half receive s_3. All of the investors receiving a given s_j receive the *same* realization of the signal. Each investor knows the quality of his or her own signal, but not the quality of the information received by others. In particular, an investor receiving s_2 does not know whether half of the agents are receiving s_3, in which case s_2 provides the best available information about α, or half are receiving s_1, in which case strictly superior information is available.

To make trade possible, I assume that the supply of the risky asset is random. In the absence of some source of uncertainty other than heterogeneous information, the equilibrium asset price would be fully revealing. I therefore assume that the asset supply, Q, is normally distributed with mean $\overline{Q}$ and variance V_Q. Q is independent of α and the s_j's.

Each investor's demand depends on the signal he or she receives, the signal's quality, and the price of the asset. Formally, one can think of each investor as submitting a demand schedule for the asset. The price of the asset is then determined by the requirement that total demand equal supply.

Part B of this section demonstrates the two key characteristics of this economy. The first is that the asset's price does not reveal with certainty the distribution of information quality. Thus information that is available to a large number of investors is initially incorporated only imperfectly into the asset's price. The second is that a shift in asset supply after the initial price has been determined reveals the distribution of information quality and therefore causes a discrete change in price.

Part C then characterizes the equilibrium behavior of each type of investor. As I describe there, the uncertainty of agents receiving signal s_2 about the distribution of information quality makes their demand functions nonlinear in s_2 and P. This makes it impossible to solve for the equilibrium analytically. I therefore solve the model numerically. The solution, in addition to illustrating the characteristics identified in part B, reveals a variety of other ways in which uncertainty about the quality of others' information affects the workings of asset markets.

Finally, part D describes how a mechanism like the one suggested by the theoretical model might have played an important role in the 1987 crash.

B. *The Incorporation of Information into Asset Prices*

The demonstration that the price of the asset is not fully revealing about the distribution of signals is by contradiction. Suppose that prices are fully revealing. Then, under either distribution of signals, the economy is a conventional imperfect information economy in which investors know the distribution of signals and make inferences from the asset's price (P) and their own signals. The investors receiving the best available information would know that they possessed all of the useful information available about the asset's payoff (α) and would therefore place no weight on P in estimating α. The remaining investors would know that superior information was available; the randomness in supply, however, would prevent them from fully inferring the superior signal from P. Because of the assumptions of exponential utility and normality, the resulting equilibrium would be linear (see e.g., Grossman, 1977): agents' demand functions would be linear in the asset's price and their own signals, and the equilibrium price would be a linear function of the signals and of the random supply Q.

It follows immediately that this cannot in fact be the equilibrium. With P linear in the signals and in Q (and with the signals and Q drawn from continuous distributions), for a fixed s_2 a given P could arise with either possible distribution of information quality. But then individuals receiving s_2 could not deduce the distribution. Thus the equilibrium price cannot fully reveal the distribution of information quality.

Further trading, however, can cause investors to learn the distribution of information quality. Specifically, consider the effect of a change in the supply of the asset after an initial price has been determined. For simplicity, assume that the change is unexpected and that its size is known to all investors. From the response of the asset price to this shock, the investors receiving s_2 can deduce the slope of the remaining agents' demand curve for the asset. If the remaining agents are receiving high-quality information, that slope is simply $1/\rho\hat{V}$, where $\hat{V} = [V_1/(V_1 + V_\alpha)]V_\alpha$ is the variance of the payoff α given s_1. If the remaining agents are receiving low-quality information, their uncertainty about α is necessarily larger, and so the slope of their demand function is smaller. Thus the investors receiving s_2 can now deduce the quality of others' information.[3] This discrete change in their estimate of the likelihood of the two distributions of quality causes a discrete change in their demand and, hence, a discrete change in the asset price. Thus market activity, rather than the arrival of external information, can cause rational changes in asset valuations.

The source of the result that market activity can cause rational investors to revise their assessments of fundamentals is simply that the response of prices to noninformational changes in supply can provide information beyond that conveyed by initial prices. Thus, although the model presented here is highly stylized, the central result is likely to carry over to settings with more complex and realistic financial markets and informational heterogeneity.

Assuming that investors initially attached some small probability to a change in supply and a second round of trading, for example, would not alter the argument. Assuming that investors were uncertain about the magnitude of the supply shift, on the other hand, would prevent investors from learning the distribution of information quality with certainty in the second round of trading but would not affect the result that a noninformational event allowed investors to learn more about each other's information and thus led to rational revisions in prices. In this case, the amount that investors learned about the distribution of information quality would be increasing in the mean (and decreasing in the variance) of the shift in supply.

Finally, in the specific model presented here, the price of an option would reveal investors' uncertainty about the asset's payoff and would thus reveal the quality of investors' information. Thus the introduction of an option market would mean that the response of price to a noninformational event no longer reveals information. All that is needed to restore the ability of market activity to convey information about investors' uncertainty is that the form of uncertainty be sufficiently complicated that it cannot be summarized in a single parameter (namely, the price of the option); if this is the case, then in general the price of options is no longer perfectly revealing about how stock prices would respond to a change in supply.

One important implication of the model is that rational investors are concerned with the beliefs and uncertainties of other investors. When knowledge is heterogeneous, information about what others believe is valuable. Indeed, when most investors' information is small relative to that embodied in market prices, most investors place much greater weight on the market price than on their own information in attempting to as-

[3]This discussion of the slope of the demand curve of the agents receiving s_3 neglects the fact that the change in P in response to the shift in supply provides these investors with additional information. As described in Subsection I-C, the initial P reveals to them that s_2 and Q must lie on some nonlinear locus. If the shift in supply reveals the distribution of information quality to the investors receiving s_2, their demands become linear, and so those receiving s_3 now observe some linear combination of s_2 and Q. Thus they now possess additional information about s_2. It is possible for this new information about s_2 to cause them to respond to the change in supply exactly as would investors observing a high-quality signal. Because of the nonlinearity of the initial demand curves, however, for any given value of s_2 this is a measure zero possibility. Thus this complication does not alter the conclusion that the investors observing s_2 deduce that other agents are receiving s_1 if and only if they observe that other agents' demand curves have slope $1/\rho\hat{V}$.

sess fundamental values. For want of a better term, a change in prices caused by the revelation of information about investors' uncertainty could be described as a change in the "confidence" of market participants. Thus, such phenomena as concern with other investors' behavior and the importance of "confidence" and "sentiment" in price movements, which are often cited in support of models of irrational asset-price movements (e.g., Robert J. Shiller [1984], J. Bradford De Long et al. [1990], and Keynes's "beauty contest" metaphor), are consistent with rationality. In a world of heterogeneous information, even an investor who is in the market "for the long haul" will be preoccupied with attempting to gauge others' beliefs and confidence.

C. *Description of the Equilibrium*

Equilibrium in the initial round of trading is described by functions $x_1(x_1, P)$, $x_2(s_2, P)$, and $x_3(s_3, P)$ giving the demands of each type of agent as functions of the observed signal and price. Given these functions, the asset's price for a given realization of the signals and of supply is the price that equates demand and supply. Specifically, the equilibrium asset demand functions occur when, assuming demand functions $x_i(s_i, P)$ $(i = 1,2,3)$, if each investor draws inferences optimally about the conditional distribution of α given his or her signal, the prevailing price, and these demand functions, the optimal choices of the amounts to purchase are given by the assumed $x_i(\cdot)$ functions.

The behavior of a type-1 investor (i.e., an investor receiving signal s_1) is straightforward. Given the assumptions of normality and exponential utility, the investor's demand is simply $(\hat{\mu} - P)/\rho\hat{V}$, where

$$\hat{\mu} = \mu + [V_\alpha/(V_1 + V_\alpha)](s_1 - \mu)$$

and

$$\hat{V} = [V_1/(V_1 + V_\alpha)]V_\alpha$$

are the mean and variance of α given s_1.

The problem facing a type-3 investor is more complex. He or she knows that the economy is made up of type-2 and type-3 investors. Since s_2 contains more information than s_3 about the asset's payoff, information about s_2 is valuable. Because the investor observes s_3 and P, he or she knows the amount of the asset purchased by other type-3 investors, namely, $x_3(s_3, P)$. Equilibrium requires $x_2(s_2, P) + x_3(s_3, P) = Q$ (I assume a unit mass of each type of investor for simplicity). Knowledge of $x_2(\cdot)$ and $x_3(\cdot)$ and of the joint distribution of s_2, s_3, and Q thus allows the investor to compute the distribution of s_2 conditional on s_3 and P. The investor chooses the amount of the asset to hold to maximize expected utility given this conditional distribution and P. If $x_2(\cdot)$ were linear in s_2 and P, $x_3(\cdot)$ would also be linear. As I now describe, however, $x_2(\cdot)$ is not linear, and this causes $x_3(\cdot)$ also to be nonlinear.

The problem facing a type-2 investor is similar—but slightly more complicated—than that facing a type-3 investor. The investor can use his or her knowledge of $x_1(\cdot)$ and $x_3(\cdot)$, of the joint distribution of the signals and Q, and of s_2 and P to compute both the probability that other investors are type 1's and the distribution of s_1 conditional on this being the case and on the investor's other information. The investor then chooses the amount of the asset to hold to maximize expected utility.

A type-2 investor's prior probability that other investors are type 1's is $\frac{1}{2}$. In general, however, observing s_2 and P causes the investor to update that probability. For example, if the variance of P conditional on the observation of s_2 is lower when other investors are type 1's than when they are type 3's, an extreme observation of P (given s_2) lowers the estimated probability that others are type 1's. The fact that the probability that others are type 1's varies with P implies that both uncertainty about α and the information content of P are not constant. As a result, type-2 investors' demand functions are not linear.

The nonlinearity of $x_2(\cdot)$ and $x_3(\cdot)$ makes an analytical solution of the model impossible. I therefore solve it numerically.[4] Figures 1–3 show some features of the equilibrium for the case $\mu = 10$, $V_\alpha = 1$, $V_1 = 1$, $V_2 = 2$, $V_3 = 4$, $\rho = 1$, $\bar{Q} = 0$, and $V_Q = 2$.[5] All three figures depict what occurs when the realization of s_2 equals its mean, μ.

Figure 1 shows type-2 investors' estimate of the probability that others are type 1's as a function of P. For the parameter values chosen, the variance of P given $s_2 = \mu$ is smaller if others are type 1's than if they are type 3's. Thus, type-2 investors' estimated probability that others are type 1's is greater than $\frac{1}{2}$ if P is close to μ and less than $\frac{1}{2}$ for

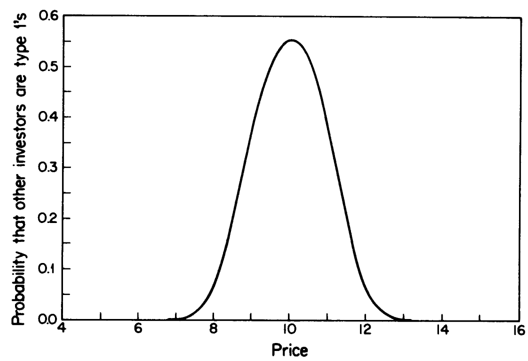

FIGURE 1. TYPE-2 INVESTORS' ESTIMATE OF THE PROBABILITY THAT OTHER INVESTORS ARE TYPE 1'S

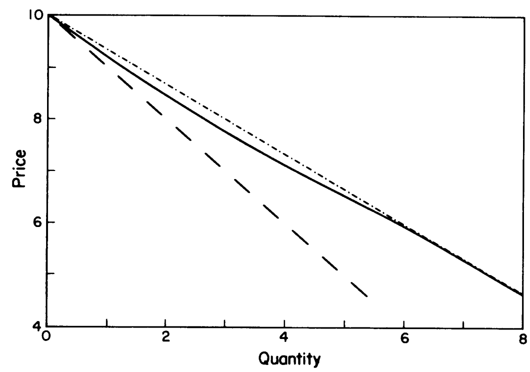

FIGURE 2. TYPE-2 INVESTORS' DEMAND FUNCTIONS WHEN OTHERS' TYPE IS UNKNOWN (SOLID LINE), WHEN IT IS KNOWN THAT OTHERS ARE TYPE 1'S (DASHED LINE), AND WHEN IT IS KNOWN THAT OTHERS ARE TYPE 3'S (DASH-DOTTED LINE)

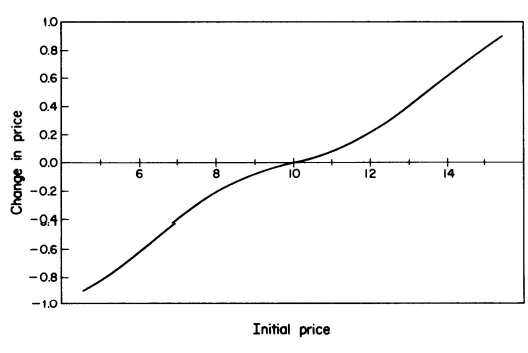

FIGURE 3. THE IMPACT ON PRICE OF A REVELATION THAT OTHER INVESTORS ARE TYPE 1'S

[4]As described above, $s_1(\cdot)$ can be found analytically. I find $x_2(\cdot)$ and $x_3(\cdot)$ over the points of $N \times N$ grids defined by considering N equally spaced values of s_i $(i = 2,3)$ over $[\mu - M\sigma_i, \mu + M\sigma_i]$, where σ_i is the standard deviation of s_i, and N equally spaced values of P over $[\tilde{\mu}_P - M\tilde{\sigma}_P, \tilde{\mu}_P + M\tilde{\sigma}_P]$, where $\tilde{\mu}_p$ and $\tilde{\sigma}_P$ are what the mean and standard deviation of P would be if the best available information (either s_1 or s_2) were always publicly known. I set $N = 43$, $M = 7$.

I first posit initial $x_2(\cdot)$ and $x_3(\cdot)$ functions at the points on these grids (namely, the demand functions that would prevail if all investors were type 2's or type 3's, respectively). I then solve for representative type-2 and type-3 investors' optimal asset holdings at each of these points if other investors' behavior is described by the assumed demand functions at these points and is piecewise linear between the points (and linear outside the ranges considered). The calculations of expected utility as a function of asset holdings require approximating integrals numerically; for example, a type-3 investor knows neither s_2 nor Q but knows, from knowledge of $x_3(s_3, P)$ and $x_2(\cdot)$, how Q must vary with s_2. All such integrals are approximated by considering N' equally spaced values of s_i (in this case, s_2) over $[\tilde{\mu}_i - M'\tilde{\sigma}_i, \tilde{\mu}_i + M'\tilde{\sigma}_i]$, where $\tilde{\mu}_i$ and $\tilde{\sigma}_i$ are the mean and standard deviation of s_i conditional on the investor's own signal (in this case, s_3). I set $N' = 169$ and $M' = 14$.

I then use the resulting $x_2(\cdot)$ and $x_3(\cdot)$ functions as the starting point for the next iteration. Twenty-four iterations achieved convergence to four decimal places. Changes in N, M, N', and M' had no discernible effect on the results. The calculations were performed in GAUSS 2.2 and required approximately 30 hours of computing time on an IBM 386 clone.

[5]Because the model is so stylized, I make no effort to choose "realistic" parameter values. The figures are intended simply to illustrate the qualitative properties of the model.

extreme values. For example, the probability that others are type 1's is 0.56 if $P = \mu = 10$; 0.06 if $P = 8$; and 0.00004 if $P = 6$.

Figure 2 shows the demand function of type-2 investors (again for $s_2 = \mu$). For comparison, the figure also shows the demand functions these investors would have if the distribution of information quality were publicly known. All of the demand functions are symmetric around $P = \mu$; thus for simplicity they are shown only for $P < \mu$. The impact of price on demand is influenced by two factors. The first is the probability that the price is informative (i.e., that other investors are type 1's). At extreme values the price is very unlikely to be informative; as a result, the impact of price on demand is large, and demand is virtually identical to what it would be if the investors were certain that others were type 3's. The second factor is how the probability that the price is informative *varies* with P. A change in price affects type-2 investors' estimate of α both by its effect on their estimate of s_1 conditional on other investors being type 1's and through its impact on the estimated probability that the price they observe is in fact a signal about α. At very low prices, the second effect dominates, so that type-2 investors' estimate of α is *declining* in the price. As a result, over some ranges demand is more responsive to price than it would be under *either* distribution of information quality if the distribution were publicly known.

Finally, Figure 3 shows the impact of a shift in supply after the initial round of trading. The figure shows, as a function of P, how the price of the asset changes if the response of the market to a change in supply reveals to type-2 investors that others are type 1's. This information causes type-2 investors to place more weight on price in estimating value and therefore pushes the price further away from its mean; thus the price falls if it is initially less than μ and rises if it is initially greater than μ.[6]

D. *The 1987 Crash*

This analysis suggests a candidate source of large changes in prices without the arrival of significant external news about dividends or discount factors: the process of learning about the quality of other investors' information can lead to sudden shifts in the weight that investors put on their own information and thus can lead to sudden changes in prices. Indeed, this process may have played an important role in the 1987 stock-market crash.

Any candidate explanation of the crash must face several difficulties. The most obvious is that there was no apparent significant news about fundamentals on the weekend before October 19. But there are other puzzles as well. One is why the crash occurred at a time of large noninformational sales (James F. Gammill, Jr., and Terry A. Marsh, 1988; Shiller, 1989). Another is why there was no rapid rebound from the crash, as would be expected if the crash resulted from a failure of liquidity or from a misinterpretation of the noninformational sales. A final puzzle—and one that is rarely discussed in accounts of the crash—is why market participants, in response to surveys, cited market developments themselves and the continuing high federal budget deficits as important sources of the crash (Shiller, 1989); in simple models of asset-pricing, neither factor would lead to any change in prices, much less to a crash.

Here I sketch a highly stylized account of the crash that provides candidate explanations for all of these puzzles. Thus, although I make no claim that the account explains the crash in its entirety, I believe that it represents a potentially important element of the crash.

[6]Because the response of type-1 investors to a change in P is independent of s_1, learning that other investors are type 1's provides type-2 investors with no additional information about the distribution of s_1 conditional on others being type 1's. As a result, the new price when it becomes known that others are type 1's is a deterministic function of P (and s_2). In contrast, the nonlinearity of $x_2(\cdot)$ causes type-3 investors to obtain new information about s_2 when type-2 investors learn that others are type 3's (see footnote 3). This makes the response of the asset price to this news depend not just on P and s_2 but also on Q and s_3.

My stylized account is a straightforward variation on the model presented above. It consists of two parts. The first part is a description of the situation before the crash. Suppose that well before the crash there was some new piece of information whose implications were difficult to evaluate; for concreteness, and for consistency with the survey evidence, suppose that the information was that there would be unprecedentedly large government budget deficits for the foreseeable future. It was probably difficult for market participants to gauge how easily others could estimate the implications of this news for future profits. To simplify, imagine that there were two possibilities. The first, and most likely, was that most investors could estimate the implications relatively precisely, while the remainder had estimates of medium and low quality; the second was that no investors were able to estimate the implications with high precision, a few could estimate them with medium precision, and the remainder could estimate them with low precision. As it happened, however, it was the second possibility that occurred. In addition, the realization of the intermediate-quality signal was low, and that of the low-quality signal was high (and/or the realization of Q was low).

In this situation, all investors, believing that most others were trading on superior information, put little weight on their own information. In the absence of a high-quality signal, however, the main determinants of the equilibrium price were in fact the low-quality signal and the random shock to asset supply. The result was that stock prices were high. Each individual investor, however, believed that the most likely reason that prices were high was that there were other investors who possessed reliable information that large and persistent budget deficits were not extremely harmful to future earnings.

The second part of the account concerns the crash itself. In this situation of "rationally overpriced" stock prices, a large quantity of noninformational selling orders arrived on the morning of October 19, 1987 (or late in the afternoon of October 16). As described above, natural extensions of the theoretical model would imply that the amount of information revealed by a noninformational change in supply about investors' uncertainty is increasing in the size of the change; thus the large quantity of mechanical selling in effect served as a powerful experiment for revealing investors' confidence in their assessments of fundamentals. Investors, believing that others were confident of the market's value, expected the sales to cause only a small fall in prices. When a larger-than-expected fall occurred at the opening of trading on October 19 (and/or at the close of trading on October 16), investors deduced that no one in fact possessed high-quality information that justified the high level of stock prices. Investors who observed the signal of intermediate quality therefore realized that the best available information suggested that deficits are in fact highly detrimental to future earnings. They moved rapidly to sell stocks. Other investors observed this and hence also changed their estimates of fundamentals sharply. Thus, a noninformational event triggered a "market meltdown."[7]

Grossman (1988), Genotte and Leland (1990), and Jacklin et al. (1992) also present rational theories of the 1987 crash. In these theories, the crash arose from investors' inability to determine whether trading was information-based. In Grossman's model and Genotte and Leland's model, investors, not knowing that initial sell orders on October 16 and 19 to a large extent represented the execution of portfolio-insurance programs, believed that others possessed information that had caused them to change their assessments of fundamentals drastically; they therefore revised down their own estimates of fundamentals. Jacklin et al.'s

[7]A natural question is whether this mechanism could be large enough to account for a crash of the size that occurred on October 19. Unfortunately, the theoretical model is so stylized that it cannot be used to make even approximate predictions concerning the magnitudes of the price changes that could result from investors learning about the quality of others' information. Thus it is not yet possible to address this question formally.

account is essentially the reverse of this. In their explanation, investors did not realize that many of the purchases in the months preceding October were driven by portfolio insurance and therefore revised up their own estimates of fundamentals. When the portfolio-insurance sales on October 16 revealed the extent of insurance, investors realized that the purchases of the preceding months did not reflect important information and therefore revised down their estimates of fundamentals sharply.

Both Grossman's account and Genotte and Leland's account are premised on the idea that there can be large movements in prices that genuinely do convey new information about fundamentals without any evident news: unless such movements are possible, investors would never rationally misinterpret a large price movement caused by noninformational selling or buying as providing information about fundamentals. Thus, these models do not provide a candidate explanation of the general phenomenon of large price shifts without news. The models also predict that the price drop should have been reversed as soon as it became known to a substantial number of market participants that the selling on October 19 was not information-based. Since this occurred shortly after the crash, the models predict that there should have been an extremely rapid rebound. No such rebound occurred.

In contrast, Jacklin et al.'s account, like the one presented here, is based on uncertainty about the distribution of information quality and consequent imperfections in information aggregation. Although the specifics of the two accounts differ, they are not mutually exclusive; thus they should be viewed as complementary.

II. The Dispersion of Information

This section describes an entirely different possible source of delayed reaction of asset prices to publicly available information. The central idea is that information about the implications of some piece of news for asset values may be widely dispersed and that this may cause the incentives for any given investor to trade solely to take advantage of that information to be small.[8]

A. *Assumptions*

The basic structure of the model is similar to that of the previous section. There is a single risky asset supplied inelastically; its payoff, α, is distributed normally with mean μ and variance V_α. There is also a riskless asset yielding zero rate of return available in perfectly elastic supply. There are M investors who receive signals about the payoff to the risky asset. Investor i has utility function $U_i = -e^{-\rho C_i}$.

There are three sets of differences from the model of Section I. The first differences concern the signals that investors receive. In this section, I make the standard assumption that investors' signals are independent and of uniform quality. I also assume that there is a component of the asset's payoff about which no investors receive signals. I thus write $\alpha = \alpha_0 + \omega$, where α_0 and ω are independent normal random variables with means μ and 0 and variances V_0 and V_ω ($V_0 + V_\omega = V_\alpha$). Investor i receives the signal $s_i = \alpha_0 + \varepsilon_i$, where ε_i is distributed normally with mean 0 and variance V_ε; the ε_i's are independent of one another and of α_0 and ω.[9]

[8]The model in Albert S. Kyle (1985) also has the property that information initially held privately is gradually incorporated into prices through trading activity. My model differs from Kyle's in two important respects. First, I show that the potential gains to an investor from trading on the basis of superior information may be small. I therefore focus on small costs to trading rather than strategic manipulation of timing as the source of gradual incorporation of information into prices. Second, I show explicitly that the incorporation of private information into prices can plausibly cause significant changes in the aggregate value of the market. The very small gains to trading on the basis of private information that I find suggest that, for the aggregate market, small trading costs appear more likely than strategic choice of timing to be an important source of gradual incorporation of information into prices.

[9]The parameter ω is introduced simply so that observing a large number of signals would not allow one to estimate the payoff with high precision.

Second, I assume that, in addition to the investors possessing private information, there is a class of risk-neutral uninformed investors. I refer to these investors as arbitrageurs. Their presence ensures that the asset's price is always equal to the expected value of the payoff given publicly observable information.

The third and most important differences from the model of Section I concern the structure of trading. Trading occurs at T dates. At date t, quantity Q_t of the asset is supplied; the Q_t's are independently and identically distributed normal variables with mean 0 and variance V_Q and are independent of α_0, ω, and the ε's. The arbitrageurs trade on each date. Each informed investor, however, trades on at most one date. Specifically, an informed investor can either pay a cost F, in which case he or she trades at the first date, or forgo the cost, in which case the investor with probability p trades at a date selected at random and with probability $1-p$ does not trade at all. The decision concerning whether to pay the fixed cost must be made before observing s_i. After the final trading date, the payoff is realized, and consumption occurs.

These assumptions capture the fact that trading on the basis of information is more costly when the trading is done immediately. If, for example, there are transactions costs, trading immediately requires incurring those costs. But if trading is postponed, other considerations, such as liquidity needs or the desire to trade on the basis of other information, may cause the investor to trade at some later date; at this point there are no costs associated with incorporating the information into demand. Similarly, costs of processing information to arrive at an estimate of fundamentals are likely to be higher when trading is done immediately.

Part B of this section describes the equilibrium of the model. Part C shows that the incentives to pay the fixed cost and trade at the initial date can be small and that the price movements arising from informed investors' subsequent trades can be significant. I demonstrate these results in two ways. First, I perform a back-of-the-envelope calculation that overstates the incentives to trade at the initial date and understates the magnitudes of price movements at subsequent trading dates. Second, I report the results of fully solving the model numerically.

B. *Description of the Equilibrium*

There are two requirements for equilibrium at a single trading date given the number of informed investors trading at that date. First, each informed investor must be choosing the quantity of the asset to purchase optimally given his or her information and given the impact of his or her purchases on the equilibrium price. Second, the price of the asset must equal the expectation of its payoff conditional on the information available to the arbitrageurs.

Finding this equilibrium is a conceptually straightforward (though algebraically complicated) extension of the analysis in Kyle (1989). Given the assumptions of exponential utility and normally distributed shocks, informed investors' demands are linear in the items in their information sets. The result is that the sum of informed investors' demands less the random supply is a linear combination of the investors' average signal and the supply; thus the arbitrageurs (and the informed investors themselves) face a standard signal-extraction problem. This causes the supply curve facing each informed investor to be linear. Equilibrium at a single trading date occurs when utility-maximization on the part of a representative informed investor, taking as given the coefficients of the other informed investors' demand functions (and hence taking as given the signal-extraction problem and asset supply curve that he or she faces), implies an asset demand function with those same coefficients.

The equilibria in the individual periods, given the number of informed investors trading at each date, determine the benefits to trading at each date. The equilibrium allocation of informed investors across trading dates is then determined by the requirement that investors be indifferent concerning whether to pay the fixed cost and trade at the initial date.

Consider the problem facing an informed investor trading at date t. The investor possesses three pieces of information. The first is the previous period's price, P_{t-1}. The presence of the arbitrageurs implies that P_{t-1} is the expectation of α_0 given all information that is publicly available through date $t-1$; one can therefore write $\alpha_0 = P_{t-1} + u_{t-1}$, where u_{t-1} is uncorrelated with P_{t-1}. As will be seen below, u_{t-1} is normal. Let $V_{u,t-1}$ denote its variance.[10]

The investor's second piece of information is his or her own signal, $s_i = \alpha_0 + \varepsilon_i$. Since ε_i is independent of other informed investors' ε's and of the Q's, it is independent of u_{t-1}.

The investor's third piece of information is the sum of other investors' demands minus the asset supply, $\Sigma_{j \neq i} x_j - Q$, where the sum is taken over the other informed investors who trade at time t (and where time subscripts are suppressed for simplicity).[11]

As described above, investor i's demand will be linear in the three pieces of information he or she observes. In addition, I will show that if $s_i = P_{t-1}$ and $\Sigma_{j \neq i} x_j = Q$, the investor's demand is zero. Imposing this condition at the outset for expositional simplicity, the investor's demand takes the form:

$$(1) \quad x_i = a(s_i - P_{t-1}) + b\left(\sum_{j \neq i} x_j - Q\right)$$

where the values of a and b (which in general depend on t) are to be determined.

[10]If $t=1$, define $P_{t-1} = \mu$, $V_{u,t-1} = V_0$.

[11]Because traders who are literally risk-neutral would be willing to purchase any amount when the asset price equals the expectation of α_0, informed investors would not be able to deduce $\Sigma_{j \neq i} x_j - Q$ (and arbitrageurs would not be able to deduce $\Sigma_j x_j - Q$) in this case. With any positive amount of risk aversion on the part of the arbitrageurs, their demand functions become single-valued, and the difficulty therefore disappears. The analysis should thus be thought of as applying to the limiting case in which the risk aversion of the arbitrageurs goes to zero.

The arbitrageurs observe only two pieces of information, P_{t-1} and $\Sigma_j x_j - Q$. Aggregating (1) over the informed investors trading at t and solving yields

$$(2) \quad \sum_j x_j - Q = \frac{a}{1-(N-1)b}\left(\sum_j s_j - NP_{t-1}\right) - \frac{1+b}{1-(N-1)b} Q$$

where N is the number of informed investors trading at t.

The existence of the arbitrageurs implies that P_t equals the expectation of α_0 conditional on P_{t-1} and $\Sigma_j x_j - Q$. The arbitrageurs face a standard signal-extraction problem. The solution is

$$(3) \quad P_t = P_{t-1} + \theta\left[\sum_j x_j - Q\right]$$

$$\theta = \frac{[1-(N-1)b]V_{u,t-1}}{aNV_{u,t-1} + aV_\varepsilon + \left[(1+b)^2/aN\right]V_Q}.$$

Equation (3) implies that the remaining uncertainty about α_0, V_u, is

$$(4) \quad V_u = V_{u,t-1} - \theta^2 \mathrm{Var}\left(\sum_j x_j - Q\right).$$

Normality and linearity imply that u_t is normal.

Now return to the problem facing investor i. Since the investor can deduce the impact of his or her demand, x_i, on others' demands, observing $\Sigma_{j \neq i} x_j - Q$ is equivalent to observing $\Sigma_{j \neq i} x_j^{-i} - Q$, where x_j^{-i} is what investor j's demand would be if x_i were zero.[12] Setting x_i equal to zero and

[12]Specifically, equation (1) implies:

$$\sum_{j \neq i} x_j - Q = \left[\sum_{j \neq i} x_j^{-i} - Q\right] + \left[(N-1)b/[1-(N-2)b]\right] x_i.$$

aggregating (1) yields

$$(5)\quad \sum_{j\neq i} x_j^{-i} - Q = \frac{a}{1-(N-2)b}\Big(\sum_{j\neq i} s_j - NP_{t-1}\Big) - \frac{1+b}{1-(N-2)b}Q.$$

Thus investor i faces a multidimensional signal-extraction problem. The solution takes the form

$$(6)\quad \hat{\alpha}_i = P_{t-1} + c_1\Big(\sum_{j\neq i} x_j^{-i} - Q\Big) + c_2(s_i - P_{t-1})$$

where c_1, c_2, and the investor's residual uncertainty about α_0, $\hat{V}$, are complicated functions of the parameters.[13]

Equation (3) and $\sum_{j\neq i} x_j^{-i} - Q$ determine the price that would prevail if the investor did not trade; equations (1) and (3) determine the slope of the supply curve. Together these yield

$$(7)\quad P(x_i) = P_{0i} + \phi x_i$$

$$P_{0i} = P_{t-1} + \theta\Big[\sum_{j\neq i} x_j^{-i} - Q\Big]$$

$$\phi = \frac{1+b}{1-(N-2)b}\theta.$$

With constant-absolute-risk-aversion utility and normally distributed payoffs, investor i's expected utility is

$$-\exp\{-\rho(E[C_i] - \rho\operatorname{Var}[C_i]/2)\}.$$

The investor therefore maximizes

$$E[C_i] - \rho\operatorname{Var}[C_i]/2.$$

$E[C_i]$ is given by $[\hat{\alpha}_i - P(x_i)]x_i = (\hat{\alpha}_i - P_{0i} - \phi x_i)x_i$. $\operatorname{Var}[C_i]$ is simply $(\hat{V} + V_\omega)x_i^2$. Thus,

$$(8)\quad x_i = \frac{\hat{\alpha}_i - P_{0i}}{\rho(\hat{V} + V_\omega) + 2\phi}.$$

Expression (8) shows that x_i is linear in $\hat{\alpha}_i$ and P_{0i}. Since these in turn are linear in s_i, P_{t-1}, and $\sum_{j\neq i} x_j - Q$, the investor's demand is linear in the items in his or her information set, as assumed in (1). Equilibrium at a single trading date occurs when the coefficients on $s_i - P_{t-1}$ and $\sum_{j\neq i} x_j - Q$ implicit in (8) are the same as those assumed initially in (1). Solving for these equilibrium values of a and b analytically is intractable; I therefore solve for them numerically below.

Finally, characterizing the determination of the number of informed investors trading at each date is conceptually straightforward. Assuming that investors' signals are informative enough to cause some to pay the cost F and trade immediately, equilibrium occurs when the number trading at the initial date is such that investors are just indifferent concerning whether to pay the fee. Because it is not possible to solve for the equilibrium in a single period analytically, it is also not possible to solve for the allocation of investors across periods analytically; thus, again I employ numerical methods.[14]

[13]Specifically,

$$c_1 = [1-(N-2)b]V_\varepsilon V_{u,t-1}/[a\Delta]$$

$$c_2 = \Big\{V_\varepsilon + (1+b)^2 V_Q\Big/[(N-1)a^2]\Big\}V_{u,t-1}/\Delta$$

and $\hat{V} = c_2 V_\varepsilon$, where

$$\Delta = V_\varepsilon^2 + NV_\varepsilon V_{u,t-1} + (1+b)^2 V_Q(V_\varepsilon + V_{u,t-1})\Big/[(N-1)a^2].$$

[14]At least for the cases to be considered, the benefits to an investor of trading immediately are a decreasing function of the number of other investors who are also trading immediately. As a result, there is a unique equilibrium number of informed investors who trade immediately.

C. *Illustrative Calculations*

In this subsection I show that trading by informed investors after the initial trading date can yield substantial price movements even though each individual investor's incentive to trade immediately is small. For convenience, rather than assuming a given cost of trading immediately (F) and solving for the time pattern of trading by informed investors, I take that time pattern as given and find the incentive to trade immediately. In other words, I solve for the value of F needed to yield the assumed pattern of trading given the other parameters.

To make the model's quantitative implications as clear as possible, I begin with an approximate calculation of the incentives to trade and the size of the price movements after the initial date. The approximate calculation employs three simplifying assumptions.

The first simplifying assumption is that an informed investor considering trading at the first trading date faces a flat supply curve of the asset—that is, that investor i can trade any quantity at price P_{0i}. This assumption will clearly result in an overstatement of the incentive to trade immediately. With this assumption, reasoning analogous to that used to derive (8) implies

$$x_i' = \frac{\hat{\alpha}_i - P_{0i}}{\rho\left(\hat{V} + V_\omega\right)}. \tag{9}$$

My second simplifying assumption is that informed investors pay the fee F and trade at the initial date until they are indifferent between doing this and not participating in the market at all. This assumption also leads to upward bias in the estimate of the incentives to trade at the initial date. Investor i's expected utility is

$$-\exp\{-\rho(E[C_i] - \rho\operatorname{Var}[C_i]/2)\}.$$

Under the assumption that the investor can trade any amount at P_{0i}, it follows from (9) that trading raises expected utility by the same amount as would be achieved by raising $E[C_i]$ by $(\hat{\alpha}_i - P_{0i})^2/[2(\hat{V} + V_\omega)]$. Thus the expected gain from trading, in units of consumption, is[15]

$$E[\Delta U] = \frac{1}{2}\left[\frac{\operatorname{Var}(\hat{\alpha}_i - P_{0i})}{\rho\left(\hat{V} + V_\omega\right)}\right]. \tag{10}$$

Expression (10) can be written in a more readily interpretable form. The investor's coefficient of relative risk aversion (A) at a given level of wealth equals the coefficient of absolute risk aversion (ρ) times wealth (W): $A = \rho W$. $\hat{V} + V_\omega$ is the investor's uncertainty about the asset's payoff; this can be written as the variance of the market return per unit time ($\bar{V}$) times the length of time (n) before the event concerning which the investor possesses a signal is realized and therefore becomes fully incorporated in the market price. Thus,

$$\frac{E[\Delta U]}{W} = \frac{1}{2}\left[\frac{\operatorname{Var}(\hat{\alpha}_i - P_{0i})}{An\bar{V}}\right]. \tag{11}$$

My final simplification is to assume directly that the variance of the change in price due to the trading of the informed investors after the first trading date is some exogenous fraction f of what it would be if those investors' signals were simply announced publicly. Below I set $f = \frac{1}{4}$; the numerical solutions of the model that follow show that this figure is conservative. Letting M' be the number of informed traders who do not trade at the initial date, one can show that the variance of the change in P would be $[M'V_{u1}/(M'V_{u1} + V_\varepsilon)]V_{u1}$ if all of their information became known, where V_{u1} is arbitrageurs' residual uncertainty about α_0 after the initial round of trading. Thus, since only fraction f of the information

[15]Since the expected gain from trading is random *ex ante* (it depends on the realization of $\hat{\alpha}_i - P_{0i}$), the amount the investor is willing to pay to trade at the initial date is in fact less than $E[\Delta U]$; thus, again I overstate the incentives to trade immediately.

becomes known,

$$\text{(12)}\quad \operatorname{Var}(\Delta P) = f\frac{M'V_{u1}}{M'V_{u1}+V_{\varepsilon}}V_{u1}.$$

Consider first informed investors' incentives to trade immediately. I set $\bar{V}$, the variance of the annual expected return on the market, to 0.2^2. I consider two possible values of An. The first is $A=1$, $n=1$: investors are not highly risk-averse (utility is locally logarithmic) and the relevant horizon is short. The second is $A=5$, $n=4$: there is moderate risk-aversion, and the time period involved is longer. I then ask what incentives an informed investor has to trade when $\operatorname{Var}(\hat{\alpha}_i - P_{0i}) = 0.001^2$ and when $\operatorname{Var}(\hat{\alpha}_i - P_{0i}) = 0.005^2$. In the first case, each informed investor possesses information that on average causes him or her to believe that the market price is incorrect by 0.1 percent. In the second case, the error is 0.5 percent.

For $An=20$ and $\operatorname{Var}(\hat{\alpha}_i - P_{0i}) = 0.001^2$, the implied value of $E[\Delta U]/W$ is 0.00006 percent—about 60 cents for a millionaire. For $An=20$ and $\operatorname{Var}(\hat{\alpha}_i - P_{0i}) = 0.005^2$, the figure is 0.0016 percent (16 dollars for a millionaire). With $An=1$, the implied values of $E[\Delta U]/W$ are higher by a factor of 20: 0.0013 percent for $\operatorname{Var}(\hat{\alpha}_i - P_{0i}) = 0.001^2$ (13 dollars for a millionaire), and 0.031 percent for $\operatorname{Var}(\hat{\alpha}_i - P_{0i}) = 0.005^2$ (310 dollars). Thus, it is possible for individual investors to believe rationally that the market is misvalued by several tenths of a percent without possessing any significant incentive to trade on the basis of that information.

To find the size of the price movements after the first round of trading, three additional parameters are relevant: f, V_{u1}, and M'.[16] As described above, I set $f=\frac{1}{4}$. I set V_{u1}, arbitrageurs' uncertainty about α_0 after the first round of trading, to 0.2^2; for the most part, fairly substantial changes in this parameter have no important effect on the results. I consider two possible values of M', the number of informed investors who trade after the initial date: 1,000 and 10,000. With $M'=1{,}000$, the implied values of $\sigma(\Delta P)$ are 1.6 percent if $\operatorname{Var}(\hat{\alpha}_i - P_{0i}) = 0.001^2$ and 6.2 percent if $\operatorname{Var}(\hat{\alpha}_i - P_{0i}) = 0.005^2$. For $M'=10{,}000$, the corresponding figures are 4.5 percent and 9.3 percent, respectively. Thus, subsequent rounds of trading lead to price movements of several percent or more without the arrival of any outside news.

Explicit numerical solution of the model strengthens these conclusions. Most importantly, the assumption in the approximate calculations that informed investors attach zero value to trading after the first date leads to considerable overstatements of informed investors' incentives to trade immediately. A complete solution of the model requires specification of four additional parameters: the probability that a trader who does not pay the fee F trades at some date (p); the number of trading periods (T); the number of informed investors who trade at the initial date $[M-(M'/p)]$; and the variance of supply (V_Q). Two features of these additional parameters prove important. The first is the relative size of the random supply and the trading by informed investors; the larger the role of informed investors' trading, the smaller are their gains from trading, and the more their information is incorporated into prices. The second is p; the larger is p, the smaller are the benefits of trading immediately.

For my baseline computations, I assume $p=\frac{1}{2}$, 100 informed traders at the first date, T such that 20 informed investors trade at each subsequent date (so $T=51$ if $M'=1{,}000$, 501 if $M'=10{,}000$), and $V_Q=10^{10}$ (which implies that roughly 40 percent of the variance of trading at each date after the first is due to the informed investors if $\operatorname{Var}(\hat{\alpha}_i - P_{0i}) = 0.005^2$, and 25 percent if $\operatorname{Var}(\hat{\alpha}_i - P_{0i}) = 0.001^2$). I set $V_0=0.04$ and either $A=1$, $V_\omega=0$ (which corresponds to $n=1$, $\bar{V}=0.04$, since $n\bar{V}=V_\alpha=V_0+V_\omega$),

[16] Ignoring the very small amount of information that an informed investor obtains from observing $\Sigma_{j\neq i}x_j - Q$ rather than $\Sigma_j x_j - Q$ (as I do in this approximate calculation), $\operatorname{Var}(\hat{\alpha}_i - P_{0i})$ is given by $[V_{u1}/(V_\varepsilon + V_{u1})]V_{u1}$. Thus V_ε is implied by V_{u1} and $\operatorname{Var}(\hat{\alpha}_i - P_{0i})$: $V_\varepsilon \simeq \{[V_{u1}/\operatorname{Var}(\hat{\alpha}_i - P_{0i})]-1\}V_{u1}$, and so $\operatorname{Var}(\Delta P) \simeq fM'\operatorname{Var}(\hat{\alpha}_i - P_{0i})V_{u1}/[V_{u1}+(M'-1)\operatorname{Var}(\hat{\alpha}_i - P_{0i})]$.

or $A = 5$, $V_\omega = 0.12$ (corresponding to $n = 4$, $\bar{V} = 0.04$). Finally, I adjust V_ε so that $\text{Var}(\hat{\alpha}_i)$ at the first trading date is either 0.005^2 or 0.001^2.

With these assumptions, the incentives to trade immediately are small: 12 dollars for a millionaire if $An = 1$, $M' = 10{,}000$, and $\text{Var}(\hat{\alpha}_i - P_{0i}) = 0.005^2$, and 60 cents if $An = 1$, $M' = 10{,}000$, and $\text{Var}(\hat{\alpha}_i - P_{0i}) = 0.001^2$. (Again the figures are smaller if $An = 20$.) The price movements after the first period are large: for $M' = 10{,}000$ and $An = 1$, $\sigma(\Delta P) = 16.9$ percent if $\text{Var}(\hat{\alpha}_i - P_{0i}) = 0.005^2$ and 4.8 percent if $\text{Var}(\hat{\alpha}_i - P_{0i}) = 0.001^2$. For $M' = 1{,}000$, the figures are 9.1 percent and 1.6 percent.

Substantial changes in the parameter values do not change the basic character of the results. Consider the baseline case with $\text{Var}(\hat{\alpha}_i - P_{0i}) = 0.005^2$, $M' = 10{,}000$, and $An = 1$; these imply $E[\Delta U] = \$12$ for a millionaire and $\sigma(\Delta P) = 16.9$ percent. Starting from these values, changing An to 20 lowers $E[\Delta U]$ to \$5 and $\sigma(\Delta P)$ to 9.7 percent; raising the number of investors who trade at the first date to 200 lowers $E[\Delta U]$ to \$5 and has a negligible effect on $\sigma(\Delta P)$; raising V_Q to 10^{11} raises $E[\Delta U]$ to \$32 and lowers $\sigma(\Delta P)$ to 16.1 percent; lowering T to 101 (and raising V_Q to 4.96×10^{11}, so that the variance of total supply over all periods is unchanged) raises $E[\Delta U]$ to \$36 and has almost no effect on $\sigma(\Delta P)$; raising p to 1 lowers $E[\Delta U]$ to virtually zero (\$0.06) and leaves $\sigma(\Delta P)$ unchanged; and lowering V_0 to 0.0225 has little impact on $E[\Delta U]$ and reduces $\sigma(\Delta P)$ to 13.4 percent.

In such a setting, changes in asset prices without news would be commonplace. Suppose there were some event whose implications for future profits were uncertain. The event would lead to an initial jump in asset prices in response to the "conventional wisdom" about the event's implications and to any trading by informed investors. In addition, however, the gradual appearance of investors who had not yet traded in response to that information, many of whom possessed estimates of the implications of that information that differed from the market's, would lead to additional changes in prices. Thus the market, rather than information about fundamentals, would be the source of price movements, and asset prices would respond to news that was already publicly available. Yet those phenomena would reflect rational revisions of estimates of fundamentals.

III. Conclusion

Stock-market analysts, and economists, are very often unable to identify news that could plausibly have led to observed changes in stock prices. This paper shows that this fact need not reflect a failure either of market analysts or of the hypothesis of investor rationality. It demonstrates that there can be rational changes in the market's estimates of fundamentals without the arrival of any new information other than that conveyed by the market itself, and presents two models that illustrate this general idea.

I conclude the paper by arguing that this view—that price movements that occur without any clear news often do convey information about fundamentals—has several important advantages over the alternative view that they largely represent "fads" (Shiller, 1984) or "noise" (De Long et al., 1990). My argument has four elements.

First, if price movements without outside news were irrational, rational investors' estimates of fundamentals would often differ substantially from market prices. For example, if the 20-percent fall in the value of the market of October 19, 1987, contained no information about fundamentals, then the opening and closing prices that day were equally informative concerning fundamentals; thus in the absence of any other information, a rational investor's best estimate of fundamentals would be the average of the two prices. More generally, the investor's estimate of fundamentals would be considerably below the market price after a series of rises without outside news, and it would be considerably above the market price after a series of falls. In reasonable cases, both the incentives to exploit this information and the size of the resulting trades would be large. Consider for concreteness an investor who believes that the market is overvalued by 20 percent. If "fads" in prices decay exponentially at a rate of 2 percent per month (the value suggested by Lawrence H. Summers [1986] and James M. Poterba and Summers [1988]), the expected return on the market is 4.3 percent below its normal value over the coming year, 7.6 percent over two years, and 14.0 percent over five years. Paralleling the analysis in Section II, one can show that if the market return over T years has a variance of $(0.2)^2T$, the expected utility gain (as a fraction of initial wealth) from holding the market for T years is given by $(1-e^{-0.24T})^2/(AT)$. The expected utility gain is maximized for a holding period of about five years. The resulting increases in expected utility are large: roughly 10 percent of initial wealth if the coefficient of relative risk aversion, A, is 1; and 2 percent if $A=5$. The investments that would be undertaken are also large: about 68 percent of initial wealth if $A=1$, 14 percent if $A=5$. Thus "fads" models suggest large profit opportunities.

Second, Robert B. Barsky and De Long (1990, 1993) argue that the large decade-to-decade swings in the U.S. stock market over the 20th century agree closely with what would be expected if investors were rationally attempting to estimate an uncertain and potentially changing growth rate of dividends or earnings. Short-run changes in stock prices are approximately serially uncorrelated or slightly positively serially correlated (Andrew W. Lo and A. Craig MacKinlay, 1988; Poterba and Summers, 1988). Thus, if Barsky and De Long are correct that the large swings are largely rational, it would not be possible for a large fraction of short-run price movements to represent "noise." French and Roll (1986), for example, report that the "shadow volatility" of the market on days that it is closed is about one-seventh of its volatility on similar days when it is open. Yet if anything remotely close to six-sevenths of short-run price movements were unrelated to fundamentals, the amount of short-run movements that remained would be far too small for the market to track the long-run changes in rational assessments of fundamentals that Barsky and De Long argue they have identified.

Third, a variety of pieces of evidence at least suggest that there are delayed reactions to publicly available information and that price movements that are not clearly linked to news do convey information about fundamentals. To take a simple example, traders in the London market monitor the New York opening closely; such behavior makes sense if traders in New York possess relevant information that is partially conveyed by their trading activity. Mervyn A. King and Sushil Wadhwani (1990) provide formal evidence in support of this view: they show that London prices of U.S. stocks respond little to announcements of U.S. economic data until the U.S. market opens, and they speculate that this reflects the relative inability of London traders to evaluate the announcements' implications. Similarly, Robert F. Engle et al. (1990) find that the short-run volatility of exchange rates is positively serially correlated across the New York, Tokyo, and London markets; they argue that the most plausible interpretation of this finding is that new information is incorporated into exchange rates only gradually. French and Roll's (1986) finding that the market being open is itself associated with greater price volatility further supports the view that market activity conveys information about fundamentals. Theories based on fads and noise, although consistent with this finding, do not predict it.

Finally, market participants and analysts appear to believe that the market does not completely process public information immediately and that the trading process gradually conveys information about investors' beliefs. Shiller (1989) reports that many investors attributed the 1987 crash to the budget deficit and to general levels of indebtedness in the economy, despite the absence of any significant recent news about these subjects; he also reports that investors considered the declines in the market in the week before October 19 and the initial decline that morning to be the most important proximate "news" triggering the crash. Analyses of market developments, such as those in the *Wall Street Journal*, often describe price changes (particularly the direction and size of reactions to news) as conveying information. Similarly, it is not uncommon for the *Journal* to describe price movements as representing revisions of the market's assessment of the implications of past news.

In an extreme "efficient-markets" view of the functioning of financial markets, asset markets mechanically process all information and effortlessly arrive at optimal estimates of fundamentals. This extreme view has not fared well empirically. Much recent work advocates the opposite extreme: that markets are grossly irrational, with large and unfounded waves of optimism and pessimism causing sudden price shifts and large departures of prices from fundamentals. This paper suggests an intermediate view: that the market is, in effect, engaged in a many-dimensional and a many-agent inference problem with multiple layers of uncertainty and heterogeneity and with frictions in the trading process. As a result, market prices are not related in any simple and mechanical way to news. Nonetheless, market participants are groping toward reasonable estimates of fundamentals, and price movements, even when they are unrelated to outside news, generally represent improvements in assessments of underlying fundamentals.

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