NBER WORKING PAPERS SERIES

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Working Paper No. 3889

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
October 1991

I would like to thank Ricardo Caballero, Bob Cumby, Jerome Detemple, Mike Gavin, Alberto Giovannini, Jim McCarthy, and seminar participants at Columbia, MIT, NYU, and the NBER Summer Institute for helpful comments and suggestions, and E. Meng Tan for valuable research assistance. Any errors are my own. This paper is part of NBER's research program in International Studies. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

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ABSTRACT

An information externality exists in the foreign exchange market due to the fact that traders play two partially conflicting roles: (i) each is a speculator and (ii) each is an information clearinghouse in that each intermediates own-customer orders which convey information. Profit maximization induces traders to underweight fundamental information in making their trades, reducing the degree to which prices reveal information at any given time. In the model, agents update diverse beliefs over time, with transactions-mediated tatonnement. The explicit role for transactions provides a framework for interpreting the relationship between the diversity of beliefs, trading volume, and price adjustment.

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Private Beliefs and Information Externalities in the Foreign Exchange Market

The highest volume day in the history of the New York Stock Exchange was Monday, October 19, 1987. On that day $21 billion worth of equity changed hands. On the *average* day in the foreign exchange market over $450 billion of currency changes hands, of which over $100 billion is attributed to the New York market alone.[1] Though the comparison is admittedly loose, it is curious in the face of this that ranking exchange rate models admit no role for transactions per se. At the same time, one often hears the statistic that goods trade accounts for only a small fraction of spot volume as an argument why the asset approach dominates older trade flow approaches. Something is missing from the story, and surely an important part of what is missing is differing beliefs regarding the exchange rate's path and destination, and the process of updating those beliefs. This paper addresses some of the characteristics and implications of these differences in beliefs. The principal objectives are three: (i) to recognize the role of transactions per se in the updating of private beliefs *over time*, (ii) to provide some institutional structure to help explain trading volume, and (iii) to investigate the process of information revelation in a market of this type.

Agents transact because they differ. It is important to distinguish between differences in valuation beliefs and differences that arise for other reasons. Of course, it is possible for investors to agree on valuation and still choose to transact for diversification purposes. However, in the context of the typical portfolio choice

[1] The New York Fed (1989) estimated that the average in the U.S. market was about $129 billion per day, adjusted for double counting. The bulk of U.S. trading occurs in New York.

models, the trading volume that can be explained as a result of actual shifts in wealth, taxes, return second moments, etc., is minute in comparison to actual volumes, and in the simplest models is zero.[2] The burden of explanation, then, appears almost certainly to fall on differences in beliefs regarding valuation.

Though differing beliefs are likely in any asset market in which fundamentals are not easily verified, the foreign exchange market provides particularly fertile ground for investigation. First, the empirical specification of fundamentals is especially tenuous in this case, accommodating greater lack of consensus. Second, as stated above, trading volume is exceptionally high. Third, unlike equity markets for example, some of the trading in the market is for pure transactions purposes. And finally, a feature that distinguishes the foreign exchange market from many other asset markets is the fact that there is no centralized exchange, but rather a decentralized network of traders, linked by phone, who abide by certain "rules of the game." To be sure, there is no Walrasian auctioneer. This institutional feature plays an important role in the modeling below.

Turning to previous modeling efforts, the standard specification of diverse information in asset markets involves n investors, each of whom is forming belief about an unknown price P_2 on the basis of a signal that equals the unknown P_2 plus idiosyncratic noise, where the variance of the noise is a measure of the quality of an investor's information. In this context Grossman (1976) shows that there is an equilibrium price P_1 which is a sufficient statistic for all information in the market; that is, the resulting market price reveals information that is of higher quality than every trader's own information. This result is behind the well-known paradox that when information is costly to acquire, investors will simply look to the market price

[2] Though it is true that relatively small shifts in these aggregate variables might be masking considerable idiosyncratic fluctuation, it remains very difficult to explain why foreign exchange volumes should be so much higher than other asset volumes.

for their information; but, if no one chooses to acquire any information then the market cannot aggregate any information, and trading breaks down.

Using the same specification, Figlewski (1982) establishes that though there exists an equilibrium in which price is fully revealing, this is not necessarily the only equilibrium. The outcome depends upon the weights assigned to different traders in the process of price determination. He goes on to point out that when market prices deviate from fundamentals, it is possible for traders to exploit the situation on the basis of covariance between one's own information and the market's error. The problem with this point, however, is that for any trader to have a positive expected profit, another must have a negative expected profit, and surely no one would choose to trade on the basis of a negative expected profit. Therefore, as he points out, trading in this context would require some traders to be incorrect in their assessment of the relevant covariance. This element of his story is not modeled in any way.

The no–trade situation that arises in the Figlewski setting has a history [e.g., Rubinstein (1975) and Milgrom and Stokey (1982)]. Very simply, if one agent has information that induces him to want to trade at the current asset price, then other rational agents would be unwilling to trade with him, because they realize that he must have superior information. Tirole (1982) describes the possibilities for getting around the no–trade result: (1) there may be some risk–loving or irrational traders, (2) insurance and diversification considerations may play a significant role, or (3) agents may have different prior beliefs. For most, irrationality or preferences for risk are not appealing. And, as stated above, pure diversification appears an unlikely explanation for the volume observed. As for different beliefs, Varian (1989, p.6) writes:

> If differences in prior beliefs can generate trade, then these differences in

belief cannot be due to *information* as such, but rather can only be pure differences in *opinion*.

With the word opinion he means that if I convey my probability belief to another and he does not update his posterior at all, then he has interpreted my beliefs as opinion, or as being noncredible.[3] The model in this paper provides an exception to the point made by Varian: differences in belief will be wholly due to information, yet trading will still take place. Moreover, trading continues during the process of learning about others' information. This result follows from the institutional fact that when a trader is asked to quote a price in the exchange market, it is incumbent upon him to commit to a competitive bid and ask rate: to refuse to do so repeatedly, or to quote an uncompetitive spread, would induce other traders to reduce contact, thereby partially excluding the trader from the communications network that makes up the market. More important, if a firm's trader is not viewed as a substantial participant in the market, it is more difficult to attract profitable third party customer-business. Hence, price commitment is one of the rules of the game. I will return to this later.

There is a body of work related to this paper on the topic of how asset prices aggregate diverse information in the presence of exogenous noise. When exogenous (aggregate) noise is present, the fully-revealing equilibrium of Grossman (1976) does not obtain because the noise in the price system prevents agents from learning enough from market-clearing prices [e.g., Hellwig (1980) and Diamond and Verrecchia (1981)]. The model of Diamond and Verrecchia (1981), for example, describes equilibrium price determination as a one-shot outcome that results from

[3] Of course, if all agents are assumed rational, and base their expectations on relevant information, then the rationality of dismissing another's beliefs is called into question. This is not an issue here since an agent learns about others' beliefs as a *result* of trading.

traders with diverse information using both their private information and the information in market-clearing prices to determine their demands for the risky asset.[4]

In contrast, the model below differs from previous work in that transactions per se play an integral part in the expectations updating process. The ultimate equilibrium is not a one-shot outcome; rather, only after the market learns about the individual bits of information are they fully reflected. This tatonnement depends crucially on trading volume, generating a relationship between private beliefs, volume, and volatility. The central result that emerges is an information externality due to the fact that traders play two partially conflicting roles: (i) each is a speculator and (ii) each is an information clearinghouse in that each intermediates own-customer orders which convey information. Profit maximization induces traders to underweight fundamental information in making their trades, reducing the degree to which prices reveal information at any given time.

Although information externalities appear in previous work on asset pricing [Hirshleifer (1971), Grossman (1977), and Stein (1987) are a few examples], the mechanism behind them differs from the one here. In general, these models involve somewhat ad hoc distinctions as to which groups get what information, or lack information altogether. The model here, however, does not require distinctions beyond that which arises out of the institutional structure itself: each trader has sole knowledge of his own-customer order flow. To the extent that this flow conveys information, it is private information.

The paper is organized as follows. The next section describes a set of salient characteristics of foreign exchange trading. Section II introduces a model which is

[4] The example they use of information that needs to be aggregated is the case in which each price in the economy is known by at least one agent, but the consumer price index is not known by each.

useful for understanding the private beliefs/volume/volatility relationship. Section III presents the main results of the paper. Section IV provides some corroborating empirical evidence. Section V concludes.

I. Characteristics of Foreign Exchange Trading

I begin with some observations regarding foreign exchange traders that I feel provide a useful complementary perspective. Of course, traders are not the only participants in the market, and it would be incomplete at best to consider their influence on the exchange rate as the whole story. Nonetheless, their activity provides some interesting background relevant for understanding the volume of trade, diversity of beliefs, and realized exchange rate dynamics. These commonly-observed characteristics of foreign exchange trading provide a helpful backdrop for the model of section II:

(1) Within a day of trading there are typically very few theoretically-relevant pieces of information that become public. Yet, rates can move considerably throughout the day on large trading volume. Of course, this could result, for example, from revisions of expectations due purely to the passage of time; yet, this kind of explanation seems unlikely.

(2) Customer-business (transaction requests from non-traders) generates significant profits for traders, due largely to the bid-ask spread. In general, for a firm to attract customer-business, it has to be perceived as one of the significant participants in the market.

(3) There are times when a given trader will feel strongly about the mispricing of foreign exchange and will take a large open position. Usually, however, open

positions remain fairly small.

(4) Traders very frequently telephone one another for quotes. If the calling party chooses to do the trade, the quoting trader usually rapidly undoes the change in his position.

(5) Traders are continuously reading the size of the order flow, and, perhaps more important, the extent to which trades are effected at the bid or the ask side of the market; when market volume is high, traders are on the edges of their seats.

Before turning to the model I provide a bit more evidence which not only corroborates much of what is outlined above, but also provides considerable further motivation for the model itself. The description is from the appendix of Goodhart (1988, p. 456) in which he describes some of his discussions with London bankers regarding foreign exchange operations:

> A further source of informational advantage to the traders is their access to, and trained interpretation of, the information contained in the order flow. Examples are various . . . Each bank seeks to interpret the activity of other banks in the market; some have a reputation of being able to position themselves well in certain currencies, and their perceived operations may cause others to follow their lead. Each bank will also know what their own customer enquiries and orders have been in the course of the day, and will try to deduce from that the positions of others in the market, and overall market developments as they unfold.

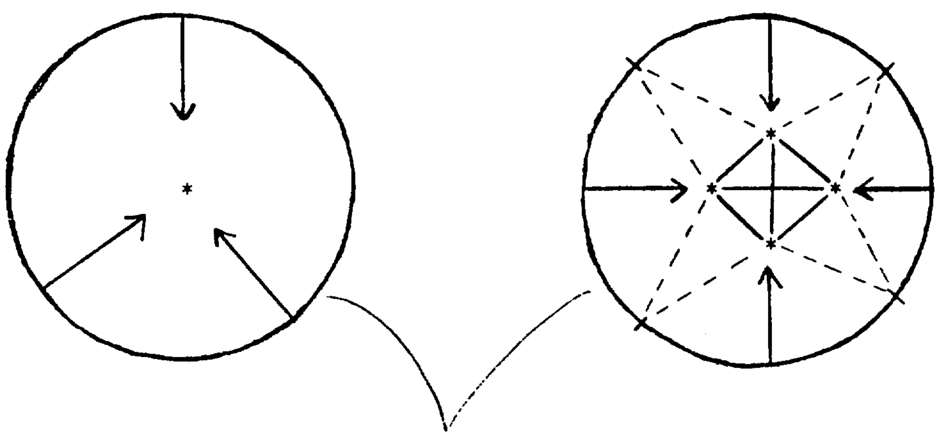
The information contained in the order flow plays an important role in the model of this paper: reading the order flow is an essential part of the tatonnement process. To help set the stage, Figure 1 below provides graphical representation of how the foreign exchange market differs from markets in which there is a single market-maker. The arrows represent the order flow, or more specifically the information contained therein. In the case of a single market-maker, there is a centralized clearinghouse for all information bearing on the proper asset price. In the case of foreign exchange, however, the clearinghouse is partially decentralized in the sense that there is an inner circle of traders through whom the order flow of market participants is funneled. Each, then, has access to this private information, and uses it in placing orders with other traders.[5]

<u>Figure 1</u>

Information Contained in the Order Flow

(A) <u>Centralized Market-Maker</u>

(B) <u>Inner Circle of Traders</u>



Universe of trade-orders at the wholesale level.

[5] In the words of Mr Chris Deuters, Citibank's head of foreign exchange and derivatives in Europe: "If you don't have access to the end user your view of the market will be severely limited" (reported in the <u>London Financial Times</u>, 4/29/91).

II. A Model of Trading

The structure of the model is as follows. There are n traders, each with identical exponential utility (CARA), where n is small in a convergence sense. The initial fundamental value of a single risky asset, P_1, is public information. Before any change in the fundamental, each of the traders is asked by one other trader to quote a price. Hereafter, I will abstract from the bid–ask spread, so that each optimally quotes a single price at the current fundamental of P_1;[6] since each trader must commit to his quote, there would not be any incentive to deviate from this price.

Each of the n traders then observes a one–time–only signal equal to ny_i, where:

$$(1) \qquad y_i \sim \text{Normal}\,(0,\sigma_y^2).$$

Henceforth, I will refer to y_i as trader i's individual information. This information includes, but is certainly not limited to, the information each trader receives from his portion of the total order flow; for this reason I choose to model it as a direct signal, rather than simply as information inferred from the orders he receives. The change in the fundamental of the asset price, Δ, will be the average of the n independent signals:

$$(2) \qquad \Delta = (1/n)\sum_{i=1}^{n} ny_i = \sum_{i=1}^{n} y_i$$

Hence, before observation each trader expects the change in the fundamental to be

[6] Although traders do vary the bid–ask spread at times, there tends to be a common spread in the interbank market at any given time, suggesting this variable is less relevant for heterogeneity issues. For a recent paper on bid–ask spreads see Wei (1991).

zero, with a variance of $n\sigma_y^2$.

This is a setting in which each of the n traders has partial knowledge of fundamentals, each with a different partial view. Of course, it is natural to believe that in reality there is considerable overlap, due to certain types of easily–evaluated public information. However, since my interest here is to focus on the extent to which the partial views differ, I model each trader as possessing some information that no other trader has, in effect orthogonalizing the information sets. Suppose, realistically enough, that it is unclear exactly which regressors belong in the true exchange rate equation, that coefficients are likely to be stochastic, and that different agents have different insights into how to utilize available information. In this setting one might think, as an example, of each trader having received a signal reflecting a better interpretation of public information bearing on a particular dimension of the fundamental, where better refers to recognizing something new of definite relevance, rather than simply smaller error variance. In the end, though, it is not necessary that the differences in beliefs stem wholly from information, only that they are not perceived by traders wholly as differences in *opinion* in the sense defined by Varian. Moreover, the spirit of the approach should not be interpreted as suggesting that only private information matters in the market, but rather that the independent dimension of beliefs is essential for better understanding the diversity of beliefs/volume/volatility relationship, and that the independent dimension of beliefs is not purely noise.

Traders participate in the market for two reasons. First, on the basis of information gleaned from the order flow and elsewhere they attempt to earn profits through speculation. Second, by virtue of being a significant participant in the market, traders earn profits by mediating transaction requests from customers.[7]

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[7] I will assume that the profits earned from customer–business via the bid–ask spread are sufficient to induce a trader to continue in the process of trading even through times of lower

Here, I focus on a particular type of customer business: non-fundamentals transaction requests. In contrast to most other asset markets, foreign exchange trades have a transactions motive as well as a pure speculative motive. Examples include customer transactions for trade in goods/services, the clearing of hedged financial flows, and certain longer-term capital flows (e.g. direct investment). I model this as follows: immediately after traders observe the signal y_i, each receives a one-time-only amount of non-fundamentals customer-business, ϵ_i, where:

$$\epsilon_i \sim N(0, \sigma_\epsilon^2) \quad \text{and} \quad \sigma_{\epsilon\Delta} = 0. \tag{3}$$

At this point, on the basis of his individual information and customer-business, each trader calculates his demand for the asset, and either buys or sells the given quantity from one other trader (denoted T_{i1}, which is positive for purchases, negative for sales). Simultaneously, each trader receives exactly one order from another trader (T_{j1}). Though the received order has an expected value of zero, each trader's actual position at the end of the period will have been disturbed from his ex-ante desired position by the magnitude of the order he receives.[8]

In order to tie the model to fundamentals, it is necessary to specify more fully the possible payoffs. There are two scenarios under which the period-two trading price is determined, with exogenous probabilities ϕ and $(1-\phi)$:

ϕ: The probability that Δ, the change in the fundamental, will be revealed to all at the end of the period.

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quality information, although this is not modeled in any way. Additionally, I make no attempt to model brokers in the market. Typically, brokers mediate much less than half of the volume in major foreign exchange markets, though their share does fluctuate.

[8] In the model there is no limit to the size of the order that must be accommodated by a given trader at the quoted price. In reality, to take the current British pound market as an example, a sale or purchase of more than 5 million pounds would involve an inquiry as to whether the initial quote applies to larger volume.

$1-\phi$: The probability that Δ will not be revealed, and must be estimated.

In the event that Δ is not known at the end of the period traders must estimate it from available information. The statistic available to traders for this purpose is the observed *net* period–one volume, V_1, where:

$$(4) \qquad V_1 \equiv \sum_{i=1}^{n} T_{i1} + \nu_1.$$

Per the definition, the net volume captures the difference in the volume effected at the buying side of the market and the volume at the selling side (since T_{i1} is negative in the case of a sale), with the addition of a noise term, ν_t. It is precisely this statistic that traders say constitutes "feel" for the market, and where it is headed in the (very) short run. Every trader has a sense of it. Its value is communicated by intercoms linked to the primary brokers in the market (not modeled here), where trades effected at the bid are distinguished from those at the ask.

Contingent upon an unknown Δ, the price traders optimally quote in period–two will be determined through signal extraction applied to the net volume V_1. Since the price that each quotes derives from the common signal, this price reflects all public information available at that time. As established below, this will be the unique equilibrium quote since no trader has an incentive to deviate from it. Each trader then recalculates his demand on the basis of his updated beliefs. There remains, however, private information that is not yet fully reflected. The process by which this information is communicated is dependent upon successive rounds of trading. That is, tatonnement is volume–mediated.

Table 1 provides a summary of the model's timing.

Table 1

The Timing of the Model

Period 1

(1) Each trader optimally quotes P_1, the known fundamental.

(2) Each trader receives a y_i and an ϵ_i, individual information and a customer–order.

(3) Each trader simultaneously issues a trade–order, T_{i1}, and receives one at P_1.

(4) Each trader observes V_1, the (noisy) net period–one volume.

Period 2 (Δ unknown)

(1) Each trader optimally quotes P_2 at the conditional–on–public–information mean.

(2) Each trader simultaneously issues a trade–order and receives one at P_2.

(3) Each trader observes V_2.

Consider now the investment decision. Each agent determines his demand for the risky asset by maximizing utility defined over the mean and variance of end–of–period wealth. Letting W_{ij} denote the end–of–period j wealth of trader i, (r–1) the risk–free rate, and Z_{ij} the period j position in the risky asset, we have:

$$\max_{Z_{i1}} U[E(W_{i1}), \mathrm{Var}(W_{i1})] \tag{5}$$

$$\text{s.t.} \quad \begin{cases} W_{i1} = rW_{i0} + Z_{i1}(P_2 - rP_1) & \text{for } Z_{i1} \geq 0 \\ W_{i1} = rW_{i0} + Z_{i1}(P_2 - P_1/r) & \text{for } Z_{i1} < 0 \end{cases}$$

where P_2 is the beginning–of–period–two price as described above, which is the price at which the trader unwinds his position. Henceforth, the risk–free rate is set equal to zero. With exponential utility we can write the problem as:

$$\max_{Z_{i1}} \; [E(W_{i1}) - (\theta/2)\mathrm{Var}(W_{i1})] \tag{6}$$

which yields an optimal position in the risky asset, whether investor or trader, of:[9]

$$Z_{i1} = \frac{E_i P_2 - P_1}{\theta \sigma^2_{P_2} - \alpha_1} \tag{7}$$

and resulting trade–order from the trader of:

$$T_{i1} = Z_{i1} + \epsilon_i \tag{8}$$

where $E_i P_2$ is the expected beginning–of–period–two price, θ is the coefficient of absolute risk aversion, $\sigma^2_{P_2}$ is the conditional variance of P_2, and $\alpha_1 \equiv dP_2/dZ_{i1}$, a coefficient representing the impact of individual demands on price, which is common to all traders.

It is not true in this context that trader i expects the price change between periods one and two, $E_i P_2 - P_1$, to be equal to y_i, his individual information. The reason is that, in determining the proper period–two price, the market can respond only to i's total trade (via the net volume V_1), some of which results from i's non–fundamentals customer–order, ϵ_i. If trader i's non–fundamentals customer–order differs from the market's best estimate of it from applying a signal–extraction procedure to his total trade then the information content of trader i's order will be misinterpreted. Given this, trader i would be acting myopically if

[9] This first order condition is derived under the assumption that traders take into account the impact of their demands on market prices but do not take into account their impact on the variability of prices; the latter introduces a non–linearity that renders the problem intractable. To the extent that traders moderate their responses to information because of induced second moment effects, this would involve quantitative but not qualitative changes in the results.

he did not factor this privately-predictable market error into his desired position. For example, if the trader receives a large (relative to y_i) non-fundamental customer buy-order, the market will interpret the total order as reflecting a higher y_i than it does. Hence, the trader would increase his speculative demand in order to profit from the market's mistake. (Recall that P_1 is a committed price.) In the end, the realized price will be consistent with this behavior on the part of individual traders.

Trader i's expectation of P_2-P_1 can be calculated from his total trade insofar as the market interprets his trade as communicating information and sets price accordingly, a process which is described by the signal extraction coefficient R, where R is defined implicitly by:

(9) $$R \equiv \frac{\left[\beta_1/(\theta\sigma_{P_2}^2-\alpha_1)\right]^2\sigma_y^2}{\left[\beta_1/(\theta\sigma_{P_2}^2-\alpha_1)\right]^2\sigma_y^2 + \beta_2^2\sigma_\epsilon^2 + \sigma_\eta^2}.$$

The coefficients β_1 and β_2 are defined below and come from the traders' optimal trade-order as a function of the customer-order and individual information.

Given the market's best (and consistent) signal-extraction estimate of fundamentals from trader i's order, which is equal to $RT_{i1}[(\theta\sigma_{P_2}^2-\alpha_1)/\beta_1]$, trader i's optimal trade-order is (see Appendix):

(10) $$T_{i1} = \beta_1\left[\frac{y_i}{\theta\sigma_{P_2}^2-\alpha_1}\right] + \beta_2\epsilon_i$$

where $$\beta_1 \equiv \phi + (1-\phi)R$$

and $$\beta_2 \equiv 1 + \frac{(1-\phi)R}{\phi}$$

The coefficient β_1 is the fixed point which is consistent with both optimization by traders on the basis of their private beliefs and optimal signal extraction on the part of all traders on the basis of the observed net trading volume V_1. Note that the value of β_1 is less than one and that the value of β_2 is greater than one: because trader i knows the extent to which his customer-order distorts the market price he will reduce the weight he places on individual information and increase the weight on extraneous information (the non-fundamental customer-order) in determining his desired trade-order, per equation (10). This equation also provides a basis for evaluating the volume effects of various changes in dispersion, which I consider in the next section.

Consistent with optimization by each trader, the resulting price quote in the event that Δ remains unknown is:

$$\text{(11)} \quad P_2 = P_1 + E[\Delta | V_1] = P_1 + R\Delta + R\beta_2\left[\frac{\theta\sigma^2_{P2} - \alpha_1}{\beta_1}\right]\sum_{i=1}^{n}\epsilon_i + R\left[\frac{\theta\sigma^2_{P2} - \alpha_1}{\beta_1}\right]\nu_1.$$

This pricing equation provides a basis for evaluating the volatility effects of volume changes, also considered in the next section.

The reason no trader would deviate from quoting this price and condition his quote on private information is as follows. Quoting at P_2 results in an expected open position after that period's trading (one order given and one received, *simultaneously*) equal to the desired position, with a position variance equal to the variance of the trade-order received, or σ^2_T, where the expected value of the trade-order received is zero. If a trader who receives a high y_i, for example, chose to quote slightly higher than P_2, then the expected trade-order received would not be zero since the recipient of the quote would be expected to want to sell at that price. The quoting trader could adjust his own order such that his expected open position after trading still equals his desired position, but the variance of his position would necessarily be higher than σ_T^2; that is, the variance would be the second moment of the same normal distribution of possible orders received about something other than its mean. Moreover, the expected units purchased on the order received would be more expensive than simply purchasing them at P_2 by means of his own order placed with another trader. Hence, each trader would optimally condition his quote on public information only.

One might also consider the possibility that traders coordinate on some other price. Suppose, for example, the quoted price in period j, P_j, is less than the expectation of the fundamental conditional on all public information (the argument is symmetric). Since y_i and ϵ_i are distributed mean zero, each trader would expect to get hit with another's buy order. In determining an optimal trade-order, each would adjust upward in an effort to offset the expected sale. However, since each would adjust upward, each would have an incentive to adjust upward again to offset the initial adjustment, and on ad infinitum. Hence, this cannot be an equilibrium price.

Shifting back to the flow of the model, if Δ remains unknown, trading in the second period will be conditioned on an unchanged probability ϕ that Δ will be revealed at the end of period-two trading. Trader i's expectation of the period-two price change, which determines his desired period-two position, is:[10]

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[10] The reason the trader does not also condition on the order received is that it would be redundant given the signal extraction applied to the net volume V_1. Of course, this is not strictly true in the case where V_1 is noisy; the assumption is less tenable the smaller is n and the larger the noise relative to true net volume.

$$(12) \qquad E_iP_3-P_2 = \phi\Big[(1-R)y_i - R\beta_2\Big(\frac{\theta\sigma^2_{P2}-\alpha_1}{\beta_1}\Big)\epsilon_i\Big] + (1-\phi)E\Big[\Delta-E[\Delta\,|\,V_1]\,\Big|\,y_i,\epsilon_i,V_1\Big],$$

where the term weighted by ϕ is a measure of the extent to which the market has misread trader i's period-one order; that is, conditional on the fundamental being revealed at the end of the period trader i expects this to be the price change.

In period two there is no additional customer-business. The conditional variance of the period-three price will be the same for each of the traders because each has received the same *quantity* of information, though the quality and derived forecasts are of course different. Notice that the period-one net position included the order received from one of the other traders. This trade has to be offset in the period-two trading, as does the original speculative position. Since it is assumed that non-trader demand at fundamentals conditional on public information is perfectly elastic, these stock effects will not disturb the period-two price.

III. Some Implications of the Model

First, the model is helpful for explaining the immense trading volume in the foreign exchange market, as well as other asset markets for which the notion of a Walrasian auctioneer seems strained. Central to the framework is the idea that the communication of private beliefs requires transactions. Trade is based on information without irrationality, and traders have a realistic incentive to trade even when they do not have strong beliefs.

To compare the model to some recent theory on trading volume, consider the model of Karpoff (1986). In his model asset trading is the result of random pairing of heterogeneous agents. As he candidly admits, this assumption is "simply untrue." It is particularly egregious in the context of the foreign exchange market where willing trading partners are always available at essentially no cost. Additionally, his model does not yield a unique market price. This, too, is untenable with respect to the market for foreign exchange. In my model there always exists a unique market price. One of the attractive features of both models is that they can generate positive trading volume in non-event periods.

Turning to the process by which information is revealed, the coefficients β_1 and β_2 summarize a number of interesting properties of the model:

Proposition 1: Profit maximization induces traders to increase the weight on extraneous information and decrease the weight on fundamentals in determining their trades, which weakens the information signal used for price determination.

-Per the previous section, the weight on fundamentals, β_1, is less than one while the weight on extraneous information, β_2, is greater than one.

Stated another way, an information externality is present. More heuristically, traders are playing two roles in the market, that of speculator and that of information intermediary. The motivation of the speculator interferes (in the short run) with the process of information intermediation, reducing the degree to which prices reveal information at any given time.

At the outset I suggested that the market for foreign exchange is particularly interesting for the issues at hand for a number of reasons, one of which is the fact that the empirical specification of fundamentals is especially tenuous. The following proposition corresponds, albeit in a rough way, to that statement:

Proposition 2: A lower probability that fundamentals will be revealed, ϕ, induces each trader to put more weight on extraneous information in formulating his optimal trade.

-This follows from differentiating β_1 and β_2 with respect to ϕ.

Hence, the information externality is accentuated when fundamentals are less likely to be pinned down.

The following two propositions address the implied relationship between the diversity of beliefs, volume, and volatility:

Proposition 3: Greater dispersion of beliefs induces higher trading volume (conventionally measured).

–Given an underlying stochastic structure, this follows directly from the role of realized individual information, y_i, in the equation for trader i's optimal trade–order [equation (10)].

Notice that the experiment here is not an increase in σ_y^2, a less natural choice since it involves an ex ante change in the variance of fundamentals. It should be noted that this stands in contrast to models in which differences in beliefs are due simply to idiosyncratic noise [e.g., Pfleiderer (1984)]: when private beliefs are less certain (noisier) investors typically choose to take smaller speculative positions, and therefore trade less. Since I demonstrate below that diversity of beliefs is positively related to volume, this provides some support for the specification of the diversity of beliefs as deriving from information rather than simply noise or opinion.

Proposition 4: Higher trading volume induces greater volatility when caused by greater dispersion of beliefs.

–Given an underlying stochastic structure, this follows directly from the equation for prices determined conditionally on net volume [equation (11)].

When caused by greater variance of customer–business, the effect of higher trading volume on volatility is ambiguous. Other things equal, one would expect the relationship to be positive; however, a greater customer–business variance reduces R (the signal extraction coefficient reflecting the information content of trades) thereby offsetting the effect in the process of price determination.

IV. Some Suggestive Empirical Evidence

There is a considerable body of empirical work which addresses the correlations between the three central variables of the model: (i) the dispersion of beliefs, (ii) trading volume, and (iii) exchange rate volatility. First, I provide some suggestive evidence on the dispersion/volume relationship, focusing only on whether there is a positive correlation as predicted by the model. Then, I review some related evidence provided by Frankel and Froot (1990), Karpoff (1987), and Grammatikos and Saunders (1986).

Table 2 presents the results from regressing log volume on the *first lag* of log dispersion at a weekly frequency from January 1988 through December 1989 for the yen/dollar and mark/dollar exchange rates. Volume is measured two ways: (i) by the weekly volume in the Tokyo interbank spot market as reported by the Bank of Japan (source: Nikkei Telecom), and (ii) by the weekly volume of futures contracts (all terms) traded on the IMM of the Chicago Mercantile Exchange.[11] Dispersion is measured by the high–low spread of one–month forecasts across respondents in the survey conducted weekly by MMS International. In order to account for secular growth in trading, the log volume series are smoothed using an exponential smoothing procedure before running the regressions.[12] In all cases, the relationship between the two variables is positive, significant, and consistent with that predicted by the model. Moreover, the spot market results, which are the most relevant here,

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[11] The 1989 volume on the IMM for each of these two currencies is considerably higher than for any other currency.

[12] The procedure is ESMOOTH in RATS with a linear trend and an additive seasonal.

are particularly sharp.

<u>Table 2</u>

The Dispersion–Trading Volume Relationship
$\log(\text{Volume}_t) = \beta_0 + \beta_1 \log(\text{Dispersion}_{t-1}) + \eta_t$

	β_1 *	R^2
Yen (spot)	0.47 (8.19)	0.40
Yen (futures)	0.25 (6.52)	0.28
Mark (futures)	0.15 (2.07)	0.08

* T–statistics in parentheses, using corrected standard errors.

Consider now the evidence on the dispersion/volume relationship presented in Frankel and Froot (1990), which is in the form of Granger–causality tests. Using the percentage standard deviation of forecasts across the MMS survey respondents for dispersion, and trading volume on the nearest–term IMM futures contract for volume, they find that dispersion Granger–causes volume at the 5 percent level in three of the four currencies they consider (the mark, yen, pound, and Swiss franc). On the flip side, in only one of the four cases do they find a significant (5 percent level) Granger–causal relationship running from volume to dispersion. These results too are consistent with the predictions of the model.

I turn now to the volume/volatility relationship. Surveying various work on a number of different asset markets, Karpoff (1987) asserts that the positive relationship between volume and the magnitude of price change is clear and significant. As for the exchange market, Grammatikos and Saunders (1986) use futures volumes to demonstrate that the relationship is significant in this case as well. In sum, the model presented here provides a consistent explanation of the broad empirical facts concerning the dispersion/volume/volatility relationship. Moreover, it does so without resorting to the behavioral distinctions of the noise-trader approach, an approach that is also broadly consistent with the empirical record.

V. Conclusions

The objectives of this paper were three: (i) to recognize the role of transactions per se in the updating of private beliefs over time, (ii) to provide some institutional structure to help explain huge trading volume, and (iii) to investigate the process of information revelation in a market of this type. First, consider the updating of private beliefs. Previous work on how asset prices aggregate diverse information in the presence of exogenous noise generally models equilibrium price determination as a one-shot outcome, where traders use both their private information and the information in market-clearing prices to determine their demands for the risky asset. In contrast, the model here recognizes that transactions play an integral part in the updating of expectations and eventual tatonnement, linking the diversity of beliefs, volume, and price adjustment.

Regarding the institutional features that influence trading volume, I short-circuit the no-trade results highlighted in previous work by recognizing that when participating in the market as a trader, one is expected to quote a competitive price when requested. Refusing to do so is costly in terms of foregone customer-business and the profits derived therefrom. Thus, as a result of price commitment, traders continue to trade even through periods when they do not feel they have a good sense of where the market is going. This aspect is a simple addition to previous models, but essential for understanding the volume of trading in a world where the heterogeneity of beliefs is due to relevant information.

An additional institutional feature that the model emphasizes is the fact that trading in the foreign exchange market does not involve a centralized clearinghouse for information, rather a partially decentralized inner circle of traders each of whom has monopoly access to particular information contained in the order flow. The upshot is that in maximizing the value of this private information additional noise is introduced into the process of exchange rate determination as a result of the information externality.

Finally, the findings are consistent with a number of empirical regularities. First, the model produces considerable trading and price adjustment in non-event periods. Second, the model produces a realistic means through which market participants learn about fundamentals through volume-mediated tatonnement. Third, the model generates a joint behavior of the diversity of beliefs, volume, and volatility that jibes with those documented here and elsewhere. And fourth, the model can explain the patterns of causality found by Frankel and Froot (1990) without depending upon the behavioral distinctions and irrationality associated with the noise-trader approach. Of course, rigorous empirical testing of the model is an important direction for further work. Nevertheless, the information externality is in general consistent with a much broader class of specifications as long as they admit a transactions motive and volume-mediated tatonnement.

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APPENDIX

Derivation of the Optimal Period-One Trade-Order

Let $\phi \equiv \text{prob}\{P_2 = P_1 + \Delta\}$

$1-\phi = \text{prob}\{P_2 = P_1 + E[\Delta \mid V_1]\}$,

where implicitly I have assumed that non-trader demand at expected fundamentals conditional on public information is perfectly elastic. One can then write:

$$E_iP_2 - P_1 = \phi E[\Delta \mid y_i] + (1-\phi)E[\Delta \mid T_{i1}] \tag{A.1}$$

$$= \phi y_i + (1-\phi)RT_{i1}[(\theta\sigma^2_{P_2} - \alpha_1)/\beta_1]$$

where R and β_1 are defined below by the market's optimal signal extraction.

Plugging this into the first order condition of the trader's problem:

$$Z_{i1} = \frac{E_iP_2 - P_1}{\theta\sigma^2_{P_2} - \alpha_1} \tag{7}$$

one gets:

$$Z_{i1} = \left[\frac{\phi}{1-(1-\phi)(R/\beta_1)}\right]\left[\frac{y_i}{\theta\sigma^2_{P_2} - \alpha_1}\right] + \left[\frac{(1-\phi)(R/\beta_1)}{1-(1-\phi)(R/\beta_1)}\right]\epsilon_i. \tag{A.2}$$

Recognizing that $T_{i1} = Z_{i1} + \epsilon_i$, the trader's optimal trade order is:

$$T_{i1} = \left[\frac{\phi}{1-(1-\phi)(R/\beta_1)}\right]\left[\frac{y_i}{\theta\sigma^2_{P_2} - \alpha_1}\right] + \left[1 + \frac{(1-\phi)(R/\beta_1)}{1-(1-\phi)(R/\beta_1)}\right]\epsilon_i \tag{A.3}$$

$$\equiv \beta_1\left[\frac{y_i}{\theta\sigma^2_{P_2} - \alpha_1}\right] + \beta_2\epsilon_i.$$

At the outset I asserted that the market signal extraction would yield:

$$E[\Delta | T_{i1}] = (1-\phi)RT_{i1}[(\theta\sigma^2_{P_2}-\alpha_1)/\beta_1]$$

this must be consistent with trader i's optimal trade-order, that is:

$$\beta_1 = \left[\frac{\phi}{1-(1-\phi)(R/\beta_1)}\right]$$

which implies: $\beta_1 = \phi + (1-\phi)R$

and substituting into equation (A.3) one gets:

$$\beta_2 \equiv 1 + \frac{(1-\phi)R}{\phi}.$$

These expressions for the optimal trade-order defines the appropriate signal extraction coefficient, R, where R is (implicitly) defined by:

(9) $$R \equiv \frac{\left[\beta_1/(\theta\sigma^2_{P_2}-\alpha_1)\right]^2\sigma^2_y}{\left[\beta_1/(\theta\sigma^2_{P_2}-\alpha_1)\right]^2\sigma^2_y + \beta_2^2\sigma^2_\epsilon + \sigma^2_\eta}$$

where σ^2_η enters as a result of the noise in the observed net volume, and $\eta \equiv \nu/\sqrt{n}$.