Price Discovery in Multiple-Dealer Markets: The Case of the Interbank Foreign Exchange Market*

by

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Abstract

Price discovery is a principal function of financial markets. Yet, especially for dealership markets, financial economists know little about how prices are determined. In this paper I analyze the process of price discovery in the multiple-dealer, interbank spot market for foreign exchange. I use DM/$ quotes to calculate interbank dealers' "information shares," their proportional contributions to the variance of innovations in the implicit, efficient exchange rate. These information shares are used to analyze relationships between price discovery and dealer characteristics. Unlike the U.S. equity markets, where regional exchanges contribute relatively little to price discovery, less-active interbank dealers play a large role, impounding most of the information into quotes. A pooled analysis of dealers' intraday information shares indicates that the lower the relative bid-ask spread and the greater the number of regional foreign exchange branches, the higher is a dealer's contribution to price discovery. Dealer nationality, however, does not appear related to price discovery within dealers' domestic markets.

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1. Introduction

"Price discovery" is a dynamic process in which a diverse group of traders and market makers gather, evaluate, and interpret disparate pieces of information; coordinate trading demands; and generate market-clearing prices. Though it is a principal function of securities markets, price discovery has received little, but growing attention from financial economists. The literature includes few theoretical models or empirical studies, especially for multiple-dealer markets. The classical notion of price discovery involves a Walrasian auctioneer who observes quantities supplied and demanded at different prices and determines the price that clears the market. With this framework economists ask, "how do prices work?" but not "how are prices set?" And, while this model yields obvious practical advantages, it trivializes complex and economically important pricing decisions. In reality, many individuals generate prices concurrently, and the interactions among institutional features, preferences, and asset characteristics imply that the quotes we observe in markets vary in their informative quality.

The 24-hour interbank spot market for foreign exchange (FX) is one market that operates in contrast to the simple, Walrasian model. It is comprised of multiple dealers who generate quotes in a decentralized, opaque, and unregulated trading environment. Proprietary electronic dealing systems provide subscribers with FX quotes posted to the system, news, current interest rates, and other commodity prices. But, apart from anonymously brokered transaction prices, which are announced via an intercom system, dealers choose not to disclose trading information. In this opaque market, dealers' own customer order flow provides private information because it is correlated with exchange rate fundamentals, unique to each dealer, and observed before news services or other organizations collect and publish exchange rate fundamentals (Goodhart, 1988; and Lyons, 1995).

Correspondingly, understanding the process of price discovery in the FX market begins with understanding how dealers attract order flow and what factors influence their decisions to incorporate the information they produce into their quotes. Dealers may quote exchange rates that do not reflect their expected value either to profit from less informed customers or to avoid subsidizing the production of information by other dealers (Madrigal and Scheinkman, 1997; Madhavan, 1995; and Chowdhry and Nanda 1991).[1] For example, large dealers like Deutsche Bank and Citibank, who attract a large share of order flow and produce more information than most interbank dealers, may choose to conceal some information from the quotes they post.[2] This paper analyzes whether the contributions by dealers to the

[1] While these models generate implications for price characteristics, none generates predictions for relative rates of price discovery among multiple dealers.

[2] Dealers may be willing to sell at a price which is lower or buy at a price which is higher than their current quote indicates.

discovery of the Mark-Dollar quote indications, as measured by dealers' "information shares," relate to characteristics of dealers that are correlated with order flow, and thereby, private information.[3]

The statistical relationship between information production and dealer characteristics suggests a fragmented and strategic process of price discovery in the interbank FX market. A pooled regression of intraday information shares shows that dealers who (actively or passively) post better bid or ask quotes generate more information about the Mark-Dollar quote, but the effect is small: lowering the average spread by one basis point increases a dealer's information share by 0.012%. Information shares also appear to be related to dealer size. Given equivalent spreads, the greater the number of cities from which a dealer quotes the Mark-Dollar currency pair within a specific region, the greater is his or her contribution to the implicit efficient exchange rate. Adding one quoting location corresponds to a 1.25% increase in that dealer's share of information. Average shares in the most active FX region typically average about 9%.

Finally, information shares do not appear to be related to dealer nationality. The lack of a statistical relationship between information shares and nationality is not consistent with turnover measures collected by the Bank for International Settlements (BIS), and it suggests that dealers conceal their information from Mark-Dollar quote indications. Although there is no evidence that American dealers dominate price discovery in any market., the English government reported to the BIS that during 1993, American dealers dominated FX turnover in the largest, U.K. market. And, although the U.S. government does not report relative turnover of domestic and foreign dealers operating in the U.S, it is likely that American dealers also dominate this market.

This investigation is the first comprehensive study of the process of price discovery in a dealership market. The results are consistent with Madhavan's (1995) model of fragmented markets in which dealers do not disclose trades and Lyons' (1997) view that volume and price share the burden of information transmission. Additionally, this is the first paper to analyze the relationship between price discovery and dealer characteristics. It builds on the few prior empirical investigations of price discovery in the FX market, including Ito, Lyons, and Melvin (1998), who find evidence of private information in this market, and Peiers (1997) and Sapp (1999), who respectively document Deutsche Bank's quote leadership and information generation around announcements of Bundesbank intervention.

2. The Interbank Foreign Exchange Market

The expression, the "foreign exchange market," connotes a single location where individuals exchange one currency for another. More accurately, the foreign exchange market is an electronic, quote-driven market comprised of several hundred "interbank dealers." The term "interbank" refers to the fact that banks quote prices and trade currency directly, bank-to-bank, in several market centers around the world. These dealing banks trade currency on the behalf of their customers: high-net-worth individuals, institutional investors, investment banks, and multinational corporations.

During the 1970's and early 1980's dealers traded currency using telephones and telex machines. Computer technology introduced in the mid-80's led to automated dealing systems, which dramatically expanded the efficiency and reliability of trading in the interbank market. Now, electronic networks like Reuters, Telerate, MINEX, and Bloomberg link dealers both within and across market centers, and enable dealers to quote and trade currencies 24 hours a day. Using these electronic networks, interbank dealers quote two-way bid and ask prices at which they are willing, but not contractually required, to trade, and complete transactions over dedicated telephone lines.[4] Newer systems enable dealers to hold conversations with many dealers simultaneously and to transact instantly at others' quotes.[5] In addition to bank-to-bank dealing, interbank dealers can submit one-way quotes and trade anonymously using foreign exchange brokers.[6]

2.1 Market Activity and Regulation

Every day, FX market participants trade nearly $1.2 trillion in spot, forward, swap, futures, and options transactions. Table 1 summarizes FX activity of the major market centers. London dominates all market centers with 30% of total FX turnover. According to statistics reported by the Bank for International Settlements (BIS), dealers who are located in London trade far more U.S. dollars (Dollars) and Deutsche marks (Marks), the most common FX transaction, than dealers in the U.S. or Germany. Aggregated by region, 65% of all FX turnover occurs during European market hours, 18% occurs during American market hours, 15% occurs during Asian market hours, and the 2% occurs during Australian/New

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[3] The proportion of the variance the variance of permanent innovations contributed by each dealer represents that dealer's "information share." In this sense, a dealer's information share represents the percentage contribution to innovations in the implicit, efficient exchange rate (Hasbrouck, 1995).

[4] Dealers honor their quote indications, however, because their reputations depend on their ability to commit to them (Goodhart and Figulioli, 1992).

[5] See Luca (1995), *Trading in the Global Currency Market*, for details of the Reuters Dealer 2000 system and other electronic dealing systems.

[6] Since April 1992, dealers have been able to conduct their brokered trading electronically, however until recently, most brokered business has been transacted by voice via direct telephone lines (Luca, 1995).

Zealand market hours. In each market center, interdealer trading typically constitutes about 75% of all activity, but the number of dealers in each market center is not proportionate to turnover. In market centers with 2% or less of the total FX activity, between 2 and 15 dealers (average is 8) conduct 75% of the deals. Market centers like London and New York, which have about 10 to 15 times the activity, have about twice as many dealers.

The FX market has no formal regulatory body. In this relatively free market, organizational features are noteworthy inasmuch as they mimic or depart from regulated markets. First, similar to equity market makers, interbank dealers employ standard depth and tick size to facilitate trading. The smallest amount by which an interbank dealer will update the Mark-Dollar quote is one "pip," or DEM/USD 0.0001, and the depth at the posted quotes is understood to be $10 million (Lyons, 1995). Second, interbank dealers have not established formal trading rules such as those imposed by the exchanges or the SEC in U.S. equity market makers. NYSE specialists and Nasdaq market makers must register to trade stocks and provide an active, orderly market, but in contrast, FX dealers can quote and trade any set of currencies at will. Third, FX dealers do not make transaction information available to third party dealers or the public; only the transacting parties know the details of a transaction. In the U.S., the SEC instituted a "Consolidated Tape" rule in 1972 that requires U.S. securities exchanges and the NASD to provide real-time transaction information to the public (Hasbrouck, Sofianos, and Sosebee, 1993).

2.2. Asset character and the nature of information

Asset characteristics like maturity, creditworthiness of the issuer, the nature and priority of the claim affect how individuals value them. For example, a share of common equity represents residual ownership of the assets and earnings of a corporation. To value an equity share, individuals will gather firm-specific information. Illessy and Shastri (1998, p. 3) note that the "…cash flow forecast critically depends on private information about idiosyncratic factors that is available to insiders only or can be observed by outsiders by incurring non-trivial transactions costs."

Like an equity share, currency value reflects the nature of information: what information is relevant and who is likely to produce it. To value exchange rates, individuals will gather information that is macroeconomic in nature. Factors that influence exchange rates include central bank intervention, changes in the fiscal decisions of governments, expected economic growth, interest rates, public confidence in the monetary or financial system, international trade, and the accumulated decisions of individuals and firms. Though macroeconomic in nature, information still can be considered private in the sense that one can be the first to produce it. The likely producers of private information in the FX market are the interbank dealers. Located at the center of a decentralized and opaque market, dealers have a unique opportunity to

be the first to gather and process information about exchange rates. A primary source of private information is dealers' own customer order flow (Goodhart, 1988; Chowdhry and Nanda, 1991; Lyons, 1996, 1997; Madrigal and Scheinkman, 1997). Order flow represents an accumulation of atomistic trading decisions made by investment banks, central banks, corporations, wealthy individuals, and individuals traveling abroad. Lyons (1997) suggests that customer trades may be informative because they reveal information about their net export performance. Similarly, as Ito, Lyons, and Melvin (1998) elucidate, the aggregation of orders – some of which are driven by liquidity needs and others by economic fundamentals – provides dealers with private signals of real trade in the form of export and import activity before the accompanying statistics are published.

Dealers use other sources of information, which are common to dealers, but not the trading public. One is a fee-based, electronic dealing system that not only enables dealers to keep track of their own bilateral trading information, but also it lets them observe others' absolute and relative quote revisions, from which they can make inferences about the information held by other dealers (Chowdhry and Nanda, 1991). Another source of information available exclusively to dealers is the information that FX brokers post electronically and broadcast on an open-speaker system. Brokers quote the best spread, report whether transactions occur at the bid or ask, and announce the price of the transaction. Finally, through their positions as primary dealers in government securities, some FX dealers may learn about central bank intervention before others (Peiers, 1997).

3. The Hypotheses

Operating on the premise that dealers are the informed agents in the interbank FX market, hypotheses about relative rates of price discovery fundamentally center on two separate questions. First, how does a dealer generate an informational advantage relative to other dealers? Second, if a dealer has an informational advantage, will that dealer incorporate it into market quotes?

In order to generate an informational advantage in the interbank market, a dealer must either process more order flow, or have a comparative advantage in processing information from order flow or sources common to all dealers. Dealers compete to attract orders through several mechanisms; one is the best spread. Chowdhry and Nanda (1991) posit that small, discretionary liquidity traders will trade in the market where the expected costs of trading are the lowest. In the spirit of Admati and Pfleiderer (1988), trading attracts trading cross-sectionally, as traders concentrate in markets with the largest number of non-discretionary liquidity traders. Similarly, with multiple market makers, Madrigal and Scheinkman (1997, p. 42) assert that "…sellers sell to the market maker who posts the highest bid price and buyers trade with the

market maker who posts the lowest ask price." In Dutta and Madhavan (1997), dealers who quote the inside spread attract and share the order flow. Blume and Goldstein (1997) find evidence to support this view in U.S. equities markets. They observe that when market makers of NYSE-based, cross-listed stocks improve the quoted bid or ask, their market shares increase substantially.

In the interbank FX market, dealer quotes cannot be observed freely by retail customers. In fact, corporate customers interact with the bank's sales team and typically do not contact the interbank dealer. They either ask for a price or they leave an order with the bank (Luca, 1995). Under this structure, customers can spend time searching across foreign exchange dealers for the best quote. In many cases, banks will agree to give the customer a price that is some function of current market quotes. Others simply may quote the customer the running market price in exchange for information or a large order (Luca, 1995). Pratt, Wise, and Zeckhauser (1979) demonstrate that the cost of searching for the best price alone is sufficient to create price differences in dealer markets. Nonetheless, if search costs are relatively small, or if dealers can produce original information from the orders submitted by other dealers, we would expect a relationship between the best quote, order flow, and information. This leads to the following hypothesis:

Hypothesis 1: Interbank dealers with the narrowest quoted spreads incorporate more information into exchange rates.

It is conceivable that dealers compete for order flow through mechanisms other than the best quote. Factors like reputation, relationships, and order flow arrangements can attract, or in some cases, retain customer order flow. Besides providing foreign exchange services, some banks offer investment advice, and account and risk management services. By competing on the basis of these services, banks in a sense may "capture" their customer base because they reward longer term relationships with lower foreign exchange transaction costs (Luca, 1995). Dealers also might secure order flow through arrangements with small dealers or other foreign exchange agents, much like the preferencing agreements or payment for order flow in equities markets. Arguably, dealers capable of providing a menu of services and of establishing strong networks are highly capitalized, large banks. In fact, they may have a comparative advantage if their size enables them to process order flow and dealer-wide information better than others. Thus, even if dealers post equivalent spreads, highly capitalized dealers may generate more information about exchange rates than do smaller competitors. This leads to the second hypothesis:

Hypothesis 2: Large interbank dealers incorporate more information into exchange rates than do small interbank dealers.

It is also conceivable that order flow is related to dealer nationality. Using the New York market as an example, American dealers based in New York may attract relatively more order flow from foreign and

domestic (local and cross-border) customers because customers perceive that American dealers have networks that provide greater reciprocity in dollar-based dealing.[7] Additionally, foreign dealers whose domestic business hours have ended may be unable to process customer trades because of limits on overnight positions. If that foreign dealer has no satellite office, these trades may be funneled to an American dealer. Third, American banks that manage accounts, provide lines of credit, and provide advisory services for American corporate customers by default may process their FX orders. Finally, similar to evidence documented by Peiers (1997) and Sapp (1999) for Deutsche Bank and the Bundesbank, American dealers may be the first to learn about Fed intervention.

Hypothesis 3: Domestic interbank dealers incorporate more information into exchange rates in their domestic market center than do foreign dealers.

These hypotheses are based on the assumption that dealers incorporate order flow information into quotes. However, these predictions may not be supported empirically because dealers may benefit from concealing their information from quotes. Concealing information from quotes may lower the information subsidy to competing dealers, lower inventory risk, and it can reduce direct price competition among dealers (Chowdhry and Nanda, 1991; Lyons, 1996; and Madhavan, 1995). In Chowdhry and Nanda (1991) risk-neutral market makers set prices conditional on their own, unique customer order flow. Discretionary liquidity traders place their orders with the market maker who is the least expensive in terms of adverse selection costs. In order to create the lowest-cost trading location, market makers sets prices to reveal the private information in their order flow. This strategy attracts liquidity traders and repels informed traders. The model implies that prices will fully reveal the private information held by the market maker. In contrast, Lyons (1996) argues that FX dealers will garble prices to manage the risk associated with inventory fluctuations. Lyons argues that when a dealer revises prices with new information, she increases the fluctuations in her inventory. This happens because the revised quote increases the quantity other dealers desire to trade. Consequently, a risk averse dealer has no incentive to reveal any private information through prices. Each period, dealers will quote the same, "common," price and only reveal information through the unique quantities that they trade. Madhavan (1995)

Both Chowdhry and Nanda (1991) and Lyons (1996) recognize that market makers likely choose some middle ground regarding price informativeness. Chowdhry and Nanda note that market makers who attract a large portion of the aggregate order flow may choose to strategically withhold price information in earlier trading periods to avoid subsidizing other market makers and lower trading costs in later periods. In

choosing when to disclose order flow information through prices, ultimately market makers weigh subsidizing other market makers against attracting liquidity traders. Lyons acknowledges that dealers likely intermediate information through volume and prices.

To determine how these motivations impact the predictions, it is helpful to consider the tradeoff that dealers make when making quotes informative. If we initially assume that inventory risk and subsidization concerns are equal across dealers, the decision may rest on differential benefits. Because large dealers have highly liquid markets due to visibility, networks, or other non-price competitive differences, attracting order flow through quote improvement yields fewer benefits relative to smaller, less liquid dealers. Thus, the smallest dealer is most likely to undercut the prevailing spread to attract order flow, and the degree of quote competition by small dealers will be higher than that of large dealers.

Realistically, inventory risk may depend on dealer size. If improving the quote increases the likelihood and magnitude of inventory shocks, small dealers, without the networks and liquidity of large dealers, face considerably higher costs to managing these shocks. Whether small dealers are willing to bear higher inventory risks for the increase in order flow that ensues from improving quotes ultimately is an empirical question. The relationship between dealer size and price discovery could be positive, negative, or independent. A negative relationship would suggest that small dealers have greater incentive to improve quotes and that large dealers conceal information. Similar reasoning applies to domestic versus foreign dealers. If dealers conceal information from their quotes, we would not necessarily expect domestic dealers to produce more information in their own markets.

4. Methodology and Data

To test the above hypotheses, I adapt a general econometric methodology introduced in Hasbrouck (1995), which statistically measures price discovery as dealers' contributions to the variance of permanent changes in exchange rate quotes.[8] Termed "information shares," these estimates are calculated by transforming the parameter estimates of an error-correction system (ECM) of dealers' quote changes. Initially, to formulate a broad view of price discovery, I estimate "aggregate" information shares. I then estimate "intraday" information shares and use these estimates in regression analysis.

Using data from the high frequency database (HFDF-93) made available by Olsen and Associates I estimate the ECM system. The data includes the sequence of bid and ask quotes posted by dealers to the

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[7] In 1995 dollar-based dealing comprised 86% of all foreign exchange transactions in New York (BIS).
[8] A detailed description of the econometric model adapted for this study can be found in the Appendix.

Reuters 'FXFX' screen over the period October 1, 1992 to September 30, 1993. Olsen and Associates provide data for several currency pairs, but I employ the Deutsche mark-U.S. dollar (Mark-Dollar) spot quotes. Each set of quotes is labeled with a time stamp, and the name and branch location of the interbank dealer who posted the quotes. Most empirical studies of the foreign exchange market use the data in this single time series format.[9] Because this analysis requires quote series for individual dealers, I reorganize the data to create an event-time series for each dealer. For those periods over which the model is estimated, I assign each new quote to the dealer who posted it. For the n-1 dealers who did not initiate the new quote, their prior quotes are carried forward in event-time.

4.1 Data Issues

Organizing the FX quotes in event time presents some econometric issues. Of particular concern is the non-synchronous character of the data. For example, the market is deterministic in some cases, as quoting activity declines or halts over weekends and on holidays; I omit these data. At other times, quote changes occur discretely, at unequal time intervals. When quote data are irregularly spaced over time, returns formed using the quotes may not reflect the true return process for microstructural or other reasons. To address this non-synchronous data problem, deJong and Nijman (1997) suggest a very general econometric method that estimates the covariance and correlations of the true return process. Given the nature of high frequency data in the foreign exchange market and the irregular nature of observed quotes, one might conclude that this methodology is appropriate. However, unlike deJong and Nijman, this paper endeavors to identify not the "true" or "underlying" flow of information, but rather the flow of information observed by market participants. Price discovery is the information revealed (observed) in the publicly posted quotes. It would be misleading to attribute price discovery to a dealer who systematically fails to update or updates late, for strategic or other reasons, even if that dealer had the "true" information first. Therefore, dealers' quotes are sufficient to estimate the model because they contain information that dealers choose to share with the trading public.[10]

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[9]The Olsen and Associates data spawned several studies of the foreign exchange market. Many are macroeconomic in nature and attempt to identify patterns or seasonalities in the aggregate market. Some examine information flows in aggregate, but do not explicitly examine individual dealers. For example, see Bollerslev and Domowitz (1993); Guillaume et al. (1995); DeJong, Mahieu, and Schotman (1996); Payne (1996); Anderson and Bollerslev (1998); Ito, Lyons, and Melvin (1998).

[10] Campbell, Lo, and MacKinlay (1997, p. 99) reflect on this point: "The premise of the extensive literature on nonsynchronous trading is that nontrading is an outcome of institutional features such as lagged adjustments and nonsynchronously reported prices. But if nonsynchronicity is purposeful and informationally motivated, then the serial dependence it induces in asset returns should be considered genuine, since it is the result of economic forces rather than measurement error. In such cases, purely statistical models of nontrading are clearly inappropriate and an economic model of strategic interactions is needed."

A second concern arises from the exclusivity of the Reuters' electronic network. The database lists over 500 interbank dealers, most of which are European and North American, but alternative electronic systems or trading technologies like telephones, telexes, and faxes are missing from the analysis. Consequently, evidence regarding the process of price discovery may apply only to Reuters-system dealers. While not an issue for European and American regions, results for the Asian and Pacific regions must be interpreted as a limited view.

4.2. Aggregate descriptive statistics

The foreign exchange market operates 24-hours a day, but economic activity – and thus foreign exchange trading – rises and falls around four geographic regions. Accordingly, the aggregate descriptive statistics are reported for the full, 24-hour sample and four regional markets, including the Pacific, Asian, European, and American markets.[11] Table 2 shows the aggregate quote activity of the "most active" interbank dealers and the composite dealer for the 24-hour market. The "most active" dealers include the top five most frequently quoting dealers and the top three interbank dealers selected by retail corporate customers in *Euromoney*'s 1993 Foreign Exchange Survey, which include Citibank, Chemical Bank, and Deutsche Bank. [12] In the 24-hour sample, Deutsche Bank posts more quotes than any other interbank dealer. During a typical 24-hour period Deutsche Bank posts approximately 400 bid-ask quotes, which corresponds to 17 quotes per hour. This activity is not surprising considering its domestic currency is the Mark and it is one of the largest banks in terms of dollar value of total assets. Despite the fact that Deutsche Bank clearly dominates the quote activity of all other dealers, its activity represents only about 9% of all quotes. Dealers in the composite (96% of the total number of dealers) post about two-thirds of the total Mark-Dollar exchange quotes. This fact suggests that omitting these dealers from the analyses effectively would ignore a significant part of the FX market.

Table 2 also reveals that there is a tendency for dealers to dominate the quote activity in their domestic regions. Along with three other European dealers, Deutsche Bank concentrates its quote activity during the European region. Deutsche Bank also contributes a large fraction of quotes, 10%, in the Asian market, where about 20% of all Mark-Dollar turnover occurs. Still, Deutsche Bank's percentage is less than Credit Suisse, which updates its quotes 1.5 times more frequently. In the American region, where turnover is roughly similar to that in Asia, Deutsche Bank is much less prominent, posting a relatively small 2% of the quotes. In this region, the top dealers post quotes relatively similarly. In the Pacific region,

[11] Regional markets are defined according to time and are listed in the Appendix. Each sample employs quotes for the full year that correspond to the time definitions.

Banker's Trust and Morgan Guaranty, with about 25% and 17% of all quotes respectively, dominate the activity. Finally, Table 2 shows that the typical interbank dealer, as represented by the composite, exhibits quite different quoting behavior. Most dealers post far fewer quotes per day than the most active dealers. This is consistent with their relatively low profiles. Whereas the most active dealers post quotes on average between 230 and 275 days of the year, the typical dealer participates during one-half to one-third as many days.

Table 3 presents measures of dealer bid-ask spreads calculated for the 24-hour market and for each region. Average absolute and relative spreads are calculated using event-time and time weights. Absolute spreads are reported in pips, for example, 6 pips equals DEM/USD 0.0006, and relative spreads are defined as the current spread over the ask price and are reported in basis points. By far, Societe Generale posts the narrowest quotes in those markets where it is one of the most actively quoting dealers. In the American region, where Chemical Bank offers the lowest spread on average, the lowest spread is noticeably higher than the banks in the other regions. In the Pacific region, Bankers Trust posts the lowest spread on average, and in the Asian region AMEX Bank posts the lowest.

4.3 Aggregate Information Shares

Aggregate information shares, which provide a broad, if static, view of price discovery, are reported in Table 4. In the 24-hour sample, Societe Generale and Deutsche Bank appear to lead the price discovery process, each generating 7.7% and 5.7% of the variance in permanent innovations in Mark-Dollar quotes. Combined with Chemical Bank, and Citibank these dealers collectively contribute nearly 19% of the price discovery in the spot Mark-Dollar market. Given that another 138 dealers at one time or another participate in this sample, 19% is sizable contribution, but relative to their aggregate quoting activity, this contribution is low. In the European region, Deutsche Bank's share is much smaller at 1.31%, and Societe Generale's share is higher at about 9%. Combined with Citibank and Chemical Bank, these dealers contribute a little more than 11% to price discovery. Like the 24-hour market, the 134 banks comprising the composite dealer contribute the remaining 86%, which exceeds their 62% contribution to quote activity. Information shares in the American region are similar. Lloyd's Bank, Citibank, Chemical Bank, and Deutsche Bank also contribute just over 11% to price discovery, while the rest is shared among 114 banks that generate 62% of the quote activity. In the Asian region, price discovery appears highly fragmented. The 86 dealers in the composite contribute 96% of the information in exchange rates, but only about 50% of the quote activity. In stark contrast, in the Pacific region Banker's Trust dominates price

[12] This approach is similar to Peiers (1997) and Sapp(1999), who identify the major interbank dealers by their quoting activity.

discovery with a 29.5% information share. Morgan Guaranty and Chemical Bank together contribute another 7%, and the remaining 69 interbank dealers comprising the composite discover 63.5%.

5. Dealer Characteristics and Price Discovery

Hypotheses in this paper rest on the fundamental premise that dealers are the informed agents in the interbank market, and that dealers obtain new information from the order flow of corporate clients, hedge funds, financial institutions and high net-worth individuals. Dealer characteristics, such as spread, size, and nationality all potentially create a competitive advantage in attracting order flow, information production, and price discovery. However, even when dealers create informational advantages, some are motivated to conceal it from their quotes.

To examine whether dealer characteristics relate to price discovery, I use intraday information shares in regression analysis. Intraday information shares correspond to each hour and one-half interval over a set of 14 trading days, including Feb 1-5, Feb 8-12, March 3-5, and October 2, 1993. For example, for the first time interval, I estimate information shares over the period 0:00-1:30 Greenwich Mean Time on February 1, 1993; the second estimation period is 1:30-3:00, and so on. This procedure generates information shares for all dealers present in the interbank market during every interval in each of the 14 trading days. Dealers who post fewer than 10 quotes during an interval are included in the composite interbank dealer. As is the case for the aggregate estimates, the intraday information shares of the composite dealer represent the collective contribution of price discovery by the dealers who comprise it.[13] The regression model used to test the hypotheses has the following general form:

$$shares_{n,i,t} = a + b_1*spread_{n,i,t} + b_2*size_{n,i,t} + b_3*nationality_{n,i,t} + e_{n,i,t}$$

where n represents dealers, i corresponds to the intraday interval, and t represents the number of days. For example, if 10 dealers quote the Mark-Dollar rate during the 0:00-1:30 GMT interval (i=1) on February 1, 1993 (t=1), this would generate n=10 information share estimates, which sum to 100%. If any of the 10 dealers are included in the composite, less than 10 information shares are estimated, but they still sum to 100%.

Summary measures of intraday information shares for selected interbank dealers are reported in Table 5. Information shares vary greatly, from zero to nearly 100% during the intervals analyzed. Panel A presents statistics calculated using all intervals. Banker's Trust, Citibank, American Express, the

[13] Some periods will not include a composite dealer, and some periods do not have enough quote activity to estimate the model. In all, this process generates 1,289 pooled observations of information shares.

composite bank, and Morgan Guaranty exhibit the largest information shares on average. During at least one interval, the composite, Banker's Trust, and Morgan Guaranty contribute nearly all of the price discovery. Except for the composite, these dealers participate mainly in the Pacific region, so their averages do not apply to the entire trading day. Because only two or three banks typically are present during the intervals that correspond to the Pacific region, the information shares of dealers operating in this region are high relative to dealers in other regions. Panel B shows summary statistics for the intervals that correspond to the European region. Averages and standard deviations generally are lower compared to the full sample of estimates. Excluding the composite bank, dealers participating in Europe on average contribute 8.71% to price discovery in each interval. Given that 18 dealers on average participate in each European market interval, dealers tend to generate more than an equal share of information (an equal share would be about 5.5%). Notable exceptions include Societe Generale, which on average contributes 17.7%, and the composite bank, which on average contributes about 22% . Because eight dealers typically comprise the composite, each contributes about 3% to price discovery in each interval.

5.1. Bid-ask spreads

Although possibly limited by search and transaction costs, customers in the Mark-Dollar currency market will seek out the best prices at which to trade, all else equal. Many theoretical models of trading incorporate this straightforward idea (Chowdhry and Nanda, 1991; Madrigal and Scheinkman, 1997; and Dutta and Madhavan, 1997), which implies that interbank dealers with the best bid or ask quotes attract the greatest order flow, and thereby generate an informational advantage relative to other dealers. Empirically, we would expect to find a positive relationship between information shares and dealers' relative spreads. Regression results weakly support this hypothesis. Table 8, column I presents the results from the regression of information shares on dealer spreads. The coefficient is significant at the 1% level, but the economic significance is small. A 1 basis point decrease in the relative spread is associated with 0.012% increase in the share of information during a trading interval. This result suggests three possible explanations: the order flow they attract contains little information; for strategic reasons they impound into quotes little of the information they generate; or tighter spreads typically correspond to inventory management and not information. Because nearly 90% of turnover in the FX market is due to interdealer trading, dealers post lower spreads likely to attract dealer orders and manage inventory, and these dealer orders are only marginally informative.

5.2. Size

Apart from spreads, banks differentiate their foreign exchange services by providing derivatives expertise, risk management consulting, a broad range of currency coverage, asset management, research,

and other specialized services. The head of Citibank's European FX operations claims, "This is a business of individuals at corporates dealing with individual at a bank, and you have to enhance the value of the transaction…customer flows are determined by how the product (foreign exchange) is marketed."[14] Large dealers are apt to attract customer order flow because of the additional services they offer, because of their perceived or real access to liquidity or networks, and because they can offer special pricing arrangements in exchange for a commitment to provide regular business. This view implies a positive relationship between dealer size and information shares.

The local presence and regional network of dealers is measured using the number of distinct locations from which dealers submit quotes during a time interval. Similar to Wahal (1997), who shows that in the Nasdaq market the number of dealers trading a stock is related to trading intensity, more interbank branches likely support greater order flow and reflect a greater investment in assets dedicated to FX dealing. While some might suggest that quoting activity is an appropriate measure of size, quote activity can be misleading because small banks may quote heavily to advertise their presence to large dealers, and dealers with a strong network in less active regions may quote less often. Asset values of interbank dealers may proxy for size, but regional accounting data is unavailable for most dealers. Although dealer size varies from one to 30 locations in the full, years' sample of quotes, typically dealers post quotes from three distinct locations in a trading interval. Excluding the composite dealer from this average, dealers on average post quotes from less than two distinct locations in an interval (average is 1.64). This number expectedly increases during transition intervals. During the Asian to European region transition interval (6:00-7:30) and the European to American region transition interval (15:00-16:30), dealers tend to quote from a greater number of locations, indicating their presence in multiple regions.

The regression result for size supports the hypothesis that larger interbank dealers produce more price information. Table 8 column II reports the parameter estimate for the regression of information shares on size, which is positive and statistically significant at the 1% level. For an increase in the number of local quoting locations, the average increase in price discovery is estimated at 1.2%. Because the relationship between size and price discovery is positive and economically significant, this suggests that although dealers may price strategically, on average, the larger they are within an interval, the greater is their contribution to the price discovery process.

5.3. Nationality

[14] *Euromoney*, May 1993, page 83.

In addition to size, customer bases may depend on nationality if dealers' networks are specific to their domestic market and customers chose dealers because of they are from the same country or region. For example, customers desiring to trade the Mark-Dollar currency pair in Europe will choose Deutsche Bank if Deutsche Bank already provides the customer other services. For the same reason, American retail customers will choose Citibank or Chemical Bank, for example, over Deutsche Bank whether they are trading the Mark-Dollar currency pair in America or repatriating mark-denominated profits in foreign regions. Order flow may not be limited to retail customers. Domestic dealers may attract order flow from domestic dealers that are smaller or not members of the Reuters system. Domestic dealers also may attract the order flow of their central bank (Peiers, 1998; Sapp, 1999). Under this view, the fact that American FX dealers dominate the turnover in the London, which has the largest share of the European region, suggests that turnover in these markets result from the intermediation of corporate profits by American firms. Therefore, we might expect to see a positive relationship between American dealers and information shares in the European region. However, in general we expect a positive relationship between dealer nationality in dealers' domestic markets and information shares.

Alternatively, some order flow may be relatively more informative, the Reuters system may not correctly represent foreign exchange activity in a particular region, or dealers set the Mark-Dollar quote strategically to hide the information contained in their order flow. Foreign banks may have more incentive to attract order flow in foreign markets because they can not develop networks and customer bases as naturally as domestic dealers, especially if domestic dealer-customer relationships are long standing, domestic dealers are well-known, or regulatory constraints prohibit or limit foreign dealer participation. Under the alternative, we could observe a positive relationship or no relationship between domestic dealers and information shares in these regions.

To test the relationship between bank nationality and price discovery, dummy variables are included in the regression. Dummy variables are created for American, European, and German dealers in each region, with some exceptions. For example, DV_AmAm denotes an American dealer operating during the American region, and DV_AmEur denotes a European dealer operating in the American region. Other dummy variables are similarly constructed. Asian and Pacific dealers are not included in the set of dummy variables because they are not present or do not quote enough in the sample to be estimated individually. Table 7 reports quote activity by dealer nationality across intraday intervals. Of the 1,289 information share estimates, only four are associated with Asian dealers and only twelve are associated with Pacific dealers. None are present during the European and American market intervals. Except perhaps through the composite dealer, German dealers generally do not participate in the Pacific region, where the American

dealers exhibit a strong presence. In the most active region, the number of American dealers is about half the number of German dealers, and the number of German dealers is about half of the number of European dealers.

Regression results do not support the hypothesis that domestic dealers produce more price information in their own markets. In Table 8, information shares do not appear related to dealer nationality beyond size. Regression results reported in column III show the effects of nationality in the Pacific, Asian, European, and American markets relative to the intercept, which can be interpreted simply as a benchmark information share. Only the parameter estimate for European dealers in the Asian market is significant. Given equivalent size and spreads, European dealers exhibit significantly lower information shares. This suggests that in the Asian region, European dealers either do not attract as much or as informative order flow or they set prices strategically relative to their competitors. Even though only one parameter is significant, the amount of explained variation (adjusted) in information shares rises from 16% to 22%. Although the estimates are insignficant, size is correlated with nationality in the European region, which suggests a collinearity problem. In this region, American dealers appear to contribute the least information relative to European and German dealers. The European dealers appear to contribute the most.

Overall, it appears that at least American FX dealers price the Mark-Dollar strategically. BIS statistics on foreign exchange indicate that in London, American dealers have the largest market share. Although London is only part of the European region, American dealers produce relatively less information in Europe. In the American market, where American dealers have natural access to networks and customer bases, American dealers do not exhibit significantly higher information shares. One might suggest that the reason American dealers do exhibit higher information shares in Europe is that they do not have special access to central bank activity like Deutsche Bank does. However, intervention occurs relatively infrequently in the FX market. Intervention would have to occur often and information would have to be high in quality for this effect to drive the results. Even if this were possible, it would be inconsistent with the evidence that European dealers contribute relatively more to the Mark-Dollar quote than German dealers in their own markets. As is the case for spreads and size, a more informative test of nationality would include direct measures of dealer order flow.

6. Conclusion

Price discovery, a central function of any market, is a process that is not well understood. Theories regarding price discovery are few, especially with respect to multiple-dealer markets, where inventory control and self-regulation characterize the trading environment. Empirical contributions also are few. This

paper is the first to analyze price discovery comprehensively in a multiple-dealer market. Specifically, it develops and tests hypotheses about how interbank dealers discover the implicit efficient Mark-Dollar exchange rate in a typical trading day. It broadens the scope of the existing empirical literature by estimating the informational contributions to quotes made by dealers participating in the market, from aggregate and intraday perspectives.

This paper documents several empirical facts. First, dealers rely on one another for information. We observe that all dealers contribute to the price discovery process, and on average they participate fairly equally. In aggregate, while the most actively quoting interbank dealers participate in the process of price discovery, less active banks collectively contribute the majority of the permanent innovations in the implicit efficient exchange rate. Second, dealers set Mark-Dollar quotes dynamically. Intraday, no dealer systematically dominates price discovery and contributions vary in intensity. Third, price discovery is related to dealer characteristics. Of spread, size, and nationality, the most important dealer characteristic that relates to price discovery is a dealer's local presence. Nonetheless, a dealer who on average lowers his spread increases his or her contribution to price discovery by a small percentage. While price discovery appears unrelated to dealer nationality, the BIS foreign exchange survey on market share suggests that American dealers set quotes strategically.

Many avenues for future empirical investigation are available. In terms of the methodology, one could estimate the variance of the system of dealers' quotes directly, using a discrete Kalman filtering process. The process skirts many time-series issues caused by unequally-spaced observations, and it would generate multiple estimates of information shares for aggregate market samples. With respect to other markets, the methodology is general and can be applied easily to understand the price discovery process in other markets. To date no study has examined the process of price discovery across the similarly structured multiple-dealer bond market, and no study examines the general process of price discovery in the Nasdaq market system. The results documented here may provide a useful benchmark for understanding the process of price discovery in these markets and the newly-emerging electronic exchanges. With new technology and its unknown impact on markets, future research would provide relevant information regarding the promotion of price discovery, a major policy objective of the SEC.

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APPENDIX

A.1 Error Correction Model of Dealer Quotes

The econometric model that generates information shares rests upon the assertion that there exists an implicit, efficient exchange rate, m_t (Hasbrouck, 1995, 1996). Reflected in the independently and identically distributed random innovation, e_t, each dealer contributes current information, $u_{i,t}$, to the implicit exchange rate. Because this information is impounded permanently in the implicit exchange rate, m_t cumulatively sums, or "integrates," the random e_t's and evolves as a random walk:

$$m_t = m_{t-1} + e_t \qquad \text{(a.1)}$$

$$e_t = u_{1,t} + u_{2,t} + u_{3,t} + \ldots + u_{n,t} \qquad \text{(a.2)}$$

Dealers cannot observe the implicit exchange rate. Given the opaqueness of the interbank market, dealers have a difficult time discerning whether exchange rate changes are due to new information, inventory management, or strategic pricing. Because dealers only imperfectly can infer new information in other dealers' quotes, the system of equations in which n dealers set exchange rates ($p_{1,t} \ldots, p_{n,t}$) is structured so that dealers only partially adjust $(1 - a_{i,j})$ to the current information processed by the other n-1 interbank dealers. The system also incorporates a white noise error process, $v_{i,t}$:

$$p_{1,t} = m_{t-1} + u_{1,t} + (1 - a_{1,2})u_{2,t} + (1 - a_{1,3})u_{3,t} + \ldots + (1 - a_{1,n})u_{n,t} + v_{1,t}$$

$$p_{2,t} = m_{t-1} + u_{2,t} + (1 - a_{2,1})u_{1,t} + (1 - a_{2,3})u_{3,t} + \ldots + (1 - a_{2,n})u_{n,t} + v_{2,t}$$

$$\ldots$$

$$p_{n,t} = m_{t-1} + u_{n,t} + (1 - a_{n,1})u_{1,t} + (1 - a_{n,2})u_{2,t} + \ldots + (1 - a_{n,n-1})u_{n-1,t} + v_{n,t} \qquad \text{(a.3)}$$

Collecting terms, the system can be rewritten:

$$p_{i,t} = m_t - \sum_{j=1}^{n} a_{ij}u_{jt} + v_{i,t} \qquad i=1, \ldots, n;\ i \neq j \qquad \text{(a.4)}$$

System a.4 is not estimable given its infinite variance. A correctly transformed model is the "error-correction representation" (Hasbrouck, 1995).[15] Though many different specifications of the error-correction model are possible, the economic tenet "the law of one price" motivates the restrictions needed to identify the appropriate error-correction model. The law of one price implies that in an efficient market, identical securities trading in different locations should exhibit the same price. If not, an individual could profit without risk by buying currency from the dealer who prices it relatively low and selling currency to the dealer who prices it relatively high. Short of market imperfections, this implies equilibrium exchange

[15] For an in depth discussion of non-stationary variables, cointegration, and error-correction see Banerjee et al. (1993) and Hasbrouck (1995).

rates that are set by different dealers will not diverge in the long-run, as they are driven by the same fundamental information (m_t). If a dealer's exchange rates were to drift away from others' rates, eventually that dealer faces the risk of being arbitraged. The fact that dealers correct deviations from equilibrium exchange rates helps to identify the error-correction model:

$$\Delta p_{i,t} = \alpha\beta(p_{i,t-1} - k) + \Gamma_1\Delta p_{i,t-1} + \ldots + \Gamma_{K-1}\Delta p_{i,t-K+1} + e_{i,t} \qquad (a.5)$$

In (5) i=1…n dealers, t=1…T time periods, and K corresponds to the lag length of a finite vector autoregression model of exchange rate levels. By subtracting average prices from prior period prices, the error-correction term, $\alpha(\beta' p_{i,t-1} - \beta' k)$, statistically captures the idea that dealers "correct" for differences among dealers' deviations from average prices.[16] β is constrained such that there are n-1 linearly independent dealer prices, reflecting one common factor among exchange rates. Error-corrections are defined relative to the benchmark price, $p_{1,t-1}$.

To calculate information shares, I distinguish between the variation in observed prices and the variation in the common, efficient price. Likelihood ratio tests show that that dealers' innovations are uncorrelated. Therefore, the contribution by dealer j to the random walk exchange rate changes is given by S_j, which is the *information share* that corresponds to the series of prices set by dealer j:

$$S_j = \frac{\gamma_j^2 \Omega_{jj}}{\gamma \Omega \gamma'} \qquad (a.6)$$

The denominator is the variance of γe_t, which normalizes the information shares. Ω is the total variance of the implicit efficient exchange rate changes, e_t. Conditional on the assertion that dealer innovations are independent, the total variance can be expressed as the sum of the variances of innovations in each series of dealer prices:[17][18]

$$\Omega = \sigma^2_{u1,t} + \sigma^2_{u2,t} + \ldots + \sigma^2_{un,t} \qquad (a.7)$$

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[16] Without this term, the cointegrated system of price changes will be specified incorrectly (Hasbrouck, 1995).

[17] Estimating information shares becomes difficult if the variance-covariance matrix is not diagonal. This problem is more likely to occur when price data are coarser or aggregated. As the time between price changes among dealers lengthens, the probability that multiple dealers observe the same events increases. Consequently, coarser price changes include collective innovations, and therefore, dealer price changes tend to be correlated. To reduce the correlation among dealer's innovations, one could shorten the time interval between price changes and preserve the sequence of independent innovations. Alternatively, Hasbrouck (1995) recommends diagonalizing the variance matrix using Cholesky factorization.

[18] Simply estimating information shares says nothing about their significance. Hasbrouck (1995) explains that it is possible to compute a standard error for information shares, but also notes that the distribution is difficult to obtain. Hasbrouck (1995) addresses this issue by estimating information shares for several stocks that trade concurrently in separate equity markets. The significance of an equity market's share of information is given by the preponderance of evidence. The NYSE is the first market to adjust prices for most equities. In the FX market, Sapp (1999) more formally uses Cholesky decomposition to obtain upper and lower bounds of information shares for large interbank dealers. Additionally, Sapp performs a "stationary boot-strap technique" to generate confidence intervals for information shares.

A.2 Definitions

24-hour Market[19]
October 1, 1992 to September 30, 1993
00:00 to 24:00 GMT
European Region
September 30,1992 to October 24, 1992: 07:00 to 15:00 GMT
October 25,1992 to March 27,1993: 07:00 to 16:00 GMT
March 26, 1993 to September 25, 1993: 06:00 to 15:00 GMT
September 26, 1993 to September 30,1993: 07:00 to 15:00 GMT
American Region
September 30, 1992 to October 24, 1992: 15:00 to 20:30 GMT
October 25, 1992 to March 25, 1993: 16:00 to 20:30 GMT
March 26, 1993 to September 30,1993: 15:00 to 20:30 GMT
Pacific Region
September 30, 1992 to September 29, 1993
20:55 to 24:00 GMT
Asian Region
September 30, 1992 to September 29, 1993
00:00 to 06:00 GMT

Dealer Mnemonics

ABN	Algemene Bank Nederland
AMEX	American Express
BHF	BHF Bank
BNP	Banque Nationale de Paris
BT	Banker's Trust
CHEM	Chemical Bank
CITI	Citibank
COMP	Composite Bank
CRS	Credit Suisse
DB	Deutsche Bank
DDSK	Den Danske
DNSK	Den Norske
DRES	Dresdner
LLYD	Lloyd's Bank
MRG	Morgan Guaranty
RAB	Rabobank Nederland
SBC	Swiss Banking Corporation
SOG	Societe Generale

[19] All market center date and time classifications exclude weekends. A weekend is defined as Friday 21:00 GMT to Sunday 21:00 GMT.

UBS Union Bank of Switzerland

Table 1
Foreign Exchange Activity by Market Center

This table presents measures of activity of foreign exchange trading for individual market centers. The data are compiled from the
Settlements *Central Bank Survey of Foreign Exchange and Derivatives Market Activity, 1995* . All numbers are net of local inter-
Total FX market activity includes global turnover in all foreign exchange transactions (spot, forward, future, and derivatives). DE
Deutsche Mark-U.S. Dollar exchange rate. Interdealer turnover measures foreign exchange activity among interbank dealers. Loca
transactions originating in the respective market center, and represents transactions made by dealers, financial institutions, and non
some of whom may be foreign, but based locally. Retail turnover includes the transactions of financial and non-financial, non-deale

Market Center	% Share of Total FX Market	% Share of Spot FX Market	DEM/USD Turnover as % of Total FX Activity	% Share of Total DEM/USD Market	Number of Dealers Covering 75% of Activity	Interdealer Turnover as a % of Spot Activity	Local Turnover as a % of Spot Activity	I T % S
United Kingdom	30	27	22	27	20 (=68%)	78	37	
United States	16	20	30	20	20 (=70%)	61	43	
Japan	10	8	12	5	24	78	43	
Singapore	7	7	25	7	25	78	27	
Hong Kong	6	5	25	6	13-22	83	29	
Switzerland	6	7	23	6	5	87	22	
Germany	5	5	50	11	10	84	19	
France	4	4	17	3	7-12	79	28	
Australia	3	3	22	2	10 (=70%)	76	45	
Denmark	2	1	13	1	2-4	83	19	
Canada	2	2	13	1	6-7	63	36	
Belgium	2	1	15	1	10	64	18	
Netherlands	2	2	18	1	3-5	80	19	
Italy	1	2	7	0	6-8	68	27	
Sweden	1	1	19	1	2-3	76	26	
Luxembourg	1	1	42	2	14-15	81	19	
Spain	1	1	18	1	12 (=83%)	90	27	
Austria	1	1	56	2	3 (=70%)	56	32	
Norway	0	1	16	0	4-5	61	33	
Residual	0	0	20	0	8	72	31	
Average	n.a.	n.a.	23	n.a.	11	75	34	

Table 2
Aggregate Quote Activity of Interbank Dealers in Four Major Regions

This table reports aggregate Mark-Dollar quote activity on the Reuters dealing system from October 1992 to September 1993 by the most active interbank dealers and a composite interbank dealer for the 24-hour and regional foreign exchange market samples. The most active dealers are the union of the five most actively quoting dealers in the respective sample and the top three interbank dealers chosen by retail customers in *Euromoney*'s 1993 survey of foreign exchange. The "Composite Bank" represents all other dealers present in the sample. Samples are defined according to time and listed in the Appendix.

Interbank Dealer	Total	Average/Day	% of Total
24-Hour Market			
Deutsche Bank	121,027	403	9.36%
Credit Suisse	76,122	292	5.89
Societe Generale	72,865	257	5.63
BHF Bank	70,222	269	5.43
Chemical Bank	67,422	232	5.21
Citibank	35,446	121	2.74
Composite Bank (138)	850,373	30	65.74
European/Overlap Market			
Deutsche Bank	89,466	347	10.78%
Societe Generale	63,079	245	7.60
Rabobank Nederland	51,277	203	6.18
BHF Bank	48,327	187	5.82
Chemical Bank	46,954	182	5.66
Citibank	12,102	45	1.46
Composite Bank (134)	518,512	22	62.49
American Market			
Lloyd's Bank	12,476	67	8.56%
Citibank	12,431	49	8.53
Chemical Bank	11,586	45	7.95
Morgan Guaranty	8,286	33	5.69
Royal Bank of Canada	7,710	30	5.29
Deutsche Bank	3,116	13	2.14
Composite Bank (114)	90,157	7	61.84
Pacific Market			
Banker's Trust	10,652	42	22.95%
Morgan Guaranty	7,788	31	16.78
Australia & NZ BG	3,498	14	7.54
HSBC	2,115	11	4.56
Dresdner Bank	1,719	7	3.70
Citibank	1,336	6	2.88
Deutsche Bank	1,149	5	2.48
Chemical Bank	967	5	2.08
Composite Bank (69)	17,222	4	37.03
Asian Market			
Credit Suisse	38,725	156	15.78%
Deutsche Bank	24,593	96	10.02
BHF Bank	20,461	88	8.34
ABN Amro	13,145	52	5.36
AMEX Bank	12,226	52	4.98
Citibank	8,419	34	3.43
Chemical Bank	6,178	24	2.52

Composite Bank (86)	121,649	10	49.57

Table 3
Average and Time-Weighted Average and Relative Spreads

This table reports the mean absolute and relative bid-ask spreads for the Mark-Dollar exchange rate quotes posted by interbank dealers to the Reuters dealing system from October 1992 to September 1993. Means are calculated both in event-time and weighted by time for the 24-hour and regional samples. Absolute spreads are reported in "pips," or 0.0001 DEM/USD increments, and relative spreads are reported as basis points of the ask quote. Samples are defined according to time and listed in the Appendix.

Interbank Dealer	Mean Absolute Spread	Time-Weighted Spread	Mean Relative Spread	Time-Weighted Relative Spread
		24-Hour Market		
Deutsche Bank	8.77	8.58	5.42	5.31
Credit Suisse	9.65	9.36	5.97	5.78
Societe Generale	5.79	6.13	3.59	3.80
BHF Bank	9.20	9.39	5.70	5.81
Chemical Bank	6.03	7.30	3.73	4.52
Citibank	7.81	8.67	4.84	5.36
Composite Bank (138)				
		European/Overlap Market		
Deutsche Bank	8.44	9.33	5.21	5.76
Societe Generale	5.32	5.42	3.30	3.37
Rabobank Nederland	9.33	9.36	5.77	5.79
BHF Bank	9.77	9.70	6.04	6.00
Chemical Bank	5.46	5.58	3.38	3.45
Citibank	7.59	9.20	4.70	5.69
Composite Bank (134)	7.61	8.34	4.71	5.15
		American Market		
Lloyd's Bank	10.00	10.00	6.23	6.19
Citibank	9.87	9.68	6.14	5.98
Chemical Bank	6.87	7.78	4.28	4.82
Morgan Guaranty	10.01	10.05	6.22	6.21
Royal Bank of Canada	10.04	10.47	6.24	6.47
Deutsche Bank	8.22	7.65	5.12	4.74
Composite Bank (114)	8.49	8.04	5.29	4.98
		Pacific Market		
Banker's Trust	5.45	5.86	3.38	3.63
Morgan Guaranty	8.70	8.75	5.38	5.42
Australia & NZ BG	7.67	7.66	4.74	4.74
HSBC	6.71	6.78	4.16	4.21
Dresdner Bank	7.49	7.98	4.62	4.94
Citibank	7.83	7.83	4.84	4.85
Deutsche Bank	9.20	9.52	5.68	5.89
Chemical Bank	7.62	7.50	4.71	4.65
Composite Bank (69)	7.82	8.82	4.84	5.46
		Asian Market		
Credit Suisse	9.63	9.90	5.96	6.12
Deutsche Bank	10.06	10.02	6.22	6.20
BHF Bank	6.73	6.99	4.19	4.36
ABN	9.36	9.18	5.78	5.68
AMEX Bank	5.59	5.64	3.45	3.50
Citibank	7.54	7.59	4.67	4.71
Chemical Bank	6.88	7.11	4.26	4.41

Composite Bank (86)	8.16	8.38	5.04	5.18

Table 4
Aggregate Information Share Estimates

This table presents information shares estimated using quotes posted by the most active interbank dealers and a composite interbank dealer to the Reuters dealing system from October 1992 to September 1993. The most active dealers are the union of the five most actively quoting dealers in the respective sample and the top three interbank dealers chosen by retail customers in *Euromoney*'s 1993 survey of foreign exchange. The "Composite Bank" represents all other dealers present in the sample. Information shares are defined as the total variance of the permanent innovations in the implicit efficient, Mark-Dollar exchange rate during the 24-hour and regional samples. Samples are defined according to time and listed in the Appendix.

Interbank Dealer	Information Share
	24-Hour Market
Deutsche Bank	5.70%
Credit Suisse	0.01%
Societe Generale	7.66%
BHF Bank	0.13%
Chemical Bank	2.65%
Citibank	3.06%
Composite Bank (138)	80.79%
	European Market
Deutsche Bank	1.31%
Societe Generale	8.82%
Rabobank Nederland	0.11%
BHF Bank	0.34%
Chemical Bank	1.20%
Citibank	0.02%
Composite Bank (134)	85.85%
	American Market
Lloyd's Bank	3.87%
Citibank	1.31%
Chemical Bank	4.25%
Morgan Guaranty	0.04%
Royal Bank of Canada	0.01%
Deutsche Bank	1.78%
Composite Bank (114)	88.73%
	Pacific Market
Banker's Trust	29.52%
Morgan Guaranty	4.65%
Australia & NZ BG	0.71%
HSBC	1.84%
Dresdner Bank	0.18%
Citibank	1.72%
Deutsche Bank	1.08%
Chemical Bank	2.63%
Composite Bank (69)	57.66%
	Asian Market
Credit Suisse	0.48%
Deutsche Bank	0.85%
BHF Bank	0.10%
ABN	0.68%
AMEX Bank	1.66%
Citibank	0.56%

Chemical Bank	0.02%
Composite Bank (86)	95.66%

Table 5
Summary Statistics for Intraday Information Shares

The two tables exhibit summary statistics of information shares for selected interbank dealers, estimated for every 16 hour and or separate days. This generated a total of 1,289 observations. An information share is defined as a dealer's proportional contribution permanent innovations in the Mark-Dollar exchange rate quotes, and is calculated using transformed parameter estimates from an e dealer quote changes. Dealer mnemonics .

Panel A: All Intervals

	COMP	DB	CHEM	SOG	BHF	LLYD	DNSK	ABN	DRES	MRG	UBS	RAB	DDSK	AMEX	CRS	CITI
Avg	23.68	12.52	11.09	18.09	8.99	10.76	6.04	9.40	10.87	20.06	12.16	9.94	10.37	27.82	9.21	29.04
Std Dev	22.76	18.27	16.75	18.32	16.35	15.87	8.32	12.08	16.77	23.06	16.92	16.22	11.60	28.28	9.54	24.73
Max	99.56	90.73	72.34	74.45	82.22	72.62	38.81	68.68	94.13	99.93	76.54	88.48	47.27	89.37	33.28	82.31
Min	0.0	0.0	0.0	0.0	0.0	0.01	0.0	0.01	0.0	0.0	0.02	0.0	0.0	0.02	0.01	0.02
Obsv.	178	134	84	86	75	73	67	52	51	43	42	39	35	32	32	26

Panel B: European Market Intervals

	COMP	DB	CHEM	SOG	BHF	LLYD	DNSK	ABN	DRES	MRG	UBS	RAB	DDSK	AMEX	CRS	CITI
Avg	21.79	7.42	6.55	17.70	4.78	7.70	6.13	7.77	8.49	0.0	11.90	7.13	10.37	13.23	9.85	0.34
Std Dev	17.37	9.38	12.81	17.29	6.97	11.98	8.35	8.09	10.76	0.0	19.31	9.69	11.60	0.0	9.75	0.50
Max	72.15	43.02	72.34	64.33	31.27	53.36	38.81	38.92	48.28	0.0	76.54	34.82	47.26	13.23	16.74	0.73
Min	0.02	0.0	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.09	0.0	0.0	13.23	2.96	0.02
Obsv	68	69	50	68	59	50	66	33	38	0	21	36	35	1	2	2

Table 6
Number of Participating Dealers by Interval and Nationality

This table reports the number of different nationalities of interbank dealers quoting the Mark-Dollar exchange rate in separate intervals throughout the 24-hour trading day over 14 separate trading days during 1993. Composite dealers represent all other dealers within an interval whose quoting activity is too low to estimate individually in an error-correction system of equations. As such, composite banks reflect multiple nationalities. Quote activity is based on Olsen and Associates FX data, which includes all quotes submitted electronically by interbank dealers to the Reuters dealing system from October 1992 through September 1993, excluding weekends and holidays.

Interval	Pacific	Asian	American	German	European	Composite	Total
0:00-1:30	1	1	23	19	23	14	81
1:30-3:00	2	2	13	17	18	13	65
3:00-4:30	0	0	1	0	1	2	4
4:30-6:00	1	0	6	15	25	11	58
6:00-7:30	0	0	13	23	36	14	86
7:30-9:00	0	0	3	43	66	13	125
9:00-10:30	0	0	13	42	74	14	143
10:30-12:00	0	0	12	36	67	14	129
12:00-13:30	0	0	14	37	78	13	142
13:30-15:00	0	0	15	37	79	14	145
15:00-16:30	0	0	17	25	62	14	118
16:30-18:00	0	0	20	1	64	14	59
18:00-19:30	1	0	15	1	16	11	44
19:30-21:00	3	1	18	0	11	8	41
21:00-22:30	2	0	14	0	5	5	26
22:30-24:00	2	0	15	0	2	4	23
All	12	4	212	296	587	178	1289

Table 7
Information Shares and Dealer Characteristics

This table reports estimates for the time-series cross-sectional regression of interbank dealers' information shares. Information shares measure dealers' contributions to the variance of the implicit efficient Mark-Dollar exchange rate. They are estimated for every hour and one-half interval for a period of 14 days during 1993 using Olsen and Associates FX data, which includes all quotes submitted electronically by interbank dealers to the Reuters dealing system from October 1992 through September 1993, excluding weekends and holidays. Coefficients are listed above standard errors, in parentheses, and are calculated using White's heteroskedasticity-consistent covariance matrix.

Parameter	I	II	III
Intercept	0.398309[a]	0.399131[a]	0.379731[a]
	(0.02474)	(0.04288)	(0.08784)
Number dealers	-0.012637[a]	-0.015989[a]	-0.015550[a]
	(0.00094)	(0.00157)	(0.00277)
Relative spread	-1.173689[a]	-0.922499	-0.448519
	(0.38507)	(0.65799)	(0.86007)
Size		0.012521[a]	0.012107[b]
		(0.00237)	(0.00524)
DV_P*Am[c]			0.053839
			(0.10981)
DV_P*Eur			0.057641
			(0.15075)
DV_A*Am			0.008316
			(0.06860)
DV_A*Eur			-0.101721[d]
			(0.05825)
DV_A*Ger			-0.018207
			(0.07118)
DV_Eur*Am			-0.076181
			(0.06174)
DV_Eur*Eur			-0.002270
			(0.05935)
DV_Eur*Ger			-0.028383
			(0.05447)
DV_Am*Am			0.026936
			(0.07593)
DV_Am*Eur			0.058065
			(0.07115)
DV_Am*Ger			0.005916
			(0.06975)
Observations	1,289	484	484
R^2 (Adj R^2)	0.1270 (0.1257)	0.2043 (0.1993)	0.2403 (0.2176)

[a] Coefficient significant at the 1% level.
[b] Coefficient significant at the 2% level.
[c] Dummy variables differentiate dealer nationality and market location. For example, DV_P*AM corresponds to an American dealer operating in the Pacific market center.
[d] Coefficient significant at the 10% level.