

PRINCETON STUDIES IN INTERNATIONAL ECONOMICS

No. 89, May 2001

THE MICROSTRUCTURE
OF THE FOREIGN-EXCHANGE MARKET:
A SELECTIVE SURVEY OF THE LITERATURE

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Library of Congress Cataloging-in-Publication Data

Sarno, Lucio

The microstructure of the foreign-exchange market: a selective survey of the literature
/ Lucio Sarno and Mark P. Taylor.

p. cm. — (Princeton studies in international economics ; no. 89)

Includes bibliographical references.

ISBN 0-88165-261-X

1. Foreign-exchange market. I. Taylor, Mark P, 1958-. II. Title. III. Series.

HG3851.S27 2001

2001024516

332.4'5—dc21

CIP

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Printed in the United States of America by Princeton University Printing Services at
Princeton, New Jersey

International Standard Serial Number: 0081-8070

International Standard Book Number: 0-88165-261-X

Library of Congress Catalog Card Number: 2001024516

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CONTENTS

1	INTRODUCTION	1
2	THE FOREIGN-EXCHANGE MARKET	3
	Institutional Features of the Foreign-Exchange Market	3
	Foreign-Exchange-Market Activity	9
3	EXCHANGE-RATE EXPECTATIONS	11
	Survey-Date Studies	11
	Order-Flow Studies	12
4	CHARTIST ANALYSIS	14
	Chartist Analysis in the Foreign-Exchange Market	14
	The Impact of Chartist Analysis	16
	Modeling Expectations of Chartists, Fundamentalists, and Portfolio Managers	17
	Summing Up	19
5	TIME-VARYING VOLATILITY, MARKET LOCATION, AND TRADING VOLUME	21
	Time-Varying Volatility in the Foreign-Exchange Market	21
	Volatility and Market Location	24
	Public Information or Private Information?	27
6	BID-ASK SPREAD DETERMINATION	33
	The Main Determinants of the Spread	33
	Modeling the Spread: Theory and Evidence	34
7	MARKET MAKERS' BEHAVIOR	40
	Private Beliefs and Information Externalities	40
	"Event Uncertainty" versus "Hot Potato"	41
8	CONCLUSION	43
	REFERENCES	44

1 INTRODUCTION

Over the last quarter century, exchange rates among the currencies of the leading industrial countries have shown substantial and often persistent movements that are largely unexplained by movements in macroeconomic fundamentals (Frankel and Rose, 1995; Taylor, 1995; Flood and Taylor, 1996). The literature on the microstructure of the foreign-exchange market in some measure reflects researchers' attempts to understand the mechanisms generating these deviations from fundamentals (Taylor, 1995; Flood and Taylor, 1996; Lyons, 2001).¹ More broadly, however, this literature is concerned with other "micro" aspects of the foreign-exchange market, such as the transmission of information among market participants, the behavior of market agents, the importance of order flow, the heterogeneity of agents' expectations, and the implications of such heterogeneity for trading volume and exchange-rate volatility.

The assumptions and methodology of the microstructure literature often differ substantially from those of the conventional macroeconomic approach. Indeed, some authors see the microstructure literature as a "radical departure from the traditional modelling strategy of treating foreign exchange rates as a macroeconomic relative price" (Frankel and Rose, 1995. p. 1710). With respect to assumptions, the foreign-exchange microstructure typically does not assume that only public information is relevant to exchange rates, that foreign-exchange-market agents are homogeneous, or that the mechanism used for trading is inconsequential (Lyons, 2001). In fact, these issues are themselves often the subject of investigation in microstructural analysis. With respect to methodology, instead of starting with a set of macroeconomic relations such as money demand and purchasing-power parity, which are then used to solve for the exchange rate (Taylor, 1995), the microstructure literature analyzes the behavior and interaction of individual decisionmaking units in the foreign-exchange market.² Simply put, the microstructure literature is concerned with the details of the mechanics of

¹One way in which a speculative movement of the exchange rate away from the level consistent with the macroeconomic fundamentals could begin would be if some agents were to have destabilizing expectations—if, for example, a 5 percent appreciation were to lead agents to expect a 10 percent appreciation, which would lead them to buy the appreciating currency, causing it to appreciate faster in a self-fulfilling fashion. "Bandwagon" effects of this kind have been examined by Frankel and Froot (1986), Allen and Taylor (1990), and others, using survey data on expectations. The evidence to date tentatively suggests that expectations may be more destabilizing over relatively short horizons.

²The microstructure approach should also be distinguished from the dynamic optimizing approach of the new "open-economy" macroeconomics (Obstfeld and Rogoff, 1995, 1996; Lane, 1999; Sarno, 2001). Although the new open-economy literature explic-

foreign-exchange trading, whereas the macroeconomic approach typically dismisses the details as unimportant.³

Although it is possible to imagine a convergence of the macroeconomic and microstructural approaches, they currently remain largely separate.⁴ Indeed, as one pioneering investigator in the area of foreign-exchange microstructure (Lyons, 2001, p. 9) notes:

Researchers working with microstructure tools are not applying them to issues on the macro end of the issues spectrum and those who are working on the macro end have not felt it worthwhile to invest in apparently inappropriate microstructure tools. For these tools to be applied to more macro foreign exchange issues, either macroeconomists need introduction to the tools or those with the tools need to extend their study rightward on the spectrum. Both of these, in fact, are occurring. As the process continues, the uneasy dichotomy between macro and micro approaches is destined to fade.

For the convergence process to continue, therefore, the microstructure literature needs to be more widely understood. It is in this spirit that the present survey is offered.

The remainder of this study is set out as follows. Chapter 2 gives a general overview of the institutional features of the foreign-exchange market. Chapter 3 discusses studies employing survey data on market participants' exchange-rate expectations and studies using data on foreign-exchange order flow. Chapter 4 reviews the literature on "chartist," or "technical," analysis. Chapter 5 summarizes recent work on modeling time-varying volatility in the foreign-exchange market, on the relation between volatility and trading volume, and on the nature of information that is relevant to trading in the foreign-exchange market. Chapter 6 reviews the literature on bid-ask spread determination in the foreign-exchange market. Chapter 7 discusses the literature on modeling market makers' behavior. A final chapter summarizes and concludes the study.

itly takes an optimizing approach (usually of representative agents in two economies), rather than relying on "off the peg" macroeconomic behavioral relations, it is generally concerned with interactions between whole economies, rather than strictly with the functioning of the foreign-exchange market.

³Flood and Taylor (1996, p. 285), for example, write: "It is apparent that there are important influences, not on the list of standard macro fundamentals, that affect short-run exchange rate behavior . . . , and it is in this context that new work on the microstructure of the foreign exchange market seems both warranted and promising."

⁴Researchers have, in the past, occasionally employed methods of analysis that effectively synthesize macroeconomic and microeconomic approaches. For example, Taylor's (1987, 1989) studies of covered interest parity may be viewed as early microstructural analysis, applying high-frequency, high-quality data from the brokered foreign-exchange market and microstructural tools to resolve an issue (the validity of covered interest parity) debated up till now only at the macroeconomic level.

2 THE FOREIGN-EXCHANGE MARKET

Institutional Features of the Foreign-Exchange Market

Much of the early microstructure literature focuses on institutional features of the foreign-exchange market. The first section of this chapter briefly discusses these features; the second section presents some simple data on the activity of real-world foreign-exchange markets.

The two main features distinguishing the foreign-exchange market from other financial markets are that the foreign-exchange market is a mostly decentralized market and that trading volume in the foreign-exchange market is very large and conducted mainly among market makers.¹ A decentralized market is a market in which participants—namely, market makers, brokers, and customers²—are generally physically separated from each other and in which transactions are made by telephone, telex, or computer networks. In a centralized market, trade is carried out at a publicly announced price and all traders in the market face the same trading opportunities. In a decentralized system, prices are quoted and transactions executed in private meetings, perhaps conducted through some form of electronic medium (Schwartz, 1988; Wolinsky, 1990). The New York Stock Exchange (NYSE) and the London Stock Exchange (LSE), for example, are centralized markets, but the direct foreign-exchange market may be classified as decentralized, and the brokered market may be classified as quasi-centralized, because each foreign-exchange broker accumulates a subset of market makers' limit orders.³

¹Another institutional feature of the foreign-exchange market is that a large fraction of the trading volume in the market is concerned with the trade of forward contracts (Flood, 1991; BIS, 1998). Forward positions (that is, contracts concerning the future exchange of currencies at pre-agreed rates) may be taken by agents engaged in international trade in goods and services, in order to hedge against adverse exchange-rate movements affecting their business, and by dealers and speculators hoping to earn windfall profits from correctly anticipating exchange-rate movements. See the following section and footnote 12 of this chapter for a discussion of forward contracts in the foreign-exchange market.

²Broadly speaking, a market maker is a firm (typically a bank) attached to the foreign-exchange market and engaged in the buying and selling of currencies; it thus establishes a market for these currencies by standing ready to buy and sell—that is, to make a “two-way” price for—particular currencies against one another. Such firms generally make significant profits from the difference between the “bid” exchange-rate price at which they buy a currency and the (higher) “ask” price at which they sell. The market maker may be seen as the *principal* in the buying and selling of currencies, whereas the broker acts as an *agent* on behalf of customers wishing to buy or sell.

³A limit order is an offer by a bank to buy or sell, but not both, a certain amount of currency against another currency at a specified rate of exchange.

The empirical evidence from the current microstructure literature strongly suggests that the different degrees of centralization across markets may be very important in explaining differences in market performance. A widely held view is that, by centralizing trading and price information, the brokered market uses time more efficiently, eliminates significant arbitrage opportunities rapidly, and ensures dealers that orders are executed according to price priority (Garbade, 1978; Garbade, Pomrenze, and Silber, 1979; Glosten and Milgrom, 1985).⁴

Flood (1994) investigates the intraday operational efficiency of the U.S. foreign-exchange market by executing simulation experiments calibrated on a particular market structure for market makers, brokers, and customers. His results support the traditional view that centralization is a key factor in achieving operational efficiency. In particular, he finds that significant operational inefficiencies may be explained by temporary inventory imbalances inherent in a decentralized market. He also finds that this inefficiency could be largely alleviated by centralizing price information.

Interesting work on the implications of decentralization in this context has been done by Perraudin and Vitale (1996), who construct an elegant theoretical framework for a decentralized dealer market and discuss the implications for price-information-transmission mechanisms and efficiency in the foreign-exchange market. They model interbank trading so as to show that market makers “sell” each other information about their transactions with outside customers by adjusting the bid and ask prices and the bid-ask spread in their price quotations (for example, by lowering the bid and ask prices for a particular currency if the bank has been given a large amount of that currency). This modeling assumption in turn implies that market makers can capture, through interdealer trades, the informational rents associated with receiving outside orders and that they can optimally adjust bid-ask spreads to maximize those rents and elicit information. The model also implies that bid-ask spreads are wider in decentralized markets, because, by using wider spreads, dealers can discourage liquidity traders, who are strongly reactive to price changes, and can therefore increase the informativeness of their order flow.⁵ Perhaps the most important finding from Perraudin and Vitale, however, is that decentralized markets are much less subject to crashes than are centralized markets. The intuition behind this conclusion is that information on order flow is used to update subjective

⁴One of the benchmark models in the literature is Glosten’s and Milgrom’s (1985) sequential-trade model, which is designed to capture the way in which bid and ask prices evolve in a dealership market as orders arrive in sequence. For a comprehensive discussion of the Glosten-Milgrom model and its subsequent extensions, see Lyons (2001).

⁵Liquidity traders can be thought of as agents who need to buy or sell foreign exchange in response to international trade in goods and services and who do not speculate or hedge their exposure in any way. Their orders are therefore largely random.

estimates of the underlying value of exchange rates. Thus, even when a centralized market can be expected to collapse from the excessive number of informed traders, dealers in a decentralized market will still have an incentive to preserve some turnover, because they can use the information in the order flow in future trading. Finally, the Perraudin-Vitale model also suggests a difference in exchange-rate behavior between the two types of market system. In a centralized market, bid and ask quotes are martingales with respect to the information available to foreign-exchange dealers; in a decentralized market, however, bid and ask spreads shrink as order flow provides new information.

One important consequence of decentralization in the foreign-exchange market is a degree of fragmentation; because not all dealer quotes are observable, transactions may occur at the same time at different prices. This feature strongly distinguishes the foreign-exchange market from other financial (for example, equity) markets. Another important implication of decentralization in the foreign-exchange market is that this market has less transparency than other financial markets, in which trades must, by law, be disclosed within minutes. Because foreign-exchange markets have no disclosure requirement, trades are not observable. As a consequence, order flow cannot communicate information about fundamentals.

Another important feature of the foreign-exchange market is that market makers, who by definition provide two-way bid and ask prices, largely dominate the market at commercial and investment banks. Market makers account for some 90 percent of overall trading volume, either by trading with each other directly—more than 50 percent of the spot-market trading volume—or through foreign-exchange brokers—about 40 percent (BIS, 1998). In the direct market, banks approach each other, and the bank receiving a call acts as a market maker for the currency to be traded by providing bid and ask prices for the bank placing the call. Brokered transactions occur when brokers collect limit orders from banks. The limit orders, specifying the quantity and the price of an offer to buy or sell, remain with the broker until they are withdrawn by the bank.⁶ Brokers trade by keeping a “book” of banks’ limit orders for buying and selling from which they quote the “inside spread” (that is, the best bid and ask orders) on demand. Traditionally, the brokered market has been conducted by voice through direct telephone links between brokers and banks, although, as we discuss below, an important recent feature of the foreign-exchange market has been the development of electronic screen-based brokering sys-

⁶The advantages of brokered transactions are well known and include the rapid dissemination of orders to other market makers, anonymity in quoting, and freedom not to quote to other market makers on a reciprocal basis, a reciprocity that may be required in direct transactions.

tems. Only a small fraction of spot-market volume (about 5 percent in the United States, for example) is traded by bank customers for the purpose of completing transactions in international trade (goods-market transactions). Finally, the other participants in the foreign-exchange market are central banks that trade mainly to complete their own transactions or to influence exchange-rate movements through official intervention.⁷

Another classifying distinction is between single-auction and double-auction systems. In the single-auction system, prices are specified either to buy or to sell, but not both. In the double-auction system, market makers provide two-way prices on both bid and ask. Clearly, in the direct foreign-exchange market, market makers provide double-auction prices, whereas the brokered market is largely single-auction.⁸

With regard to communicating prices, financial markets are generally classified as having either “open” or “closed” (or public or confidential) order-book systems. In an open system, offers to buy or sell at a specified price are announced to all agents in the market. In a closed system, offers will be known only to the entity placing the order and perhaps to a disinterested auctioneer. Clearly, the direct market is an open-order-book market, and the brokered market is a closed-order-book market. In principle, however, the optimal system of price communication is the one that minimizes the costs arising from searching out a counterparty in a transaction. Given that the foreign-exchange market is not fully centralized, it might be argued that the system is not cost-minimizing.⁹

⁷Although market makers may trade for themselves, brokers do not, but profit, instead, by charging a fee for bringing market makers together. Another distinction made in the microstructural finance literature, originally by Garman (1976) and Schwartz (1988), is between a continuous (asynchronous) market and a call (synchronous) market in order to categorize markets. In a continuous market such as the foreign-exchange market, trade is allowed to occur at its own pace, and transactions are processed as they arrive. In a call market, trade occurs only at predetermined times, and transactions are detained until the next call.

⁸Note that the distinction between single-auction and double-auction may not be as clear cut as it first seems, because, in principle, there is nothing to prevent a bank from acting as a market maker by simultaneously placing both bid and ask limit orders. The taxonomy remains useful, however, if we see the distinction between a double-auction and a single-auction market as being that the former requires a two-way price to be made, whereas the latter does not (although it may not preclude it). The type of auction used in a market is also closely related to the degree of centralization of the market itself. As noted by Flood (1991), for example, the absence of market makers in a single-auction market and, therefore, the presence of larger search costs lead to greater centralization of price information. Decentralization of price information, however, leads to a tendency toward double-auction prices in order to facilitate the searching process for the counterparty (Goldberg and Tenorio, 1997, and the references therein).

⁹This distinction may become obsolete in the future, however, and readers should be aware that the use of these terms may be shifting (Glosten, 1994). The distinction is made here as a classificatory device that is useful for the present survey.

One issue that seems not to have been fully examined in this connection is the importance of credit and the role of clearing houses.¹⁰ In a decentralized market, where trade occurs in private meetings between parties, an assessment of credit risk (whether the counterparty will deliver the agreed amount of funds at the agreed time at the agreed location) is presumably made before a deal is struck. In fact, a bank will usually have a prudential limit, determined by its senior management, on the credit exposure it is willing to have with any particular counterparty at any point in time, and it will not deal with that counterparty once this limit is reached until the net exposure is diminished.

The existence of such prudential limits may be problematic for a fully centralized system, in which prices are public information and the counterparty is known only after the deal is struck. In practice, centralized financial exchanges often circumvent this problem by having a clearing-house system. For example, the London Clearing House (LCH) acts as the central counterparty for trades conducted on several of the London financial exchanges, including the London International Financial Futures and Options Exchange. This enables the LCH to “guarantee” the financial performance of every contract registered with it by its members (the clearing members of the exchanges) up to and including delivery, exercise, and settlement. Both sides of a trade are entered in an electronic registration system by the exchange members, the exchange itself, or both, where they are matched and confirmed. At the end of each business day, the trade is registered in the name of the LCH, and the original contract between the two agents is canceled and replaced by two new ones—one between the LCH and the clearing member seller, the other between the LCH and the clearing member buyer. This is known in legal terms as “novation.”

A clearing-house system thus serves two functions in a centralized market. First, it obviates the need to assess the credit rating of the counterparty—or, indeed the need to identify the counterparty at all—before a trade is made. Second, because all trades are effectively made with the clearing house, only the net position at the end of the day is important for settlement purposes. In a decentralized system, trades may be made with a great many counterparties, so that, even though the end-of-day net position may be close to zero, the trader may have filled a number of credit limits and will still have to complete all of the agreed-upon trades (with the consequent transactions costs). In the brokered foreign-exchange market, although dealers trading on a price quoted by a broker will not know the identity of the counterparty until after the trade has been made, trades occasionally have to be canceled once the identities are revealed and one

¹⁰We are grateful to an anonymous referee for encouraging us to pursue this issue.

party finds that its credit limit with the counterparty is full.¹¹ The need to assess creditworthiness prior to trading may thus explain why the bulk of foreign-exchange trading (63 percent in April 1998) is between dealers (BIS, 1998). Moreover, in the absence of an international clearing-house system, market makers in the foreign-exchange market may fulfill many of the functions of a clearing house. This may explain why the market allows them to earn significant profits on the bid-ask spread. The issue of credit and creditworthiness may thus explain many of the institutional features of the foreign-exchange market, including the predominant system of communication of prices (open-order-book and interdealer) and the importance of established market makers. This is clearly an issue that would repay further research.

Another important feature of the foreign-exchange market is the development, since 1992, of proprietary screen-based electronic foreign-exchange-dealing and brokering systems such as the Reuters 2000-2 Dealing System (Reuters) and the Electronic Broking System Spot Dealing System (EBS). These systems may also be seen to perform many of the functions of a clearing house and are an important driving force toward the “virtual centralization” of the global foreign-exchange market. The Reuters and EBS are anonymous interactive brokering and dealing systems delivered over proprietary networks and combining standard closed-order-book brokering services with the opportunities for electronic trading. Deals are completed by keystroke or automatic deal-matching within the system. An important feature of these systems is their prescreened credit facility, so that although the closed-order-book prices on the dealer’s screen seem to be anonymous, the system has automatically checked that the bank to which the price is being fed has a sufficient open credit limit with the originator of the price. This feature eliminates the potential for failed trades by assuring traders that they can deal on the prices they see. Credit limits are set and maintained by the designated bank staff and can be modified at any time during the trading day. Access to the credit file is password driven and confidential. An automated electronic interface between the system and a bank’s internal banking system, moreover, allows for net, rather than gross, transaction processing between counterparties and eliminates duplicate trade-entry activity. Although this is not quite the same as dealing with a clearing house, it substantially reduces transactions costs. These electronic dealing and brokering systems appear to be growing rapidly in use. Reuters currently offers its 2000-2 service in forty countries, and the EBS has 800 subscriber

¹¹In practice, where a limit order is placed with a broker by a small or “exotic” bank, the broker may try to circumvent this problem by quoting the inside spread, ignoring the limit order, adding that a better bid or offer is available for a certain amount from an “exotic,” and allowing dealers to ask the identity of the potential counterparty before the trade is made.

banks throughout the world, using some 2,500 workstations to transact average daily volumes in excess of \$90 billion (although this is still very small in comparison to the total turnover of daily foreign-exchange transactions).¹² It seems likely that the continued development of these services may lead to the “virtual centralization” of the foreign-exchange market through the computer network.

Overall, the direct foreign-exchange market may be classified as decentralized, open order-book, and double-auction, whereas the brokered foreign-exchange market may be classified as quasi-centralized, closed-order-book, and single-auction. The growing importance of electronic brokering services suggests that the foreign-exchange market may, in the future, become increasingly centralized.

Foreign-Exchange-Market Activity

The Bank for International Settlements (BIS) regularly collects and documents data on exchange-traded business from individual foreign-exchange markets. This section provides a brief overview of foreign-exchange-market activity largely based on the bank’s *Central Bank Survey of Foreign Exchange and Derivatives Market Activity* (1998).

Global turnover in traditional foreign-exchange-market segments (spot transactions, outright forwards, and foreign-exchange swaps)¹³ was, in 1998, about \$1.5 trillion per day. Forward instruments (outright forwards and foreign-exchange swaps) were in a dominant position relative to spot transactions, with a market share of 60 percent (which seems still to be increasing), and the foreign-exchange market was dominated by interdealer business (about 63 percent) and cross-border transactions (about 54 percent). The falling spot-market share was caused, not by a reduction in turnover in absolute terms, but by the rapid increase in the turnover of derivatives markets.¹⁴

¹²These figures were taken from the EBS and Reuters websites, at www.ebsp.com and www.reuters.com/transactions/d22s.htm, respectively. Here and throughout, “billion” equals one thousand million.

¹³Spot transactions are outright transactions involving the exchange of two currencies at a rate agreed to on the date of the contract for “value” or delivery (cash settlement) within two business days. Outright forwards are transactions for value or delivery at some time in the future (more than two business days later). Foreign-exchange swaps are the exchange of two currencies (principal amount only) on a specific date at a rate agreed to at the conclusion of the contract (the short leg), and a reverse exchange of the same two currencies at a date further in the future at a (generally different) rate agreed to at the time of the contract (the long leg). Foreign-exchange swaps are now quite common, and the two parties involved are typically firms in different countries, each of which finds it easier (less costly) to borrow in its home country. If, however, each party wishes to borrow the foreign currency at the foreign interest rate, then a swap may create gains for both parties (Dubofsky, 1992, pp. 652-656).

¹⁴Tight arbitrage relations link the foreign-exchange market’s submarkets, which differ

The U.S. dollar was, as one would expect, the most actively traded currency in 1998, being involved in 87 percent of all transactions worldwide. The deutsche mark followed, with almost 33 percent of all currency trades (although the mark was also increasingly used as a proxy for the euro in the run-up to the euro's launch in January 1999). The yen was the third most used currency, accounting for about 21 percent of all currency trades. The British pound was the fourth, with 11 percent of trades.

Foreign-exchange-market turnover showed an increasing concentration in four centers: the United Kingdom (32 percent), the United States (18 percent), Japan (8 percent), and Singapore (7 percent). Although some smaller countries experienced low or negative growth during the 1990s (for example, Austria, Finland, and Sweden), a number of others realized quite spectacular gains, especially in the second half of the 1990s (for example, Greece, Ireland, the Netherlands, Portugal, and South Africa).¹⁵

The replacement of a number of European currencies by the euro, on January 1, 1999, has considerably modified the configuration of markets and related trading strategies, as well as the evolution of risk exposure and management. Indeed, information about the relative importance of the euro as a traded currency during its early years of operation will be one of the most widely awaited features of the 2001 BIS survey.

Overall, however, the information available suggests that foreign-exchange-market activity is continuing to grow, largely in response to the rapid growth of derivatives products. Understanding the future evolution of the foreign-exchange market, as well as the effects of the emerging euro market, poses new challenges as well as new opportunities for both practitioners and academics.

in microstructure. Although the literature covered in this study has focused largely on the spot market, extending the analysis to derivatives markets would open an important avenue of research. Our interpretation of volume shares from different instruments is essentially literal. It is arguable, however, that swaps, for example, do not involve net demand in one direction or the other. Rather, a currency swap can be replicated by buying a bond in one currency and selling a bond in another; the arbitrage does not involve a net foreign-exchange transaction. Currency swaps, therefore, with their large notional values, might lead us to underestimate the importance of the spot market in terms of net order flow (that is, in terms of market-clearing net demand). We are grateful to Richard Lyons for pointing this out.

¹⁵Although the advent of the euro may appear to have caused the decline in some European centers, the strong growth rates experienced by Ireland, Portugal, and the Netherlands suggest that other factors are in play. Portugal's growth, in particular, might be attributed to the positive effects of the liberalization of the foreign-exchange market in 1992. The Netherlands also saw strong growth in its local market as institutional investors expanded their international portfolios.

3 EXCHANGE-RATE EXPECTATIONS

Survey-Data Studies

The process by which agents form expectations about future exchange rates is the subject of much of the early literature on foreign-exchange-market microstructure. The simplifying assumption that underlies virtually all the traditional asset-based exchange-rate models is that expectations are rational. Thus, the expected exchange rate has usually been measured in empirical studies using either the forward discount or the interest-rate differential, with uncovered interest-rate parity or uncovered and covered interest-rate parity being implicitly assumed (Taylor, 1995). The strategy followed by much of the microstructure literature has been to employ direct measures of expectations—that is, data on exchange-rate expectations from surveys of market participants conducted by financial-services companies (see Takagi, 1991, or Frankel and Rose, 1995, for an overview of survey-data studies).

Although the various studies using these data differ in their specific strategies and results, some general qualitative results are discernible. All foreign-exchange-survey data sets, for example, suggest a strong heterogeneity of expectations and an increasing dispersion of expectations at longer forecast horizons. They also show a “twist” in expectations, in that long-run expectations tend to reverse the direction of short-run expectations. In other words, although a depreciation is usually followed by expectations of further depreciations in the short run, it is usually followed by expectations of a moderate appreciation in the long run.¹

Survey data have mainly been used to study the existence of foreign-exchange-market risk premia in spot-forward regressions and the validity of the rational-expectations hypothesis (Taylor, 1995). The main conclusions of these studies are that (1) survey data generally suggest the presence of

¹The discrepancy between the mechanisms for the short- and long-run exchange-rate expectations formation used by agents in the foreign-exchange market suggests that short-run expectations generally respond to lagged exchange-rate changes by moving in the same direction (*away from* the long-run equilibrium exchange rate), whereas long-run exchange-rate expectations respond to lagged exchange-rate changes by moving in the opposite direction (*toward* the long-run equilibrium exchange rate). This behavioral discrepancy has been rationalized by Froot and Ito (1989) using the concept of “consistency,” which may be considered a weaker condition than full rationality. Nevertheless, Froot and Ito (1989, p. 506) find that expectations generally do not satisfy the consistency condition: “In every one of twenty sets of time-series estimates encompassing four surveys, five forecast horizons and five currencies, shorter-term expectations overreact relative to longer-term expectations when the exchange rate changes.” See also Pesaran (1989) for an alternative derivation of the consistency condition.

a nonzero risk premium, which appears to be stable and uncorrelated with the forward discount, and (2) tests of the rational-expectations hypothesis generally reject both the “unbiasedness” condition (the condition that the expected spot exchange rate is an unbiased predictor of the future spot exchange rate) and the orthogonality condition (the condition that prediction errors are uncorrelated with any variable in the set of available current information at the time the prediction is made; see Takagi, 1991, and Taylor, 1995). These studies also agree in strongly rejecting both static expectations, where the expected change is always zero, and bandwagon effects, where the expected change is always greater than the most recent change (for example, Frankel and Froot, 1986, 1987, 1990a, 1990b; Dominguez, 1987; Allen and Taylor, 1990; Ito, 1990; Taylor and Allen, 1992).

Overall, this strand of the literature provides clear evidence for the existence of risk premia and against the pure rational-expectations hypothesis. In addition, it suggests that the true, unknown, expectations-formation process used by agents in the foreign-exchange market is likely to be more complex than other standard alternatives, and that heterogeneity of expectations may be crucial (Taylor and Allen, 1992). Although additional empirical work on survey data is needed to establish the robustness of these findings, a theoretical inquiry into the formation of expectations and the causes and implications of their heterogeneity would seem to be an immediate avenue for future research.

Order-Flow Studies

A related literature has shown that time-aggregated order-flow variables may be more powerful than macroeconomic variables in explaining exchange-rate behavior. “Order flow,” which in this context is taken to be a variant of the more familiar concept of “net demand,” measures the net of buyer-initiated and seller-initiated orders. As noted by Lyons (2001), it is a variant of, rather than a synonym for, net demand, because, in equilibrium, order flow does not necessarily equal zero.

The fact that order flow helps explain exchange-rate behavior does not necessarily imply that order flow drives exchange rates. Indeed, it may well be that macroeconomic fundamentals are the driving force, but that conventional measures of the macroeconomic fundamentals are so imprecise that an order-flow “proxy” performs better in estimation. The proxy interpretation is particularly plausible with respect to expectations, for even if macroeconomic variables fully describe the true model, they may be a poor measure of expected future fundamentals when implemented empirically. Unlike expectations measured from survey data, moreover, order flow represents a willingness to back one’s beliefs with real money (Lyons, 2001).

A model recently proposed by Evans and Lyons (1999) presents order flow as a proximate determinant of price. Using data on signed order flow from the Reuters dealing system, Evans and Lyons show that order flow is a significant determinant of some leading bilateral exchange rates, and that the coefficients of determination are significantly larger than those usually obtained using standard macroeconomic models of nominal exchange rates. The authors also show that their model of daily exchange-rate changes produces good out-of-sample forecasts at short horizons, beating the alternative of a random-walk model in standard measures of forecast accuracy.

4 CHARTIST ANALYSIS

An alternative explanation of the discrepancy between short- and long-run exchange-rate expectations is that the participants in foreign-exchange markets may use different forecasting techniques for different expectations horizons. The predominant technique used for short-run exchange-rate forecasting may be chartist analysis, for example, whereas the technique used for long-run exchange-rate forecasting may be based on fundamental analysis or on conventional exchange-rate models.

Chartist, or “technical,” analysis uses charts of financial-asset price movements—often with the aid of additional descriptive statistics—to infer the likely course of future prices and thus to derive forecasts and trading strategies. The trends and patterns that chartists consider are generally inferred through loose inductive reasoning. Perhaps the most famous example of a chartist technique (indicating a trend reversal) is the “head and shoulders” pattern presented by Allen and Taylor, (1990; Taylor and Allen, 1992). Chartists often use trends and patterns to identify broad ranges within which exchange rates or asset prices are expected to trade, attempting to “set the parameters” for price movements. They may also employ one or more mechanical indicators when forming a general view, which may be trend-following (for example, based on moving averages) or non-trend-following (for example, rate-of-change indicators or “oscillators” used on the assumption that the markets tend to “correct” when an asset has been “overbought” or “oversold”). In practice, chartist analysis includes both pattern and trend recognition, as well as information from basic statistical indicators.

Chartist Analysis in the Foreign-Exchange Market

Although casual observation suggests that the use of chartist analysis is widespread in leading financial markets, evidence about its use has been largely anecdotal (Malkiel, 1996). A survey conducted by the Group of Thirty (1985), however, reported that 97 percent of banks and 87 percent of securities houses believed that the use of technical analysis has a significant impact on the foreign-exchange market.

Applied work on the use of technical analysis includes that by Allen and Taylor (1990; Taylor and Allen, 1992), who carried out a study of the London foreign-exchange market on behalf of the Bank of England. Their questionnaire, sent to over 400 chief foreign-exchange dealers in the London market in November 1988, achieved a response rate of over 60 percent and suggested a broad consensus regarding the weight given to chartist

analysis at different time horizons. At short time horizons (intraday to one week), approximately 90 percent of respondents reported using some chartist input when forming their exchange-rate expectations, with 60 percent judging charts to be at least as important as fundamentals. At longer forecast horizons, from one month to one year, the weight given to economic fundamentals increased. At the longest forecast horizons, of one year or longer, the skew toward fundamentals was most pronounced, with about 33 percent of the respondents relying on pure fundamentals and about 85 percent judging fundamentals to be more important than charts. There was, moreover, a persistent 2 percent or so of respondents who apparently never used fundamental economic analysis at any horizon. Other findings of the Taylor-Allen study were that dealers perceived chartist analysis and fundamental (economic) analysis to be complementary approaches and that significant numbers of them viewed technical analysis as self-fulfilling.¹

More recent evidence is presented by Menkhoff (1997, 1998), who examines some of the basic assumptions of the noise-trading approach by means of a questionnaire sent to foreign-exchange-market participants in Germany. Menkhoff identifies two groups characterized by their use of different information: rational arbitrageurs (who rely primarily on fundamental analysis) and not fully rational noise traders (who prefer other forms of analysis to fundamental analysis). The empirical results also imply the existence of short horizons and sentiments assumed by the noise-trading approach, although these cannot be exclusively related to the respective groups. This finding suggests that rational agents may use nonfundamental analysis to exploit less-rational noise traders.

Cheung and Wong (1999, 2000) report findings from a survey of practitioners in the interbank foreign-exchange markets in Hong Kong, Tokyo, and Singapore. The majority of respondents agree that nonfundamental factors have significant effects on short-run exchange rates and that speculation increases volatility while improving liquidity and efficiency.² Another study, by Cheung and Chinn (1999), presents findings from a survey of practitioners in the U.S. interbank foreign-exchange market. The results from

¹In addition, Allen and Taylor (1990) analyze the accuracy of individual technical analysts' one-week-ahead and four-week-ahead forecasts of three major exchange rates. They find that, over a ten-month period, some individuals were able to outperform a range of alternative forecasting procedures, including a random-walk model, vector autoregressions, and univariate autoregressive moving-average time series. See also Curcio and Goodhart (1992, 1993).

²In a related study, Lui and Mole (1998) report the results of a survey conducted in February 1995 on the use by foreign-exchange dealers in Hong Kong of fundamental and technical analysis to form their forecasts of exchange-rate movements. They find that about 85 percent of respondents rely on both fundamental and technical analysis, and that there is a skew toward technical analysis at shorter horizons, and a skew toward fundamental analysis at longer horizons.

this study suggest that only about 30 percent of traders can be characterized as “technical” traders, although this proportion has been increasing over the last five years. Incorporation of news about fundamentals into exchange-rate expectations occurs very rapidly, and news about interest rates appears to be relatively more important in these markets. As one would expect, macroeconomic fundamentals appear to be particularly important for long-run exchange-rate expectations.³

At the very least, therefore, the empirical evidence suggests that the attitude of many financial economists toward chartist analysis—that “technical strategies are usually amusing, often comforting, but of no real value” (Malkiel, 1996, p. 154)—should not be held with 100 percent confidence, at least in the foreign-exchange market.

The Impact of Chartist Analysis

The widespread academic skepticism of nonfundamental influences in financial markets has begun to give way to active investigation of the many phenomena not captured by traditional economic models. Although analyses of the stock market have begun to consider the influence of nonfundamental factors in general (Shiller, 1984; De Long, Shleifer, Summers, and Waldmann, 1989), studies of the specific role of chartism have so far been largely confined to the foreign-exchange market.

Goodhart (1988) discusses the way in which exchange-rate misalignment might occur by considering that the rate might be determined by a balance of chartist and fundamentalist predictions. This surmise is, in some ways, similar to the simple model of the stock market suggested by Shiller (1984), in which the equilibrium price depends on the balance between fundamentalists (smart money) and ordinary investors who subscribe to popular models. A comparable approach is developed more formally by Frankel and Froot (1990b), who explain the sharp rise in the demand for the U.S. dollar over the 1981-85 period as a shift in the weight of market opinion away from fundamentalists and toward chartists. This shift is modeled as a Bayesian response to the inferior forecasting performance of the economic fundamentalists.

³Cheung and Chinn (1999) also report that speculation and official intervention, although thought to increase market volatility, are likely to restore equilibrium by moving exchange rates toward their long-run values. Finally, traders do not value purchasing-power parity highly as a long-run equilibrium concept, although they seem to believe that it might be useful for horizons of at least six months. Cheung, Chinn, and Marsh (1999) use U.K. survey data and confirm that nonfundamental factors are thought to dominate short-run movements in exchange rates, although fundamentals are deemed important over much shorter horizons than is suggested by the mainstream empirical literature.

Bilson (1990) emphasizes that technical traders employing “overbought or oversold” indicators (“oscillators”) will impart nonlinearity into exchange-rate movements, because small exchange-rate changes that do not trigger the oscillator will tend to be positively correlated, reflecting trend-following trading programs; larger exchange-rate movements, however, which trigger an oscillator, will be negatively correlated. Bilson estimates simple nonlinear exchange-rate equations that are consistent with this pattern of serial correlation and records moderate success in capturing exchange-rate changes.⁴

Researchers have also begun to analyze related microstructure issues such as the volume of trade in foreign-exchange markets, and to ask why, for example, trade volume is much higher on a gross basis (among foreign-exchange dealers and brokers) than on a net basis (involving nonfinancial companies).⁵ Frankel and Froot (1990b), for example, provide strong evidence that both volume of trade and market volatility are related to the heterogeneity of exchange-rate expectations, as reflected in the dispersion in survey expectations (see also Ito, 1990, and Hogan and Melvin, 1994).

Other studies in the microstructure literature have looked at the way information is processed and transmitted through the market, and at the effect information processing has on market volatility and volume. Lyons (1995), for example, reports that volume affects the bid-ask spread through both the information signaled by market volume and the desire of market makers to control their inventory of currencies. Bessembinder (1994) reports that bid-ask spreads widen as proxies for inventory carrying costs increase. Bollerslev and Melvin (1994) provide a model in which the bid-ask spread is determined by underlying uncertainty regarding exchange-rate movements. In related work on market volatility, others document regularities in market volatility (Hsieh, 1988) and the contagion of exchange-rate volatility across foreign-exchange markets, the so-called “meteor shower,” which may be interpreted as evidence of information processing (Engle, Ito, and Lin, 1990; Hogan and Melvin, 1994).

Modeling Expectations of Chartists, Fundamentalists, and Portfolio Managers

Frankel and Froot (1987) develop a formal model of agents’ expectations in the foreign-exchange market—with the agents classified as chartists, fundamentalists, and portfolio managers—that forms the basis for nearly all subsequent models of investors’ expectations in the foreign-exchange and

⁴Hsieh (1988) also detects evidence of nonlinearities in exchange-rate movements. See also De Grauwe, Dewachter, and Embrechts (1993).

⁵Frankel and Froot (1990b), for example, suggest that over 95 percent of market transactions in leading exchange rates involve foreign-exchange-market dealers or brokers; Lyons (1995) suggests that market makers alone account for over 80 percent.

other financial markets. Their model, designed to explain the demand for the U.S. dollar during the 1980s, functions as though “there are actually two models of the dollar operating, one at each end of the spectrum, and a blend in between” (Frankel and Froot, 1986, p. 36). The two models they use are a fundamentalist model, for which they assume a Dornbusch overshooting model (long-run), and a chartist model, for which they use a simple autoregressive integrated moving average (ARIMA) forecasting equation (short-run).

The value of a currency can then be driven by the decisions of portfolio managers who consider a weighted average of the expectations of fundamentalists and chartists of the following form:

$$\Delta s_{t+1}^m = \omega_t \Delta s_{t+1}^f + (1 - \omega_t) \Delta s_{t+1}^c, \quad (1)$$

where Δs_{t+1}^m , Δs_{t+1}^f and Δs_{t+1}^c denote the rate of change in the spot rate expected by portfolio managers (the market), fundamentalists, and chartists, respectively, and ω_t is the weight given to the fundamentalist view by portfolio managers. Assuming, for simplicity, that $\Delta s_{t+1}^c = 0$, equation (1) becomes

$$\Delta s_{t+1}^m = \omega_t \Delta s_{t+1}^f, \quad (2)$$

and thus

$$\omega_t = \Delta s_{t+1}^m / \Delta s_{t+1}^f. \quad (3)$$

Consider a general model of exchange-rate determination of the form

$$s_t = c \Delta s_{t+1}^m + z_t, \quad (4)$$

where z_t denotes the fundamentals. Clearly, equation (4) is a very general exchange-rate model that can be interpreted in terms of any of the asset-pricing exchange-rate determination models. The Frankel-Froot model incorporates an expectations-formation mechanism of the form (1) within a general asset-pricing model of the type (4).

Frankel and Froot (1987) analyze the simple case in which chartists believe that the exchange rate follows a random walk, $\Delta s_{t+1}^c = 0$, assuming a process governing the evolution of the weight ω_t and using simulation methods, rather than computing the closed-form solution of the model. They also fully specify a mechanism to endogenize the fundamentals in order to include in the model the effects of current-account imbalances, allowing the currency to revert to equilibrium and avoiding the drawbacks of an exogenous specification of the economic fundamentals—in particular, the implication that the spot rate may be stuck at a disequilibrium level.⁶

⁶Note also that the model assumes behavior that is less than fully rational, because none of the three classes of agents conditions its forecasts on the full information set of the model.

The results of the simulations suggest that a bubble in the exchange rate is generated by portfolio managers' attempts to learn the model. When the bubble takes off, as well as when it collapses, portfolio managers learn the model more slowly than when they are changing it by revising the weight given to fundamentalist and chartist views. When the weight given to the fundamentalist view leans toward any of its extreme values (zero and unity), however, the portfolio managers' exchange-rate-determination model leans toward the correct model. In addition, the revisions of the weight become smaller until the portfolio manager's model corresponds perfectly to the correct one, implying that portfolio managers change the model more slowly than they learn it.

Following the seminal article by Frankel and Froot (1987), a number of researchers constructed models to illustrate the role of nonfundamentalist traders in generating bubbles in the foreign-exchange and other financial markets. These models are generally alike in considering at least two types of traders who differ in their forecasts or beliefs, and in predicting an outcome that shows the nonstationary dynamics typical of many financial markets. Among them, those by De Long et al. (1989, 1990a, 1990b), Kirman (1991), and Goldberg and Frydman (1993) are worth citing. The models predict that periods of steady evolution are interrupted by bubbles and crashes, with noise around the turning point when one regime shifts to another. Opinions in the market are usually modified endogenously as a result of the interactions among agents. Agents make mistakes at the turning points when the opinion of the majority is not clear, but these episodes are not long enough for learning or for the generation of profitable arbitrage opportunities (Kirman, 1991). De Grauwe and Dewachter (1993) use a combined chartist-fundamentalist model to show the way in which chaotic behavior of the exchange rate may be generated; the exchange rate produced by such a process would be essentially unpredictable, regardless of whether the underlying model is deterministic or stochastic (Goodhart, 1988). If these models accurately describe the foreign-exchange market, the discrepancy between short- and long-run expectations of the exchange rate may no longer be considered a puzzle for the profession.

Summing Up

Although it seems inexorable that economic fundamentals will "win" in the long term, it is likely that short-term price movements may be dominated by "popular" models and theories, one of which is chartist analysis. Clearly, simple reliance on the extrapolation and inductive reasoning found in chartist analysis is ultimately unsatisfactory. It may be, however, that chartists (and foreign-exchange dealers in general), by working with the minutiae of market-price movements, are able to "get a feel" for lo-

cal approximations to processes that are too complex, too short-term, or too nonlinear to be captured adequately by the current state of financial economics. In any event, the fact that chartist techniques are subscribed to by large numbers of financial-market practitioners, combined with the poor performance of standard exchange-rate economics in predicting and explaining exchange-rate movements, suggests that chartism should not be lightly dismissed (Frankel and Rose, 1995; Taylor, 1995; Evans and Lyons, 1999).

5 TIME-VARYING VOLATILITY, MARKET LOCATION,
AND TRADING VOLUME

Time-Varying Volatility in the Foreign-Exchange Market

The modeling of time-varying volatility in the foreign-exchange market is the focus of an enormous literature that is largely dominated by models of autoregressive conditional heteroskedasticity (ARCH) and generalized autoregressive conditional heteroskedasticity (GARCH). The basic insight behind ARCH models, first introduced by Engle (1982), is that the second moment of the distribution of exchange rates is serially correlated. ARCH models are nonlinear conditionally Gaussian models in which the conditional variance is a function of the lagged error terms. Engle's (1982) ARCH model may be written as follows:

$$y_t \mid \Omega_{t-1} \sim N(x_t\beta, h_t) \quad (5)$$

$$h_t = f(\epsilon_{t-1}, \epsilon_{t-2}, \dots, \epsilon_{t-q}, \dots, \alpha) \quad (6)$$

$$\epsilon_t = y_t - x_t\beta, \quad (7)$$

implying that the conditional distribution of y_t , given the information set Ω_{t-1} , is normal, with mean and variance equal to $x_t\beta$ (a linear function of, say, k independent variables x_t) and h_t (a function of, say, q lagged error terms and other exogenous variables), respectively. Equation (6) may be parameterized as

$$h_t = \alpha_0 + \sum_{j=1}^q \alpha_j \epsilon_{t-j}^2 \quad \alpha_j \geq 0 \quad \forall j, \quad (8)$$

for an ARCH(q) model. These models can be estimated by maximum-likelihood methods, and a simple Lagrange multiplier (LM) test for the presence of ARCH effects may be constructed from an auxiliary regression of the form

$$\widehat{\epsilon}_t^2 = \alpha_0 + \alpha_1 \widehat{\epsilon}_{t-1}^2 + \dots + \alpha_q \widehat{\epsilon}_{t-q}^2, \quad (9)$$

where $\widehat{\epsilon}_t$ denotes the residual from ordinary least squares estimation of (7). Under the null hypothesis that $\alpha_j \geq 0 \forall j$, the LM statistic TR^2 (T being the number of observations and R^2 being the coefficient of determination from equation 9) is asymptotically distributed as $\chi^2(q-1)$.

A simple but important extension of the ARCH model is the GARCH model developed by Bollerslev (1986). A GARCH(p, q) model may be written as

$$h_t = \alpha_0 + \sum_{j=1}^q \alpha_j \epsilon_{t-j}^2 + \sum_{j=1}^p \beta_j h_{t-j}. \quad (10)$$

Because ϵ_t^2 has the same properties as an autoregressive moving-average (ARMA[m,p]) process, the appropriate orders of a GARCH process may be determined following the criteria typical of the Box and Jenkins (1970) methodology on the autocorrelations and partial autocorrelations of the squares of a set of residuals.¹

A common finding of the literature using high-frequency financial data is the strong persistence implied by the estimates of the conditional variance functions of excess returns. This persistence is consistent with the presence of a near-unit root in the autoregressive polynomial in (10), that is, $\alpha_1 + \dots + \alpha_q + \beta_1 + \dots + \beta_p = 1$. Engle and Bollerslev (1986) depict this situation as an integrated generalized autoregressive conditional heteroskedasticity (IGARCH) model. The strong implication of this sort of model is that current information remains important for forecasting the conditional variance for the indefinite future.

Time-varying volatility models of the kinds described above have been applied to exchange rates by, among others, Domowitz and Hakkio (1985), Engle and Bollerslev (1986), Milhoj (1987), Hsieh (1988), McCurdy and Morgan (1988), and Baillie and Bollerslev (1989); for a survey, see Bollerslev, Chou, and Kroner, 1992, pp. 37-46).

Hsieh (1988) uses daily data for five exchange rates vis-à-vis the U.S. dollar from 1973 to 1983. His main purpose is to investigate the statistical properties of the data and to discriminate between two competing explanations for the observed “heavy tails” of the distribution of exchange rates: namely, that the data are independently drawn from a heavy-tail distribution that remains fixed over time and that the data come from distributions that vary over time. Hsieh’s results suggest the rejection of the former hypothesis. An interesting finding is that the rejection can be attributed to changing means and variances in the data, and that an ARCH(9) model is able to capture most of the nonlinear stochastic dependencies present in the data. Similar results are provided by Milhoj (1987), Diebold (1988), and Diebold and Nerlove (1989). These findings have been reinforced by other studies using GARCH formulations, for example, McCurdy and Morgan (1988), Hsieh (1989a, 1989b), and Kugler and Lenz (1990).

Diebold and Nason (1990) argue, however, that it is not clear whether the conditional heteroskedasticity detected in the prediction error of linear exchange-rate models is, in fact, a property of the true data-generating process or whether it is attributable to some sort of general misspecification associated with linear conditional-mean representations. Diebold and

¹For comprehensive textbook expositions of ARCH and GARCH models, as well as their properties and their extensions, such as ARCH in mean (ARCH-M) and GARCH in mean (GARCH-M), in which the basic ARCH and GARCH frameworks are extended to allow the mean to depend on its own conditional variance, see Engle, Lilien, and Robins (1987), and Bollerslev, Chou, and Kroner (1992).

Nason examine this issue by estimating nonparametrically the conditional-mean functions of ten nominal dollar spot rates for the sample period 1973 to 1987, used to generate in-sample and out-of-sample nonparametric forecasts. Interestingly, their findings do not support the idea that nonlinearities in exchange rates can be exploited for prediction purposes. Their results are also consistent with the findings of other similar studies, such as that by Meese and Rose (1991).

Another finding, suggested by both Diebold (1988) and Baillie and Bollerslev (1989), is that although ARCH effects are found to be strongly statistically significant on daily and weekly exchange-rate data, they weaken and eventually disappear with less frequently sampled data, that is to say, ARCH effects “aggregate out” over time. In addition, the assumption of normality appears to be a good approximation over four-week or, perhaps, two-week frequencies, but not at higher frequencies. Baillie and Bollerslev (1989) also estimate a GARCH(1,1) model and report a value of $\alpha_1 + \beta_1$ very close to unity, suggesting an IGARCH process (see also Diebold, 1988).²

Andersen and Bollerslev (1998) have recently raised the level of analysis well beyond the standard GARCH approach. Using an annual sample of five-minute returns, their empirical model captures the intraday activity patterns in the deutsche mark-dollar exchange market, the macroeconomic announcements in the market, and the volatility persistence (ARCH) known from daily returns. The authors quantify the different features and show that they account for a substantial fraction of return variability, both at the intraday and daily level (see also DeGennaro and Shrieves, 1995, and Melvin and Yin, 1999).

ARCH models of the exchange rate also have important implications for foreign-exchange-market efficiency. The relevant empirical literature systematically finds that the forward rate is not an unbiased predictor of the corresponding future spot rate. Under the rational-expectations hypothesis, however, the existence of a risk premium can still reconcile this fact with efficiency in the foreign-exchange market (Hakkio, 1981; Hodrick and Srivastava, 1984; Domowitz and Hakkio, 1985; Baillie, 1989). The empirical literature has attempted several different specifications that make the risk premium a function of the time-varying conditional variance of the spot exchange rate. In particular, a number of authors have used ARCH-

²A nice theoretical contribution in this context has been made by Hodrick (1989), who studies the failure of log-linear exchange-rate models of the 1970s and the observed variability of the risk premium in the foreign-exchange market. Rational, maximizing models predict that changes in conditional variances of monetary policy, government spending, and income growth affect risk premia, generating conditional volatility of exchange rates. Hodrick examines theoretically the effects these exogenous conditional variances have on the level of the current exchange rate and quantifies the extent to which this channel explains exchange-rate volatility using ARCH models.

style models for the risk premium, with largely unsatisfactory results. Several researchers argue, however, that these weak results may simply be attributable to the fact that the conditional variances are poor proxies for risk. In principle, therefore, a risk premium may be modeled more satisfactorily by making it a function of time-varying cross-currency conditional covariances rather than of just its own conditional variance. Following this argument, several researchers have estimated multivariate ARCH models as a test of the foreign-exchange-market efficiency hypothesis (Lee, 1988; Baillie and Bollerslev, 1990). Tests of the conditional capital-asset-pricing model (CAPM) that allow for a time-varying conditional covariance matrix have been made, for example, by Mark (1988) and Giovannini and Jorion (1989) and perform much better than the traditional CAPM (Kaminsky and Peruga, 1990).

Multivariate ARCH models have also been used to investigate various policy issues associated with the foreign-exchange market. Examples are models by Diebold and Pauly (1988) and Bollerslev (1990), who analyze the short-run volatility of the exchange rate immediately after the inception of the European Monetary System (EMS). Their studies conclude that an increase after 1979 in the conditional variances and covariances among the member countries of the EMS occurred as a result of increased policy coordination.

Volatility and Market Location

What are the implications of time-varying volatility in the foreign-exchange market? Engle, Ito, and Lin (1990) argue that in an efficient foreign-exchange market, the ARCH effects characterizing high-frequency data may be attributed to the amount, or quality, of information reaching the market, or else to the time necessary for market agents to process the new information fully. This argument seems consistent with the observation first made by Fama (1970, p. 396) about volatility clusters, that “large daily price changes tend to be followed by large daily changes. The signs of the successive changes are apparently random, however, which indicates that the phenomenon represents a denial of the random walk model but not of the market efficiency hypothesis. Nevertheless, it is interesting to speculate why the phenomenon might arise.” Baillie and Bollerslev (1991) use four-hourly exchange-rate series for a six-month period in 1986 and develop a seasonal GARCH model to describe the time-dependent volatility of each exchange-rate series. Their empirical results suggest that hourly patterns of volatility are remarkably similar across countries and are strongly associated with the opening and closing of the leading world markets. In addition, they find that the U.S. foreign-exchange market displays more volatility than the European market shows.

Engle, Ito, and Lin (1990, p. 526; Ito, Engle, Lin, 1992) use meteorological analogies to explain their viewpoint: “news follow[s] a process like a heat wave so that a hot day in New York is likely to be followed by another hot day in New York but not typically by a hot day in Tokyo. The alternative analogy is a meteor shower which rains down on the earth as it turns. A meteor shower in New York will almost surely be followed by one in Tokyo. To anticipate our conclusion, volatility appears to be a meteor shower rather a heat wave.”³

Engle, Ito, and Lin use intradaily data on the yen-dollar exchange rate from October 3, 1985, to September 26, 1986, and define four separate market locations: Europe, New York, the Pacific, and Tokyo. They then consider a nonoverlapping market for a day, with market 1 being open first. Volatility generated into a previously open market can be considered exogenous and part of the information set for market 2 on the subsequent day. The Engle-Ito-Lin model is a GARCH-based vector autoregression model for per-hour volatility of the form

$$\begin{aligned} \epsilon_{i,t} & \mid \psi_{i,t} \sim N(0, h_{i,t}) & i = 1, 2, \dots, n \\ h_{i,t} & = \omega_i + \beta_i h_{i,t-1} + \sum_{j=1}^{i-1} \alpha_{ij} \epsilon_{j,t}^2 + \sum_{j=1}^n \alpha_{ij} \epsilon_{j,t-1}^2, \end{aligned} \quad (11)$$

where $\epsilon_{j,t}$ is defined as the intradaily exchange-rate change divided by the square root of business hours in market j on date t ; $\psi_{i,t}$ is the information set for the market segment i at time t , which includes past information until $(t-1)$ and current information from market 1 to market $(i-1)$, that is, $\psi_{i,t} = \{\epsilon_{i-1,t}, \epsilon_{i-2,t}, \dots, \epsilon_{1,t}\}$ and is a subset of $\psi_{n,t-1}$ with $n > i-1$.⁴ The heat-wave hypothesis tested by Engle, Ito, and Lin against the alternative meteor-shower hypothesis amounts to a test of $H_0 : \alpha_{ij} = 0$ jointly for $i \neq j$.

Another innovation of the Engle-Ito-Lin study is that they develop a technique for analyzing the dynamic interreaction generated by country-specific news. The intuition is to assume that the expected future per-hour variance in a market segment is a function of a shock to a different market

³Similar arguments are advanced in the theoretical models of foreign-exchange-market dynamics built by Kyle (1985) and Admati and Pfleiderer (1988). These models have the peculiar feature that prices do not fully incorporate all the information available about the fundamental value until the end of trading, a lag that explains volatility spillovers. These models are therefore consistent with semi-strong-form efficiency of the foreign-exchange market, but not with strong-form efficiency.

⁴Various assumptions underlie the model. In particular, the authors assume market efficiency, which implies that intraday exchange-rate changes are distributed with mean zero and that $\epsilon_{i,k}$ and $\epsilon_{i,k}$ are uncorrelated for $i \neq j$. Engle, Ito and, Lin also derive the likelihood function and a maximum-likelihood estimator, or MLE (which is simply an extension of the MLE developed by Engle and Bollerslev, 1986), in order to estimate their model.

segment. Thus, using vector notation, equation (11) may be rewritten as

$$h_{t+1} = \kappa + Bh_t + A\epsilon_{t+1} + C\epsilon_t, \quad (12)$$

where κ is a vector of constants, $h_t = (h_{1,t}, \dots, h_{n,t})'$, $\epsilon_t = (\epsilon_{1,t}^2, \dots, \epsilon_{n,t}^2)'$, and

$$A = \begin{pmatrix} 0 & 0 & 0 & \dots & 0 \\ \alpha_{21} & 0 & 0 & \dots & 0 \\ \vdots & & & & \vdots \\ \alpha_{n1} & \alpha_{n2} & \dots & \dots & 0 \end{pmatrix}, B = \begin{pmatrix} \beta_{11} & 0 & 0 & \dots & 0 \\ 0 & \beta_{22} & 0 & \dots & 0 \\ \vdots & & & & \vdots \\ 0 & 0 & \dots & \beta_{nn} & \end{pmatrix},$$

$$C = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \dots & \alpha_{1n} \\ 0 & \alpha_{22} & \dots & \alpha_{2n} \\ \vdots & & & \vdots \\ 0 & \dots & \dots & \alpha_{nn} \end{pmatrix}. \quad (13)$$

Defining $h_{t+s/nt} \equiv E(h_{t+s} | \psi_{n,t})$ and taking the iterated expectation of h_{t+s} , Engle, Ito, and Lin prove that the vector of conditional heteroskedasticity of all the markets follows a process of the form

$$(I - A)h_{t+s/kt} = \kappa + (B + C)h_{t+s-1/kt}. \quad (14)$$

Thus, if $R_{ik}(s) \equiv \partial h_{i,t+s/kt} / \partial \epsilon_{k,t}^2$ (for $i, k = 1, \dots, n$) is the impulse response function of per-hour volatility of market i to the squared innovation of market k , taking the derivative of (14) allows us to obtain $R_{ik}(s)$ by solving recursively the equation

$$(I - A)R_k(s) = (B + C)R_k(s - 1) \quad s \geq 2, \quad (15)$$

where $R_k(s) = [R_{ik}(s)]_{n \times 1}$. Using simulation methods, Engle, Ito, and Lin could derive per-hour volatility in each market segment in response to per-hour volatility of the other market segments and calculate impulse responses.

Applying their model to yen-dollar intradaily exchange-rate data, the authors strongly reject the heat-wave hypothesis and interpret this rejection as consistent either with market dynamics exhibiting volatility persistence (caused, for example, by private information or heterogenous beliefs) or with stochastic policy coordination or competition. Thus, they investigate the dynamic effect of country-specific innovations on conditional volatility in the subsequent markets. Their findings suggest that Tokyo news has the largest impact on volatility spillovers of the yen-dollar exchange rate. Finally, they compute the impulse response curves to examine the reaction

of one market's volatility to news coming from another market. The empirical results suggest a cross-country dynamic effect in the short run, which gradually dies out. Overall, therefore, the authors find a case for volatility clustering of the meteor-shower type, rather than of the heat-wave type.⁵

Public Information or Private Information?

A common feature of empirical and theoretical studies is the crucial role of information, especially macroeconomic news, in determining price volatility (Oldfield and Rogalski, 1980; French and Roll, 1986; Harris, 1986). It is widely thought (and implicitly assumed in conventional macroeconomic models of exchange-rate determination) that all agents in the foreign-exchange market base projections on the same public-information set, implying that private information is irrelevant. Some recent studies, however, challenge this view.

Harvey and Huang (1991) study the volatility implications of foreign-exchange trading, using transaction data on futures contracts from the Chicago Mercantile Exchange and the London International Financial Futures Exchange. To be precise, they analyze the role of public news announcements in determining volatility patterns. Harvey and Huang compute the hourly variance rates for exchange-trading and non-exchange-trading intervals and compute the ratios of both these and the total variance rates.⁶ The rationale underlying the computation is the so-called "public-information hypothesis," which suggests that even if trading outside exchange-trading time is important, the exchange-trading variance rate may exceed the non-exchange-trading variance rate, because individual exchange rates are affected by public information available both to the countries concerned and to other countries as well. The availability of this public information, released during trading hours in both countries, may thus be expected to affect the volatility of the exchange rate; volatility may increase when important macroeconomic news is made available.

This view contrasts with that of French and Roll (1986), who suggest that trading based on private information induces higher volatility when the market is open than when the market is closed (see also the theoretical framework of Admati and Pfleiderer, 1988, and Foster and Viswanathan,

⁵See also the closely related study by Hogan and Melvin (1994), who examine the role that news and heterogeneous expectations play in the meteor-shower effects. Hogan and Melvin focus on the U.S. trade-balance news, which is shown to have a significant and persistent effect on the exchange rate and its conditional variance. In addition, the impact of U.S. trade-balance news is not isolated to the U.S. foreign-exchange market. The degree to which this news affects other market locations appears to be functionally related to heterogeneous priors.

⁶The variance-rate ratios are computed under the assumption that returns are serially uncorrelated.

1990). The empirical results of the Harvey-Huang (1991) study provide strong evidence that the intraday volatility on the international monetary market varies largely by day of the week, and that the opening on Friday (to a lesser extent Thursday), in particular, is characterized by very high volatilities. Harvey and Huang interpret these results as supportive of the public-information hypothesis, because in the United States, most of the important public macroeconomic announcements occur on Friday and, to a smaller extent, on Thursday. Overall, U.S.-European and U.S.-Japanese exchange-rate volatilities are found to be higher during U.S. trading hours, and European cross-rate volatilities are found to be higher during European trading hours. Although the disclosure of private information through trading may partly explain these volatility patterns, macroeconomic announcements appear more likely to be the cause of increases in volatility.

Wasserfallen and Zimmerman (1985) and Goodhart and Giugale (1993) investigate the systematic patterns of intraday volatility of exchange rates and conclude that volatility is smaller during intervals when trading volume is known to be smaller (for example, weekends and lunch hours) and is larger during the first trading hour on Monday for each currency in the domestic country, regardless of the fact that other markets have opened earlier. This evidence may be considered supportive of the private-information hypothesis, although both the efficient-markets hypothesis and the hypothesis that news drives exchange-rate volatility are not entirely discarded (see Goodhart and Giugale, 1993, pp. 18-19).

Demos and Goodhart (1996) note that trading volume declines immediately before the weekend and report a strong correlation between intraday patterns in exchange-rate volatility and trading activity: high, for example, both at the opening and at the close of the market, displaying essentially a U-shaped pattern. It is not clear, however, whether large volumes and volatilities are caused by efficient processing of fundamentals or by other factors such as noise trading or bandwagon effects.

A number of studies in the microstructure literature have reported a strong contemporaneous correlation between trading volume and the volatility of exchange rates (Cornell, 1981; Grammatikos and Saunders, 1986; Karpoff, 1987). This correlation is important for at least three reasons: "First, it provides insight into the structure of financial markets by relating new information arrival to market prices. Also it has implications for the design of new futures contracts; a positive relation suggests that a new futures contract can succeed only when there is 'sufficient' price uncertainty with the underlying asset, which cannot be effectively cross-hedged with other contracts. Finally, the price-volume relation has a direct bearing on the empirical distribution of speculative prices" (Jorion, 1996, p. 22).

The literature generally suggests that the positive correlation between

volume and volatility is driven by an unobserved common driving variable. This so-called mixture-distribution hypothesis (MDH) was first proposed by Clark, 1973, and Epps and Epps, 1976. The seminal theoretical paper in this literature, by Tauchen and Pitts (1983), assumes that the relation between volume and volatility may be of two types. First, market-price volatility is inversely related to the number of traders, because market prices may be considered to be an average of traders' reservation prices, and an increase in the number of traders is an increase in the number of observations on which the average (market price) is computed. Second, given a certain number of traders, price variability is proportionately related to trading volume, because higher trading volume is consistent with higher disagreement among traders. In addition, the link between trading volume and volatility is stronger when new information flows to the market at a relatively higher rate.⁷ Tauchen and Pitts (1983) derive the joint distribution of daily price changes and transactions volumes from a model of intraday equilibrium price changes and intraday volumes. Traders change their reservation prices continuously during the day in response to new information until the market reaches a new equilibrium.

Frankel and Froot (1990a, 1990b) examine the relation between the dispersion of survey forecast, volatility, and trading volume and find strong evidence that the dispersion parameter (the disagreement component) affects both volatility and volume; this finding is consistent with the MDH. Jorion (1995, 1996), however, argues that implied volatilities may be more informative than time-series models, because forecasts of volatility require forecasts of parameters that are expected to be time-varying and that are typically treated as constant in the canonical MDH approach. Given that options have been traded for about fifteen years in the leading stock-exchange markets, there is sufficient data available to test time-series models using implied standard deviations (ISDs) in the foreign-exchange market. Wei and Frankel (1991) and Jorion (1995) examine the predictive ability of ISDs by relating them to future realized volatility. Their results suggest that ISDs largely outperform time-series models, although they are still biased predictors.

In order to compute ISDs, some authors use stochastic-volatility models

⁷Unfortunately, the trade-information flow is an unobservable variable, implying that the estimation of this model requires the assumption of a distribution about an unobserved variable. An alternative model, however, which leads to similar conclusions about the relation between volume and volatility, is provided by Richardson and Smith (1994; see also Bessembinder, 1994). Hartmann (1999) analyzes the dollar-yen bid-ask spread, using a long time series of daily spot foreign-exchange-trading volumes. In line with standard spread models and volume theories, he shows that unpredictable foreign-exchange turnover (a measure of the rate of information arrival) increases spreads, whereas predictable turnover decreases them (see also Hartmann, 1998a).

that, although very appealing, present high computational costs and require estimation of a large number of parameters (Hull and White, 1987; Scott, 1987; Wiggins, 1987; Chesney and Scott, 1989). An alternative approach, followed by Jorion (1996), derives ISDs using Fischer Black's (1976) option-pricing model. Jorion (1996) provides strong evidence for the superiority of ISDs over time-series models and shows a positive correlation between volume and volatility that is consistent with the mixture-distribution hypothesis.⁸

The recent empirical contribution by Ito, Lyons, and Melvin (1998) is, however, crucial to this literature. Ito, Lyons, and Melvin provide evidence in favor of the private-information hypothesis, using data for the Tokyo foreign-exchange market, which from 1972 until 1994 was restricted from trading over the lunch break (12:00 to 13:30). Following the related study by French and Roll (1986) for the New York Stock Exchange, Ito, Lyons, and Melvin start by noting that the three candidate explanations of the importance of trading for price determination are that (1) public information arrives mainly during trading hours, (2) private information induces trades that affect prices during trading hours, and (3) errors in pricing are more likely to occur during trading hours. The authors discriminate among these explanations by using the following strategy. First, comparing volatility across regimes with an unchanged flow of public information, they find that lunch return variance doubles when trading opens. Given that the foreign-exchange market is largely skewed toward public information, the fact that public information explains very little is an important finding in itself.⁹

Having eliminated public information as the cause of higher volatility, Ito, Lyons, and Melvin (1998) discriminate between private information and pricing errors by showing that the volatility U-shape flattens over the full day, because lunch-hour trading induces greater revelation during that period, leaving smaller shares of information for the morning and afternoon. The authors also show that the U-shape tilts upward for the day, a trend suggesting that the private value of the information is temporary, that is, an open lunch hour reduces the incentive to trade early, because it reduces the likelihood that prices will reflect information before a position can be opened.¹⁰ Further, there appears to be a clear U-shape in the morning

⁸Note that the use of ISDs on stock-market data produces less interesting results. The predictive power of ISDs is, in general, very low and is never higher than the predictive power of time-series models (Canina and Figlewski, 1993; Lamoureaux and Lastrapes, 1993).

⁹Ito, Lyons, and Melvin (1998) also provide a number of tests to ensure that the flow of public information was unchanged.

¹⁰This is clear, given the definition of "private information" used by Ito, Lyons, and Melvin (1998), which includes information that is not common knowledge and that is

when Tokyo closes over lunch, but this U-shape disappears after the lunch opening, as predicted by private-information models. Finally, Ito, Lyons, and Melvin also find that the contribution of mispricing to price volatility is reduced after the lunch hour, a conclusion that coincides with the view that the increase in lunch variance is caused wholly by mispricing. Overall, Ito, Lyons, and Melvin (1998) provide the strongest empirical evidence in the literature in favor of the private-information hypothesis, even though their studies conclude that private information is expected to predict prices mainly over relatively short horizons and, thus, may not be “fundamental” (see also DeGennaro and Shrieves, 1995, Andersen and Bollerslev, 1998, and Melvin and Yin, 1999).

Covrig and Melvin (1999) have also tested some implications of market-microstructure theory along the lines of Ito, Lyons, and Melvin (1998). In particular, Covrig and Melvin identify a period in the foreign-exchange market when there is a high concentration of informed yen-dollar traders active in Tokyo. Comparing the period of informed-trader clustering to a similar period without informed traders, they show that exchange-rate quotes adjust to full-information levels much more quickly when informed traders are active in the market than when they are not. Covrig and Melvin also find that Japanese quotes lead the rest of the market when the informed traders are active but show a two-way causality when the informed traders are not active. In addition, the contribution of yen-dollar price discovery relative to quotes of the rest of the world is 5 to 12 percentage points higher when the informed traders are active than when they are not. Covrig and Melvin suggest that their results are consistent with the view that private information is at times quite important, but that “normal” times seem to be those periods during which public information implies a high contemporaneous correlation across quotes, regardless of the information’s origin. The important implication of this conclusion is that the results reported earlier by Ito, Lyons, and Melvin are attributable, not to inventory rebalancing prior to the close, but to private information. This line of analysis is an important avenue for future research.

Friedman’s (1953) classic argument in favor of floating exchange rates is that rational speculators will, in addition to imparting valuable information to the market, smooth exchange-rate movements, that is, reduce exchange-rate volatility. In a recent theoretical microstructural analysis of the connection between rational speculative activity and exchange-rate volatility, Carlson and Osler (2000) argue that Friedman’s analysis implicitly and crucially excludes interest-rate differentials from his interpretation

price relevant. This definition is less stringent than that used in previous studies (for example, French and Roll, 1986), which typically require that the price changes induced by information be permanent.

of speculator behavior. They develop a microstructural model that reveals that informed, rational speculators who consider interest differentials will magnify the exchange-rate effects of interest-rate shocks and may thereby increase overall exchange-rate volatility. This connection between rational speculation and volatility, which does not rely on asymmetric information, is structural, because speculators affect the exchange-rate-generating process. Carlson and Osler demonstrate that, in their framework, rational speculation will tend to be stabilizing at low levels of speculative activity and destabilizing at high levels of activity.

6 BID-ASK SPREAD DETERMINATION

The Main Determinants of the Spread

Modeling the bid-ask spread is difficult, because many institutional details must be considered. Finance theory identifies three main determinants of the bid-ask spread: the cost of dealer services, the cost of adverse selection, and the cost of holding inventory.

The cost of dealer services has been analyzed formally by Demsetz (1968), who assumes the existence of some fixed costs of “predictable immediacy” as the service for which compensation is required by market makers. These costs may include the cost for acquiring expertise in, and subscriptions to, specialized electronic information and trading systems (for example, Reuters).¹

The effects of adverse selection on bid-ask spreads were first examined by Bagehot (1971), whose model includes both liquidity-motivated transactors, who are willing to pay the price of the spread to the market maker in exchange for predictable immediacy, and “insider” transactors, who can speculate at the expense of the market maker by using insider information. An adverse-selection problem arises because market makers cannot distinguish between the liquidity-motivated transactors and the insiders and are thus induced to widen spreads for both categories. The bid-ask spread is thus the weapon market makers use to defend themselves against adverse selection. Information-cost models based on the adverse-selection argument have been built by, among others, Copeland and Galai (1983), Glosten and Milgrom (1985), and Kyle (1985). Although these models are very appealing, they suffer from the same problem as MDH models—that is, their empirical implementation requires the estimation of the rate of information arrival, or the share of information trading relative to overall trading, and both of these variables are unobservable.²

¹The traditional view that the centralization of the foreign-exchange market implies economies of scale such that market makers have a natural monopoly is not supported by the evidence (Stigler, 1964), even though specialists in the NYSE receive monopoly rents from other investors in compensation for barriers to market entry (Smidt, 1971). Barriers to entry or exit in the foreign-exchange market are not generally so great as to justify the existence of a natural monopoly (Stoll, 1978; Black, 1991).

²It also follows, from the adverse-selection model, that predictable volume is inversely related to spreads. In fact, given that market makers gain from deals with liquidity-motivated transactors, spreads decrease as expected order flows from this class of transactors increase and increase as expected flows decrease (Easley and O’Hara, 1992).

Finally, inventory holding costs are also a determinant of bid-ask spreads. Holding inventory of foreign exchange may be risky, because the holder is exposed to market movements in the value of the inventory. Thus, the difference between the bid and ask prices and a theoretical price somewhere in between may be regarded as a premium required by the inventory holder as compensation for risk. Inventory-cost models generally assume that market makers optimize their inventory holding. The desired level of inventory is zero, and a constant spread is shifted continuously, according to the probability of receiving a purchase and a sale order. In general, inventory-cost models imply that market makers shift the spread downward (upward) and increase the width of the spread when a positive (negative) inventory is accumulated. The original argument that inventory holding costs are a crucial determinant of bid-ask spreads derives from Barnea and Logue (1975), and dynamic-optimization inventory-cost models are presented by Bradfield (1979), Amihud and Mendelson (1980), and Ho and Stoll (1981).

Modeling the Spread: Theory and Evidence

A peculiarity of the foreign-exchange market is that market making and brokering are separate functions: market makers do not operate as brokers, and brokers do not act as market makers. Brokers' spreads should thus be modeled differently than market makers' spreads. A brokered spread is usually the combination of the best bid and ask prices received by the broker as separate limit orders. Flood (1991) suggests modeling brokered spreads as a pair of extreme order statistics from independent distributions of buy and sell limit orders. By definition, the k th order statistic is the k th number in a list containing the sample realizations of a finite number of independent random variables ranked in increasing order. Modeling limit orders also requires the derivation of the distribution of these statistics, which is conditional on volume and on the constraint that the best ask always exceeds the best bid. Given the analytical complexity of such derivation, Cohen et al. (1979, 1981) assume a "yawl" distribution in modeling limit orders (see also Cohen et al., 1986). Very little work has been done, however, on modeling brokered spreads, and the underlying theory remains largely to be developed.

The directly proportional relation between spreads and exchange-rate volatility is generally accepted by the microstructure literature. Early studies modeled the spread as a function of transactions costs, banks' profits from providing liquidity service, and market makers' payoffs for facing exchange-rate risk by assuming open positions. The main conclusions of these early studies are that exchange-rate spreads are wider under floating exchange-rate regimes than under fixed regimes (Aliber, 1975) and

that measures of exchange-rate dispersion (measuring exchange-rate volatility) are followed closely by exchange-rate spreads (Fieleke, 1975; Overturf, 1982).

Glassman (1987) makes a significant contribution to the literature with a model that includes variables representing transactions frequency and considers the nonnormal distribution of exchange-rate change.³ Her model not only provides additional evidence for the proportional relation between exchange-rate volatility and bid-ask spreads, it also suggests that market makers consider a level higher than the second moment of the exchange rate in order to evaluate the probability of large exchange-rate changes. Moreover, exchange-rate volatility is predicted by market makers on the basis of the information provided by both long-run trends (some sixty-five days), and very recent experience (one day or one week). Glassman also finds that spreads widen just before weekends and holidays. Finally, she shows that transactions costs vary significantly over time in response to regime changes on capital controls.

Admati and Pfleiderer (1988) provide a model that includes three kinds of agents: informed traders, who have relatively superior information and only trade on terms favorable to themselves; discretionary liquidity traders, who must trade sometime during the day but can choose when during the day to trade in order to minimize costs; and nondiscretionary liquidity traders, who must trade at a precise time during the day regardless of the cost. Trading volume is explained by a concentration of trade by informed traders and discretionary liquidity traders at specific points in time. The concentrations occur because it is profitable for informed traders to trade when there are many liquidity traders who do not have the same information they have; discretionary liquidity traders are attracted, because the larger the number of traders, the lower the cost of trading. The Admati-Pfleiderer model also predicts the increase in both volume and volatility that is typical at the open and close of a trading day, so that trading activity displays a U-shaped pattern from open to close.

The assumption of traders' risk neutrality is, however, crucial in generating the key results of the Admati-Pfleiderer model. This is rigorously shown by Subrahmanyam (1991), who models a noncompetitive speculative market in which informed traders, as well as market makers, are risk averse. His main finding is that market liquidity is nonmonotonic in the number of informed traders, their degree of risk aversion, and the accuracy

³The evidence for a nonnormal distribution of exchange-rate change has grown since the late 1970s and early 1980s (Westerfield, 1977; McFarland, Pettit, and Sung, 1982; Boothe and Glassman, 1987). The distribution appears to be quite close to a leptokurtic pattern, with higher peaks and fatter tails than the normal distribution. Because non-normal distributions are not described completely by the first two moments, Glassman (1987) includes the first through fourth moments in her model.

of their information. His model also predicts that price efficiency is reduced by increased concentration of liquidity traders, and that market liquidity may also be nonmonotonic in the variance of liquidity traders.

Bollerslev and Domowitz (1993) use intradaily data to investigate the behavior of quote arrivals and bid-ask spreads over the trading day, across geographical locations, and across market participants. Their findings are useful for discriminating among theoretical models of trading activity. In particular, they determine that trading activity and the bid-ask spreads for traders whose activity is restricted to regional markets can be described by a U-shaped distribution consistent with the Admati-Pfeiderer (1988) predictions. The patterns of trading activity and spreads during the day, however, also strongly suggest a degree of risk aversion by traders, a finding that is consistent with Subrahmanyam's model: given a measure of risk aversion, the more trading that is executed by informed participants, the higher will be its cost.

Goodhart and Figliuoli (1991) study minute-by-minute spot rates (bid-ask Reuters quotes) on three days in 1987 (September 14, and 15, October 21) at the Reuters screen in London. They find evidence that leptokurtosis and heteroskedasticity are less pronounced at minute-by-minute frequencies than at lower frequencies. In addition, leptokurtosis, skewness, and heteroskedasticity are time-varying. Trading volume is also time-varying and is higher at the European and North American market openings and lower at the European lunch hour. The series also exhibit a first-order negative serial correlation that is especially pronounced immediately after jumps in the exchange rate. Time aggregation appears to reduce, but not eliminate, the first-order autocorrelation. Finally, multivariate analysis suggests that there is a significant link between lagged exchange rates (both the domestic rate and the deutsche mark-dollar exchange rate) and the current spot rate (see also Goodhart, Ito, and Payne, 1996).

Bollerslev and Melvin (1994), using an asymmetric-information model with informed traders and liquidity traders in the tradition of Glosten and Milgrom (1985) and Admati and Pfeiderer (1988), show that bid-ask spreads are proportionally related to exchange-rate uncertainty. Their study's innovation is that they employ an ordered probit analysis in order to capture the discreteness in the spread distribution, with the uncertainty of the spot exchange rate modeled as a GARCH process (see also Melvin and Ramirez, 2000).

Overall, the main findings of the literature on the behavior of bid-ask spreads in the foreign-exchange market during the 1980s and early 1990s may be summarized by stating that spreads are directly proportional to the volatility of exchange rates and trading volume, and that they are higher on Fridays. In a more recent study, Bessembinder (1994) finds that

bid-ask spreads are also proportionally related to forecasts of inventory price risk. Bessembinder confirms that spreads widen before weekends and other nontrading intervals but explains that this pattern reflects an increase in the sensitivity of spreads to risk and liquidity costs over nontrading intervals. He uses a regression of time series of currency spreads on proxies for inventory cost and trading volume to study the behavior of bid-ask spreads and uses the generalized method of moments to make estimations.⁴

Moreover, because the bid and ask prices quoted by market makers are not necessarily symmetric around the underlying value of the asset, Bessembinder develops a simple procedure for estimating the location of bid and ask quotes with respect to value. The main innovation in his method is that it does not require the simultaneous observation of spot and forward prices that previous attempts in the literature employ (for example, Bossaerts and Hillion, 1991). Bessembinder's method is derived as follows. He defines an unobservable value W_t as

$$W_t = \alpha_t A_t + (1 - \alpha_t) B_t, \quad (16)$$

where α_t is a time- t location parameter, A_t denotes the ask quote, and B_t denotes the bid quote. He then defines the change in the underlying value of the currency as

$$\Delta W_{t+1} = \mu_t + \varepsilon_{t+1}, \quad (17)$$

where μ_t denotes the expectation at time t of the change in value over the next period and ε_{t+1} is the unexpected change. Combining (16) and (17) yields:

$$\Delta B_{t+1} = \mu_t + \alpha_{t+1} (-S_{t+1}) + \alpha_t S_t + \varepsilon_{t+1}, \quad (18)$$

where $S_t \equiv A_t - B_t$ denotes the bid-ask spread. In addition, the two time-varying parameters μ_t and α_t are assumed to be linear functions of observable variables X_t and Z_t , respectively. Thus, equation (18) becomes

$$\Delta B_{t+1} = \mu_0 + \mu_1 X_t + \alpha_0 [-\Delta S_{t+1}] + \alpha_1 [-\Delta (Z_{t+1} S_{t+1})] + \varepsilon_{t+1}. \quad (19)$$

In estimating equation (19), Bessembinder (1994) includes in X_t a Monday indicator variable and the excess of thirty-day eurodollar interest rates over thirty-day local-currency euro rates; he considers in Z_t a Friday indicator, a preholiday indicator, the change since the preceding day in the thirty-day eurodollar deposit rate, and the change since the preceding day in the local-currency euro interest rate. The results strongly suggest that currency market makers reduce quotes in relation to the underlying dol-

⁴Bessembinder uses forecasts of price risk, interest-rate-based measures of liquidity costs, and a nontrading indicator as proxies for inventory carrying costs. He uses the forecastable and unexpected components of futures trading volume as proxies for trading volume.

lar value when U.S. interest rates are rising and also, less significantly, on Fridays. The results also suggest a Monday effect on currency values, but shifts in the placement of quotes relative to value as weekends approach make it difficult to detect. In addition, Bessembinder's (1994, p. 344) evidence "illustrates that inference regarding asset value can be altered by allowing for variation in the placement of quotes in relation to value."

Lee (1994) provides an alternative modeling strategy for the conditional heteroskedasticity of the prediction error of foreign-exchange rates. Under the assumption of cointegration between spot and forward rates, Lee uses a system of error-correction models for GARCH-type models as a function of the spread. Estimating the system using daily series for seven exchange rates, he finds a strong correlation between spreads and exchange-rate volatility.⁵

Jorion (1996) uses an option-implied volatility in his model specification of bid-ask spreads. His results are generally consistent with the implications of conventional spread theory. He (1996) also shows that ISDs dominate all other risk measures in explaining bid-ask spreads.

Bessembinder, Chan, and Seguin (1996) investigate the relation between trading volume and some proxies for information flows (ratio of volatility of returns to a diversified equity portfolio) and for divergencies in opinion (the open interest of the Standard & Poor's 500 Index futures contract). They find that, in both spot and futures markets, trading volume varies positively with the proxies for information flows. The choice of the trading venue largely depends, as one would expect, on the nature of information flows: traders informed about firm-specific matters trade primarily in the spot equity market, whereas traders with more general, market-wide information choose to trade in the spot market. Bessembinder, Chan, and Seguin (1996) also find that trading volumes in both spot and futures markets are positively related to the proxy for divergencies of opinion when these volumes rise but are unrelated to the proxies when they fall. The day-of-the-week effects appear to be asymmetric across markets, with lower futures volume relative to spot volume occurring late in the week (Foster and Viswanathan, 1990, develop a theoretical model that predicts this asymmetry). Bessembinder, Chan, and Seguin (1996, p. 132) conclude that "additional research is warranted on identifying those circumstances under which price forma-

⁵Another paper relating global foreign-exchange markets to spreads is that by Hartmann (1998b), who estimates the long-run impact of trading activity on bid-ask spreads by using a short panel containing around-the-clock Reuters quotes and global transactions volumes; allowance is made for individual and time effects in an unbalanced random-effects model. Hartmann finds that the volume parameter has a (weakly) statistically significant negative sign, in line with liquidity-effect explanations, and that the volatility parameter is positive. He finds that structural parameters are stable over time and that residuals are, as a group, heteroskedastic.

tion will depend primarily on order flow or on the observation of public information.”⁶

Hsieh and Kleidon (1996) stress the empirical difficulties in reconciling the implications of asymmetric-information models with the observed time-series behavior of stock- and foreign-exchange data, unless liquidity traders’ demand to trade is very high at market open and close for reasons that are not explained by standard asymmetric-information models. One important inconsistency lies in the fact that bid-ask spreads are observed to go up, rather than down, at both open and close, in contradiction to the implication of asymmetric-information models that liquidity traders are trading less at these times because transactions costs are higher. Another empirical regularity that is not explained by the traditional spread theory is that neither trading volume nor volatility in the New York foreign-exchange market is significantly affected at market close in London, when both volume and volatility are at a peak in that market. Hsieh and Kleidon give two different explanations for this empirical failure of information-based models of bid-ask spread determination. First, traders are known “to learn the feel of the market,” that is, they go through a learning process. This learning process, until now largely ignored in spread theory, may help explain the high trading volume, volatility, and spreads in the morning. In addition, the peaks of trading volume, volatility, and spreads at the close of foreign-exchange markets may be explained by the desire of traders to unload excess inventories. This remains an interesting area for further investigation.

⁶Brock and Kleidon (1992) examine the effect of periodic stock-market closures on transactions demand and volume of trade and, consequently, bid and ask prices. They find that transactions demand is greater and less elastic at market open and close than at other times during the trading day. A market maker such as a New York Stock Exchange specialist may thus effectively discriminate by charging a higher transaction price during these periods of peak demand. The predictions of periodic demand with high volume and concurrent wide spreads are consistent with empirical evidence, whereas the predictions of current information-based models are not.

7 MARKET MAKERS' BEHAVIOR

The microstructure literature has also examined the way in which market makers' behavior affects the efficiency of the market. The two most common concerns with respect to their behavior are the determination of bid-ask spreads and the treatment of price information. Chapter 6 discussed the former issue; this chapter discusses the latter. An extensive literature already exists for equity markets, but the foreign-exchange market is receiving increasing interest, led, notably, by Lyons (1991, 1995, 1996, 1998, 2001).

Private Beliefs and Information Externalities

Lyons (1991) examines the importance of private beliefs and information externalities in the foreign-exchange market. He argues that the absence of different beliefs about the exchange-rate path, as well as the process for updating these beliefs in standard exchange-rate-determination models, may be crucial factors in explaining the empirical failure of such models. He (Lyons, 1991, pp. 1-2) examines the way in which the transactions themselves influence beliefs over time, the effect that the market's institutional features have on patterns of trading volume, and the mechanisms that the market has for information transmission:

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 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. The burden of explanation, then, appears almost certainly to fall on differences in beliefs regarding valuation.

Most models in the literature describe equilibrium-price determination as a one-shot outcome from the activity of traders who use private information as well as the information in market-clearing prices to determine their demands for risky assets (Diamond and Verrecchia, 1981). Lyons (1991), by allowing the transactions themselves to affect the updating process of private beliefs directly over time, suggests that the equilibrium is no longer a one-shot outcome, but the outcome, instead, of an interaction among

private beliefs, volume, and volatility. This interactive process leads, however, to a sort of information externality caused by the dual role of traders as speculators, on the one hand, and as information clearinghouse (intermediating customer orders that contain information), on the other hand.¹ Profit maximization induces traders to underestimate important information in making their trading decisions, thereby reducing the information content of prices at any given time. A crucial implication of this model is that the greater the market power and the degree of traders' risk aversion, the less the information that will be revealed by market prices.

Lyons (1995) executes a number of tests on standard microstructure hypothesis in the foreign-exchange market. In order to make these tests, he builds a model based on realistic assumptions of the institutional features of the foreign-exchange market. Lyons records the transactions of one dealer and one broker in the U.S. market for five days during August 1992. The data set includes three "interlocking" components: the direct quotes and trades of a market maker from a leading New York bank, the position cards of the same market maker, and the prices and quantities for third-party transactions intermediated by a leading New York dealer. The main focus of the study is to test for effects of trading volume on quoted prices through the two channels emphasized by the literature: the information channel and the inventory-control channel. The results suggest that trading volume affects quoted prices through both channels, therefore giving some support to both strands of the microstructure literature.²

"Event Uncertainty" versus "Hot Potato"

Lyons (1996) extends his 1995 model and uses the same data set to shed light on the statistical relation between the intensity of trading and the informativeness of trades. In particular, he attempts to discriminate between the two polar views of trading intensity that he describes as (1) the "event-uncertainty" view (trades are more informative when trading intensity is high) and (2) the "hot potato" view (trades are more informative when trading intensity is low). The event-uncertainty hypothesis can be traced back to Easley and O'Hara (1992), who build a model in which new information may not exist (in contrast to most of the asymmetric-information models in this literature). In such a framework, there is a probability p of new information and $(1 - p)$ of no new information; also, the new information is good news with probability q and bad news with probability

¹Information externalities are predicted by earlier theoretical models under different mechanisms (Stein, 1987).

²In modeling the price-expectation formation process, Lyons uses a Bayesian model in the tradition of Amihud and Mendelson (1980), Cohen et al. (1981), Conroy and Winkler (1981), Glosten and Milgrom (1985), and Madhavan and Smidt (1991). For a nontechnical exposition of these models, see Flood (1991).

($1 - q$). Easley and O'Hara (1992) show that trades occurring when intensity is high should induce a larger updating of beliefs than when trading intensity is low, implying that trades are more informative when trading intensity is high. The opposite view, the hot potato view, is rationalized on the basis of asymmetric-information models in the tradition of Admati and Pfleiderer (1988), in which liquidity traders clump together in their trading in order to minimize their losses to informed traders. Because of this clumping of liquidity traders, trades are more informative when trading intensity is low.³ The main goal of Lyons (1996) is to examine whether currency-trading volume is informative and under what circumstances. Specifically, he uses transactions data to test whether trades occurring when trading intensity is high are more informative, dollar for dollar, than trades occurring when intensity is low. Lyons' empirical results in estimating his model are supportive of the one or the other hypothesis depending upon the measure of trading intensity used in estimation, implying that "taken together, the results highlight the potential complementarity between these seemingly polar views" (Lyons, 1996, p. 20).

Lyons (1998) also examines foreign-exchange trading at the dealer level. The dealer Lyons tracks averages U.S. \$100,000 in profits per day on a volume of U.S. \$1 billion per day. The half-life of the dealer's position is about ten minutes, which may be interpreted as evidence supporting inventory models. The author also identifies the dealer's speculative position over time and finds that this position determines the share of profits deriving from speculation, rather than intermediation, and that intermediation has a relatively more important role.

³See also Lyons (1997), who develops a simultaneous-trade model of the spot foreign-exchange market that produces hot-potato trading. At the outset, risk-averse dealers receive customer orders that are not generally observable. Dealers then trade among themselves. Thus, each dealer intermediates both his or her customers' trades and any information contained therein. This information is subsequently revealed in price, depending on the information in interdealer trades. Lyons shows that hot-potato trading reduces the information in interdealer trades, making price less informative.

8 CONCLUSION

We began this study by noting that the failure of fundamentals-based exchange-rate models to explain or predict exchange-rate movements reliably has, at least in part, motivated the development of the microstructure literature (Flood and Taylor, 1996). To date, however, the foreign-exchange-market microstructure seems to shed light most strongly on related issues, such as the transmission of information among market participants, the heterogeneity of agents' expectations, and the implications of agents' heterogeneity for trading volume and exchange-rate volatility.¹

There appears to be an emerging consensus in the literature, moreover, that macroeconomic fundamentals are a reasonable guide to very long-run exchange-rate movements (Flood and Taylor, 1996; Lothian and Taylor, 1996), and there is increasing interest in exchange-rate models with rigorous, stochastic, general-equilibrium microeconomic foundations (Obstfeld and Rogoff, 1995, 1996; Lane, 1999; Sarno, 2001). For the foreseeable future, therefore, it seems that research in foreign-exchange markets is likely to be dominated by three strands: long-run empirical exchange-rate modeling, the "new open-economy macroeconomics," and analyses of the foreign-exchange-market microstructure. Synthesizing these three approaches into a unified treatment would seem to be a worthwhile challenge for the economics profession.

¹An important exception is the recent paper by Evans and Lyons (1999), which demonstrates that order flow may empirically explain a large portion of nominal exchange-rate movements over periods of four months or less; this finding clearly suggests the need for further research on the relation between order flow and exchange-rate movements.

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The work of the International Economics Section is supported in part by the income of the Walker Foundation, established in memory of James Theodore Walker, Class of 1927. The offices of the Section, in Fisher Hall, were provided by a generous grant from Merrill Lynch & Company.

ISBN 0-88165-261-X

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