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TRADING, COMMUNICATION AND THE RESPONSE OF ASSET PRICES TO NEWS*

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In this paper we explore the link between asset price changes and the arrival of news. Keynes' beauty contest, and unexplained price movements such as stock market crashes, illustrate a disquiet in the economics profession that asset price movements often appear to bear little relationship to changes in fundamentals. Recent empirical work suggests that the trading process itself is the mechanism for information exchange. Stock return variances are higher during trading hours than during non-trading hours, and longer trading hours are associated with higher trading volume (see Oldfield and Rogalski, 1980; French and Roll, 1986; Meese, 1986; Barclay *et al.* 1990). Our model is designed to emphasise that the price change following the arrival of news need not be a quick, smooth response. The pattern of the price response over time may be so complicated that there is no apparent relationship between the arrival of new information and the price.

We allow for learning via trading and consider the response of price over time when there are multiple informed traders and an information structure which is intended to capture the notion that information is difficult to interpret. The potentially complex price response is caused by the complexity of the information that the traders receive. In order to illustrate this we model an example of an information structure with the property that news may cause the price to fall initially and then rise. This reversal of the price path corresponds to traders initially believing that the news is bad and then revising their valuations in light of the other traders' reactions.

Apparently unusual price paths may occur when the information differs from the standard 'truth plus noise' paradigm in which each agent receives a private signal equal to the true value plus an error term. Then the exchange of information leads to averaging the individual valuations. The 'truth plus noise' structure leads to a price response in which, on average, the initial reaction is followed by successively smaller responses in the same direction. Our information structure shows that this is not true in general. Consider the following illustration.

Cray Research is a leading manufacturer of supercomputers. In 1989 Seymour Cray, the founder of the company, was engaged in a large research project to develop a new computer technology which if successful would give the company a strong competitive advantage. The company however, had not

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decided whether to continue research on the project and Mr Cray was considering leaving to found a separate company.[1]

Consider two analysts, one of whom learns whether Mr Cray is leaving the firm or not while the other has an advantage in evaluating the new technology. The possible outcomes are as follows: (1) Mr Cray stays and the technology is successful in which case Cray stock will have a high value; (2) Mr Cray stays and the project fails in which case the stock will have a low value; (3) Mr Cray leaves and the project is successful in which case Cray stock will have a low value; (4) Mr Cray leaves but the project fails leaving Cray Research as the dominant firm and hence highly valued.

Suppose the analysts' prior beliefs are that Mr Cray will stay and that the project will succeed. What happens if one analyst learns that Mr Cray is likely to leave, and the other analyst studies the technology and decides that it is more likely to fail than is generally recognised in the market? After receiving his private signal, each analyst believes the shares are of low value. If each sells Cray stock, the price will fall. Realising that the low price reflects sales by the other trader, each infers the signal received by the other trader and revises his valuation upwards. Then buying causes the price to rise again. There is a price reversal as the information is revealed through trading. While this particular reversal is rather special, the general point is that complex price dynamics can emerge when the interpretation of agents' signals depends on the information received by other agents.

I. THE MODEL

We consider an asset market in which two informed traders interact with each other and with a downward sloping noisy linear demand curve. There are three trading periods, followed by a final period in which the value of the asset is realised and consumption takes place.[2] In period 0 the market opens but no information has been received. Then the two traders receive private signals about the value of the asset. In period 1 they trade on the basis of this information. In period 2 traders have an opportunity to trade based on their inferences from the period 1 price.

Each informed trader receives a private signal, A or B. If both get the same signal the value of the asset, V, will be 1. If they receive different signals, $V = 0$. The chance of signal A, α, exceeds $\frac{1}{2}$ and is independent of the other signal. Thus A represents 'good news' on its own, but in order to evaluate it fully the trader needs to know the other signal. Note that the unconditional (period 0) valuation is $\alpha^2 + (1-\alpha)^2$.

There is a probability $(1-\delta) \in (0, 1)$ that the asset value will be publicly revealed immediately after period 1. The characterisation of the equilibrium in period 2 will be conditional on the information not being revealed. Otherwise

[1] See *Business Week*, April 30 1990.

[2] Within each period the model is analogous to a standard Cournot duopoly, but one where the sellers have private information about the common, unknown, production cost. In our model the demand curve will also adjust to reflect past information, as will be seen.

the informed traders have no advantage in period 2, and the price will simply reflect the true value.

Let Q^j_t be the quantity sold by trader j in period t (a negative value of Q^j_t represents a purchase).[3] S^j denotes trader js signal, A or B.

Trader js strategy is a rule for choosing Q^j_t, described by a triple $\langle q_0, q_1(S^j), q_2(S^j, P_1, Q_{1j})\rangle$.[4] q_0 is the quantity sold in period 0. In period 1 the trader sells $q_1(A)$ if A was received, and $q_1(B)$ if B. In period 2 the quantity depends on the expected value of the asset, and on the prediction of the other trader's period 2 quantity. These are inferred from trader js own signal, his period 1 quantity, and the period 1 price. (Note the distinction between uppercase Q, denoting an arbitrary quantity, and lowercase q denoting the quantity prescribed by the trader's strategy.)

The payoff to a trader is the expected value of his final holding of the asset, less the amount of money paid to acquire the position. This may be decomposed into the sum of per-period payoffs, where the payoff in each period is the difference between the expected value of the assets acquired and the amount of money paid for them (and *vice versa* in the case of a sale).

The two informed traders face a noisy downward sloping demand curve,

$$P_t = a_t - bQ_t + \epsilon_t,$$

where $\epsilon_t \sim \mathrm{N}(0, \sigma^2)$.[5] Note that the intercept is the expected price if the informed traders do not trade. We assume that it adjusts over time so that uninformed speculators cannot enter and make excess returns. In particular, in period 2 the intercept depends on the period 1 price. This is a market efficiency condition. The slope and the error term may be interpreted as representing agents with random transitory alternative investment opportunities. They may be willing to sell an undervalued financial asset in order to invest in superior real alternatives (children's college, daughter's wedding, family business, etc). They are willing to pay a premium to satisfy these 'liquidity needs' but they are not willing to pay any price, hence the finite slope. We consider limiting equilibria as the variance of the noise tends to zero.

In equilibrium an informed trader has an incentive to spread his trades over both remaining periods because the market is not infinitely deep. His period 1 trade affects the price and so provides the other trader with information about his signal. Symmetrically, he will learn from the period 1 price about the other trader's signal. This gives an additional incentive to restrict period 1 quantities, because of the desire to deceive other traders.

We now discuss the symmetric Nash equilibrium of the model. For reasons of space we omit the detailed derivation of the equilibrium strategies and give

[3] There are no restrictions on borrowing and short sales.

[4] We describe the symmetric Nash equilibrium of the game, so the equilibrium strategies are not indexed by j.

[5] Since our focus in this paper is on the effect of information exchange on the price path, we adopt a simple exogenous price-formation process. The main requirement for our analysis is a price-formation institution which raises the price when people buy and lowers it when people sell. Modelling price formation is a difficult theoretical problem; there are a number of models which are less *ad hoc* than the one we use here, but they are sufficiently complicated that they would be intractable in the present setting. See Kyle (1985) and Glosten and Milgrom (1985).

only the briefest description. We also omit some of the proofs of results. The details are available in Dow and Gorton (1991).

Equilibrium in period 0 may be solved independently of the other periods. The expected price is equal to the expected value, $\alpha^2+(1-\alpha)^2$, and the informed traders do not trade ($q_0 = 0$).

Periods 1 and 2 are connected and the equilibrium solution is derived recursively. In period 2, trader j has beliefs that the other agent has the same signal. This probability that the other agent has the same signal is also equal to the expected value of the asset (since $V = 0$ or 1), conditional on the agent's information. We denote this expectation by:

$$\mathrm{E}_2^j(V \mid S^j, Q_1^j, P_1).$$

Here the superscript j on the expectation denotes the agent who is forming the expectation, and the subscript $t = 1, 2$ denotes the time period. This belief about the other agent's signal is also used to predict the other trader's period 2 quantity, given that the other trader is playing the equilibrium strategy. Together with trader js period 2 quantity, this allows him to predict the period 2 price:

$$\mathrm{E}_2^j(P_2 \mid S^j, Q_1^j, P_1, Q_2^j).$$

Trader j then chooses Q_2^j to maximise his payoff. We define $u_2^j(S^j, P_1, Q_1^j)$ to be the value function giving the period 2 payoff:

$$u_2^j(S^j, P_1, Q_1^j) = \max_{Q_2^j} [\mathrm{E}_2^j(P_2 \mid S^j, Q_1^j, P_1, Q_2^j) - \mathrm{E}_2^j(V \mid S^j, Q_1^j, P_1)]\, Q_2^j.$$

The expected value of period 2 profit, after choosing period 1 quantities but before the period 1 price is known, is:

$$\begin{aligned} U_2^j(S^j, Q_1^j) &= \mathrm{E}[u_2^j(S^j, P_1, Q_1^j)] \\ &= \int_{\mathbb{R}} u_2^j(S^j, P_1, Q_1^j)\, \phi(P_1)\, dP_1, \end{aligned}$$

where $\phi(P_1)$ is the density of P_1.[6]

The profit from period 1 is:

$$U_1^j(S^j, Q_1^j) = [\mathrm{E}_1^j(P_1 \mid S^j, Q_1^j) - \mathrm{E}_1^j(V \mid S^j)]\, Q_1^j.$$

In period 1, trader j chooses Q_1^j to maximise the sum of the period 1 payoff and the value of the period 2 payoff:

$$\max_{Q_1^j} U_1^j(S^j, Q_1^j) + \delta U_2^j(S^j, Q_1^j).$$

The period 2 value enters because his period 1 quantity will affect the price and reveal information about his signal. It is possible to derive a closed-form

[6] The density can be derived from the normal distribution of the error term, together with the distribution of the possible quantities traded by the other trader (as a function of his signal). See Dow and Gorton (1991) for details.

solution for the period 2 equilibrium strategies. It can then be shown that the optimal period 1 quantity for trader j, given that the other trader (trader i) plays the equilibrium strategy $q_1(S^i)$, is

$$Q_1^j = \{a_1 - b[\alpha q_1(A) + (1-\alpha)\, q_1(B)] - \mathrm{E}_1^j(V \mid S^j) \\ - (\delta b/\sigma^2)\, \mathrm{Cov}\, [u_2^j(S^j, P_1, Q_1^j), P_1]\}/2b, \quad (1)$$

and that

$$a_1 = a_0 + 2b[\alpha q_1(A) + (1-\alpha)\, q_1(B)] \quad (2)$$

by the market efficiency condition. The expression for the optimal quantity may be viewed as follows: the first part, $a_1 - b[\alpha q_1(A) + (1-\alpha)\, q_1(B)]$, is the expected price for trader js first (infinitesimal) unit traded. The second part, $\mathrm{E}_1^j(V \mid S^j)$ is trader j's expectation of the asset value. The third part, $(\delta b/\sigma^2)\, \mathrm{Cov}\, [u_2^j(S^j, P_1, Q_1^j), P_1]$, represents the effect of trader js period 1 trade on his period 2 payoff: by restricting his period 1 quantity, he reveals less information about his signal and increases his period 2 payoff. In equilibrium the optimal quantity, as given by the above expression, must equal $q_1(S^j)$.

II. BELIEF AND PRICE REVERSALS

We will describe the equilibrium price paths as a function of the different combinations of private signals. We focus on the case when the two traders each receive a B signal. The equilibrium price path in this case illustrates the effect of learning with our information structure: the period 1 price will be low, but will be followed by a high period 2 price.

Suppose that both traders receive signal B. In period 1 both traders believe the asset is more likely to be worth zero than one, and so they will sell the asset. Conversely if they both receive good news (signal A) they will buy the asset. This implies that when both traders receive B signals the period 1 price will, on average, be lower than the period 0 price.

In period 2 both traders will probably have observed a low price in period 1. They will tend to infer that the other trader also received a B signal. This implies that the asset is valuable, so they will both revise their beliefs upwards. In addition, since the low period 1 price is publicly observable, the rest of the market will also tend to infer that both traders received B signals and demand will shift upwards. The price in period 2 will tend to be high. So long as the amount of noise is sufficiently low, there will be a reversal: the average price in period 2 will exceed the period 0 price.[7].

In order for any learning to occur, traders must submit different quantities when they receive different signals. It is straightforward to show that this is the case.

PROPOSITION 1. $q_1(A) \neq q_1(B)$.

[7] A weaker type of reversal occurs if expected period 2 price exceed the expected period 1 price, but is less than the expected period 0 price. This will happen if the noise in the market is too large, so that the market price does not communicate much information. By supposing the amount of noise is small we can focus on cases where the period 2 expected price does reflect the correct valuation relative to the period 0 price.

Proof. The proof is by contradiction. If $q_1(A) = q_1(B)$ then no learning occurs, and a trader who deviated in period 1 would only affect his period 1 profit. He would not affect the other trader's inferences. We therefore show that if $q_1(A) = q_1(B)$, such a deviation would be profitable. There are three possible cases:

Case (i): $q_1(A) = q_1(B) = 0$. Since there is no inference from the period 1 price, $U_2^j(A, x) = U_2^j[A, q_1(A)]$ for all quantities x. But for small $x > 0$, $U_1^j(A, x) > 0 = U_1^j[A, q_1(A)]$. In other words, A is good news so the trader can profit in period 1 by buying the asset.

Case (ii): $q_1(A) = q_1(B) < 0$. Again there is no inference from the period 1 price, so $U_2^j(B, 0) = U_2^j[B, q_1(B)]$. But $U_1^j(B, 0) = 0 > U_1^j[B, q_1(B)]$. In other words, a trader who receives a B signal has no incentive to take a loss in period 1.

Case (iii): $q_1(A) = q_1(B) > 0$. This is analogous to case (ii). ■

We now address the direction of the inferences from the period 1 price. We show that traders tend to sell on bad news and buy on good news. This implies that a trader who observes a high period 1 price infers that the other trader received an A signal, and conversely for a B signal.

PROPOSITION 2. $q_1(A) < q_1(B)$.

Proof. Again the proof is by contradiction. Suppose that $q_1(A) > q_1(B)$, so that the probability a trader received a B signal is strictly increasing in the period 1 price. First, note that each trader wants to conceal his information because this leads to more favourable period 2 price. Therefore, if $q_1(A) > q_1(B)$, a trader with a B signal prefers a lower period 1 price and a trader with an A signal prefers a higher period 1 price. In other words $U_2^j(A, Q_1^j)$ is decreasing in Q_1^j, and $U_2^j(B, Q_1^j)$ is increasing in Q_1^j.

Second, observe that $q_1(A) > q_1(B)$ implies that either (i) $q_1(A) > 0$ or (ii) $q_1(B) < 0$ (or both).

Case (i): $q_1(A) > 0$. Since $U_2^j(A, Q_1^j)$ is decreasing in Q_1^j, if the trader deviates from equilibrium by trading nothing in period 1 instead of $q_1(A)$, then period 2 value rises: $U_2^j(A, 0) > U_2^j(A, Q_1^j)$. But period 1 profit rises: $q_1(A) > 0$ implies $U_1^j[A, q^1(A)] < 0$. Consequently $U_1^j(A, 0) = 0 > U_1^j[A, q^1(A)]$.

Case (ii): $q_1(B) < 0$. This is symmetric to case (i). ■

The intuition underlying this result is straightforward. If the traders react to good news initially by selling the asset, then each could unambiguously benefit by deviating: he could simultaneously increase profit in period 1, and increase period 2 profit by manipulating others' beliefs about his signal. Equilibrium requires that the immediate benefits of trading in period 1 be balanced against the subsequent costs of revealing information. This can only happen if $q_1(A) < q_1(B)$. An immediate consequence is that if both traders receive B signals, the period 1 price will fall compared to the period 0 price. If they both receive A signals the price will rise.

Since the period 1 price depends on the quantities traded, which depend on the signals, traders learn from the price. Their beliefs about the each other's signal and about the asset value will, on average, be updated in the right direction.

PROPOSITION 3. (i) *If both traders get B signals, then each trader's expected valuation in period 2 is greater than the expected valuation in period 1.*

(ii) *If both traders get A signals, then each trader's expected valuation in period 2 is greater than in period 1.*

(iii) *If the traders get different signals, then each trader's expected valuation in period 2 is less than in period 1.*

The proof is omitted. Case (i) shows that it is possible that information can initially be interpreted by the informed traders as bad news, and subsequently be viewed as good news. The reversal is not due to noise: in order to make the comparison we averaged out the noise in the system.

We now show that if both traders receive B signals a reversal may occur in which, on average, the period 2 price exceeds the period 0 price, while the period 1 price is less than the period 0 price. Proposition 3 shows that traders' beliefs are revised upwards after period 1, but this does not necessarily mean that they are revised above the initial beliefs ($E_1^j(V|B) = 1-\alpha$). The reversal of the price path will only occur if sufficient learning takes place. Since the model has only two periods after the information arrives, if the demand function is too noisy traders will not learn enough.

PROPOSITION 4. *Consider the limit of the equilibrium as σ^2 tends to zero, in the event that both traders receive B signals. The expected period 1 price is less than the expected period 0 price. The expected period 2 price is greater than the expected period 0 price.*

Proof. Period 1: If both traders receive signal B they each choose $q_1(B)$. By Proposition 2, $q_1(B) > \alpha q_1(A) + (1-\alpha)\, q_1(B)$. Thus

$$E(P_1|BB) = a_1 - b[2q_1(B)] < a_1 - b(2)\,[\alpha q_1(A) + (1-\alpha)\, q_1(B)] = E(P_0),$$

where the latter equality follows since a_1 is determined by the market efficiency condition. Period 2: Suppose that as $\sigma^2 \rightarrow 0$ the equilibrium quantities $q_1(A)$ and $q_1(B)$ are bounded away from each other. Then in the limit learning is complete. In particular if each trader received a B signal and chooses $q_1(B)$,

$$E_2^j(V|B, P_1) \rightarrow 1,$$
$$E(V|P_1) \rightarrow 1.$$

The first statement means that, in the limit, the informed traders infer each other's signal perfectly from the price. The second statement says that even an uninformed observer would learn perfectly. Hence by the market efficiency condition

$$E(P_2|BB) \rightarrow 1 > E(P_0).$$

Now suppose that as $\sigma^2 \rightarrow 0$ the equilibrium quantities $q_1(A)$ and $q_1(B)$ become arbitrarily close. We will show by contradiction that this is impossible.

If period 1 quantities are arbitrarily close then expected period 1 profits are arbitrarily small. On the other hand the period 2 profits cannot exceed δ times the maximum possible period 1 profit-since period 2 profit is the same as period 1 profit if no learning occurs, and less otherwise. Thus a trader would be better off by maximising period 1 profit and ignoring the effect on period 2. This contradicts the initial hypothesis. ■

III. CONCLUSION

When information is difficult to interpret, the price response may display a pattern which bears little resemblance to the final valuation of the asset, or to the date at which information arrived. These price dynamics can be explained by information exchange via the trading process. We have given one example of an information structure with two traders which can display an apparently anomalous price path. In general, information structures which differ from the standard 'truth-plus noise' paradigm can result in a rich pattern of price responses, while remaining consistent with rationality.

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