PRICE DISCOVERY IN CURRENCY MARKETS

Carol Osler, Brandeis University, USA,
Alexander Mende, Leibniz Universitaet Hannover, Germany, and RPM Risk & Portfolio Management AB, Sweden,
Lukas Menkhoff, Leibniz Universitaet Hannover, Germany

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Abstract

This paper makes three contributions to our understanding of the price discovery process in currency markets. First, it provides evidence that this process cannot be the familiar one based on adverse selection and customer spreads, since such spreads are inversely related to a trade's likely information content. Second, the paper suggests three potential sources for the pattern of customer spreads, two of which rely on the information structure of the market. Third, the paper suggests an alternative price discovery process for currencies, centered on inventory management strategies in the interdealer market, and provides preliminary evidence for that process.

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Keywords: Bid-ask spread, foreign exchange, asymmetric information, microstructure, price discovery, interdealer, inventory, market order, limit order

corresponding: Carol L. Osler, Brandeis International Business School, Brandeis University, Mailstop 32, Waltham, MA 02454, USA, email: cosler@brandeis. edu; Alexander Mende, Leibniz Universitaet Hannover, Department of Economics, Koenigsworther Platz 1, D-30167 Hannover, email: alexander.mende@rpm.se; Lukas Menkhoff, Leibniz Universitaet Hannover, Department of Economics, Koenigsworther Platz 1, D-30167 Hannover, email: menkhoff@gif.uni-hannover.de

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This paper investigates the price discovery process in the foreign exchange market. Understanding exactly how information becomes embedded in exchange rates is central to current efforts to understand exchange-rate dynamics (see, for example, Evans and Lyons (2002), (2004)). Within microstructure *per se* there is also a powerful incentive to study foreign exchange trading, since the currency market dwarfs all others. Nonetheless, the overall contours of price discovery in foreign exchange remain murky.

Our paper makes three contributions, all of which build on the observation that the foreign exchange market has two tiers, similar to the London Stock Exchange and some bond markets. In one, dealers trade with each other; in the other, dealers trade with (non-dealer) customers. The paper first provides evidence that spreads in the customer market are inversely related to a trade's likely information content, which implies that price discovery in FX cannot be determined by adverse selection. Second, the paper suggests three potential sources for this pattern of customer spreads, two of which are based on the information structure of the market. Finally, the paper proposes a price discovery process centered on dealers' inventory management strategies in the interbank market and provides evidence for that process. Since this process reflects the foreign exchange market's two-tiered structure it has the potential to be relevant in liquid two-tiered markets for other assets.

The adverse-selection-based price discovery process, articulated in Glosten and Milgrom (1985) and Easley and O'Hara (1987), among other important works, asserts that dealers build into their price quotes the potential information revealed by a given customer transaction. When adverse selection dominates price discovery, spreads rise with the likelihood that a given customer has private information. Theoretical research indicates that under adverse selection larger trades are more likely to carry information (Glosten and Milgrom (1985), Easley and O'Hara (1987), Glosten (1989)), which would imply that spreads vary positively with trade size. Adverse selection also implies wider spreads for informed customers if dealing is not anonymous.

Though the original adverse-selection models were inspired by equity markets, adverse selection has been assumed to dominate price discovery in FX since Lyons (1995), which shows that trade size and spreads were positively related for a particular interbank dealer during a week in 1992. Most subsequent research has instead concluded that interbank currency spreads bear little or no relation to trade size (e.g., Yao (1998), Bjønnes and Rime (2005)). Nonetheless, Bjønnes and Rime (2005) suggests that this is not necessarily inconsistent with adverse selection: spreads could be unrelated to trade size under adverse selection if it is only the direction of a trade that carries information, and presents evidence consistent with this alternative hypothesis.

Most FX microstructure papers continue to draw on adverse selection as their primary interpretive framework. Marsh and O'Rourke (2005), for example, estimates Easley, Kiefer, and O'Hara's (1996, 1997) adverse-selection-based measure of private information on daily FX customer data. Similarly, Payne (2003) estimates a VAR decomposition of interdealer trades and quotes and interprets the results, following Hasbrouck (1991), through the lense of adverse selection. Indeed, in this literature it is sometimes assumed that a transaction's immediate "price impact" is a measure of its "information content" (e.g., Luo (2002)), as implied by adverse selection.

Our evidence indicates that adverse selection may have limited practical relevance in the customer tier of the FX market. We show that customer spreads are widest for the trades least likely to carry information. More specifically, customer spreads are inversely related to trade size, and are narrower for the customers that dealers consider most informed. These reportedly informed customers are financial firms, meaning asset managers such as hedge funds or mutual funds; the other broad category of customers is commercial customers, meaning firms that import or export.[1] The resulting cross-sectional variation in customer spreads is substantial: baseline spreads in the euro-dollar market range from about four pips (or equivalently ticks) on large financial trades to 13 pips on small commercial trades. (A pip is one unit of the smallest significant digit in an exchange rate as conventionally quoted. In the euro-dollar market, where the exchange rate averaged \$1.1128/€ during our sample period; a one-pip change from that level would bring the rate to $1.112***9***/€. In this market one pip is approximately one basis point, since the exchange rate is near unity.)

If adverse selection doesn't drive customer spreads in FX, what does? The paper's second contribution is to outline three alternative hypotheses, all of which seem likely to be relevant. Microstructure theory generally divides spreads into three or four components (e.g., Huang and Stoll (1997), Harris (2003)): adverse selection, inventory risk, operating costs, and (occasionally) monopoly power. Researchers in currency microstructure generally assume the tripartite division (e.g., Rime (2003)), since intense competition among the hundreds of FX dealers rules out pure monopoly power. The three remaining components cannot fully explain the pattern of currency spreads, however. Adverse selection predicts the opposite pattern for both size- and customer-based variation, as noted above. Inventory risk also predicts the opposite size-based variation and it predicts zero customer-based variation. Operating costs cannot explain the customer-based variation in spreads, though this component can explain the negative relation between trade size and customer spreads if some costs are fixed.

To explain why FX spreads are larger for commercial than financial customers we suggest that asymmetric information – in the broad sense of information that is held by some but not all market participants – may influence spreads through two channels distinct from adverse selection. The first channel involves market power. As suggested in Green *et al.* (2004), dealers may quote the widest spreads when their market power is greatest, and market power in quote-driven markets depends on knowledge of current market conditions. In FX, commercial customers typically know far less about market conditions than financial customers so they might be expected to pay wider spreads, as they do.

The second channel through which asymmetric information might affect customer spreads in FX involves strategic dealing. Building on abundant evidence that customer order flow carries information (e.g., Evans and Lyons (2004), Daníelsson *et al.* (2002)), we argue that rational FX dealers might strategically vary spreads across customers to gain information which they can then exploit in upcoming interbank trades. In standard adverse-selection models, by contrast, dealers passively accept the information content of order flow. We suggest that FX dealers effectively subsidize spreads on the customer transactions most likely to carry information, specifically large trades and the trades of financial customers.

The idea that dealers strategically vary spreads to gather information was originally explored in Leach and Madhavan (1992, 1993), which show that dealers without access to an interdealer market might rationally vary customer spreads across time. However, our hypothesis concerns cross-section variation in a two-tier market, rather than time-series variation in a one-tier market. Naik *et al.* (1997), which also examines cross-sectional variation of spreads in a two-tier market, concludes that customer spreads will be narrower for trades with information, consistent with the pattern in FX. Further evidence for strategic dealing of this sort is provided in Ramadorai (2006). That paper shows that the narrowest spreads are paid by asset managers with the best record of profiting from exchange-rate moves, who are presumably best informed. However, Naik *et al.* concludes that customer spreads will vary positively with trade size, contrary to the pattern in FX.

The paper's third contribution is to outline a process through which information may become embedded in exchange rates. In contrast to adverse selection, which focuses on spreads in the customer market, our suggested process focuses on dealers' inventory management practices in the interdealer market. Since our process incorporates the FX market's two-tier structure it may be relevant to other liquid two-tiered markets, including perhaps the London Stock Exchange or the market for U.S Treasuries.

The mechanism is this: After trading with an informed customer, a dealer's information and inventories provide strong incentives to place a market order in the interdealer market. An informed-customer buy would thus tend to trigger market buys in the interdealer market and thus higher interdealer exchange rates. In this way the information brought to the market by informed customers will generate information-consistent changes in interdealer prices. By contrast, after trading with an uninformed customer a dealer has only weak incentives to place market orders. Thus dealer transactions with uninformed customers may be more likely to generate liquidity in the interdealer market than to move exchange rates.[2]

This view of dealer behavior differs critically from that of the "portfolio shifts" model of the FX market (Evans and Lyons (2002)). In that model, there are three rounds of trading. In the first, dealers absorb inventory from end-users; in the second round dealers trade with each other; in the third round dealers sell their inventory to end-users and prices adjust to reflect information. We suggest, by contrast, that prices begin to reflect information earlier, during interbank trading.

Our view of dealer behavior predicts a number of the key stylized facts in FX microstructure. First, it predicts the positive relation between interdealer order flow and exchange-rate returns documented in Lyons (1995), Payne (2003), Evans (2002), Evans and Lyons (2002), and Daníelsson *et al.* (2002), *inter alia*. If the dealer is responding to fundamental information it also predicts that the relation should be substantially permanent, consistent with evidence presented in Killeen *et al.* (2006) and Bjønnes *et al.* (2005). In addition, our view of dealer behavior predicts the positive relation between exchange rates and financial order flow documented in Evans and Lyons (2004), Bjønnes *et al.* (2005), and Marsh and O'Rourke (2005). Finally, our view predicts that the response of exchange rates to financial order flow will be substantially permanent, consistent with evidence in Lyons (2001) and Bjønnes and Rime (2005).

We test two additional implications of our interpretation of price discovery in FX. First, dealers should be more likely to make outgoing trades after financial-customer trades than after commercial-customer trades. Second, dealers should be more likely to make outgoing trades after large incoming trdes than after small ones. Our evidence provides encouraging support for both implications.

Our data comprise the entire USD/EUR transaction record of a single dealer at a bank in Germany during four months in 2001. These data have two advantages relative to most other tick-by-tick transactions datasets in FX: (i) they distinguish between financial and commercial transactions, and (ii) they cover a longer time period.

The rest of the paper has four sections and a conclusion. Section I describes our data. Section II shows that customer spreads in FX are narrowest for the trades most likely to carry information. Section III discusses how operating costs, market power, and strategic dealing can explain this pattern. Section IV presents our interpretation of the price discovery process in currency markets, along with supporting evidence. Section V concludes.

I. FX MARKET STRUCTURE AND DATA

The currency markets make all other markets look tiny. FX trading averages almost $2 trillion per day (B.I.S. (2004)) ─ over twenty times daily trading on all NYSE stocks. An active currency trades as much in a half hour as a high-volume stock on the Paris Bourse trades in a day. About half of this trading takes place in the interdealer market (B.I.S. (2004)), trading in which is now largely carried out on order-driven electronic exchanges. The customer market, by contrast, is quote-driven.[3] Hundreds of dealers compete in the euro-dollar market, which accounts for almost a fifth of all transactions (B.I.S. (2004)). There is no significant retail component to FX trading; virtually all trading is carried out by institutions. Since currencies are important in commerce as well as finance, however, the institutional customer base for FX includes non-financial as well as financial firms. (Bjønnes and Rime (2005) provides an excellent description of the market.)

Our data comprise the complete USD/EUR transaction record of a bank in Germany over the 87 trading days from 11 July 2001 to 9 November 2001. Though the data technically refer to the overall bank, they are an accurate reflection of a single dealer's behavior because only one dealer was responsible for the bank's USD/EUR trading. For each transaction we have the following information: (1) the date and time;[4] (2) the direction (customer buys or sells); (3) the quantity; (4) the transaction price; (5) the type of counterparty – dealing bank, financial customer, commercial customer, preferred customer; (6) the initiator; and (7) the forward points if applicable. We include outright forward trades, adjusted to a spot-comparable basis by the forward points, as recommended by Lyons (2001). The bank's inventory position is inferred by cumulating successive transactions.[5] Following Lyons (1995), we set the daily starting position at zero. This should not introduce significant distortions since our dealer keeps his inventory quite close to zero, as shown Figure 1. The dealer’s average inventory position is EUR 3.4 million during the trading day and only EUR 1.0 million at the end of the day. Table I provides basic descriptive statistics.[6]

A preliminary comparison of our dealer with the large dealers described in the literature is provided in Table II. Table III provides information on the size distribution of our dealer’s transactions. The small size of our dealer is reflected in his total daily trading value, average transactions per day, average inventory position, and mean absolute price change between transactions.[7] Our dealer is comparable in size to a NOK/DEM dealer at the large dealing bank examined in Bjønnes and Rime (2004). Our bank is probably a reasonably good representative of the average currency dealing bank because small dealing banks are far more common than large ones (B.I.S. (2002)). Nonetheless, big banks dominate currency dealing.

Despite the small size of our bank, our main qualitative conclusions should generalize to the entire foreign exchange market for at least four reasons. First, the FX market is extremely competitive. Hundreds of banks deal in the major currency pairs and even the largest dealer's market share is only on the order of 10 percent. In such a market, the behavior of any (successful) dealer should accurately represent the behavior of all (successful) dealers. Second, surveys of currency dealers reveal that the primary determinant of currency spreads is the conventional level of such spreads (Cheung and Chinn (2001)). Third, market participants consistently confirm that the pattern we identify is correct.

Finally, our small bank's behavior should be representative because it is broadly consistent with that of large banks in many well-studied dimensions. The Appendix provides a detailed comparison of our bank's pricing and inventory management practices with those of large banks analyzed in earlier studies. This analysis suggests that the following statements about larger dealers are equally true for our dealer:

- The baseline spread for interbank trades is on the order of two pips
- The baseline spread for customer trades is a few times larger than the spread on interbank trades
- Existing inventories are not statistically related to quoted prices
- The dealer typically brings his inventory back to zero by the end of the trading day
- The dealer tends to bring inventory back to zero in a matter of minutes, a speed that is comparable with that of futures traders and lightning fast relative to traders in equity and bond markets.

These parallels support the reasonableness of generalizing from this bank to the market.

II. The Cross-Sectional Pattern of Currency Spreads

This section shows that currency spreads are wider for small trades than for large trades and that they are wider for commercial customers than for financial customers. Together these results imply that currency spreads are widest when customers are least likely to be informed, a pattern that is not predicted by adverse-selection theory. We begin the section by presenting the regression-based framework we use to estimate spreads from transactions data and then examine the influence of trade size and customer type. We close the section by showing that our qualitative conclusions are sustained using the alternative regression model of Huang and Stoll (1997).

A. Estimating Spreads

Though our transactions data do not provide direct measures of spreads, we can extract indirect measures from a statistical analysis of successive price changes. Consider a simple market where everyone pays the same spread and the spread never changes. If the market price is stable then prices only change if trading moves from the bid to the ask or vice versa, so the spread equals the price change. Even if the market is volatile, any associated distortions should ultimately average to zero if there is no dominant trend.[8] In reality, of course, spreads vary for a number of reasons, so the average price change itself is not a reliable estimate. Instead, researchers use regression models in which price changes are regressed on a number of relevant variables.

In foreign exchange, the most commonly used regression model is that of Madhavan-Smidt (1991), which controls for the possibilities of inventory shading and adverse selection (this model is applied, for example, in Lyons (1995) and Bjønnes and Rime (2005)). This approach analyzes the pricing decision of a representative dealer in a competitive market whose counterparties have private information about the asset's fundamental value. Agents are fully rational and there is a detailed information setting. Agent *j* calls dealer *i* requesting a quote on amount Q_{jt}, which is determined as $Q_{jt} = \xi(\mu_{jt} - P_{it}) + X_{jt}$. The term μ_{jt} represents agent *j*'s expectation of the asset's true value, conditional on a noisy private signal of the asset’s true value and on a noisy public signal. X_{jt} represents agent *j*'s liquidity demand. The coefficient ξ is positive, so demand increases with the gap between the true value and the quoted price; this underlies the positive predicted relationship between trade size and spread.

Dealer i's regret-free price, P_{it}, is determined as $P_{it} = \mu_{it} + \zeta(I_{it} - I_i^*) + \chi D_t$. Here, μ_{jt} is dealer i's expectation of the asset's true value, conditional on the same noisy public signal; I_{it} is dealer i's inventory at the beginning of period t; I^*_i is his desired inventory, which is presumably zero for FX dealers; and D_t is the direction of trade [D_t = 1 (-1) if agent j is a buyer (seller)]. The model assumes that dealers shade prices to manage existing inventories (e.g., dealers lower prices in response to high inventory), which implies $\zeta < 0$. After solving for conditional expectations and taking first differences, one arrives at the following expression for the price change between incoming transactions, $\Delta P_{it} = P_{it} - P_{it-1}$:

$$\Delta P_{it} = \alpha + \beta_1 D_t + \beta_2 D_{t-1} + \gamma_1 I_{it} + \gamma_2 I_{it-1} + \delta Q_{jt} + \eta_t \tag{1}$$

Much of our discussion will focus on β_2, the coefficient on lagged direction, which according to the model is the negative of the "baseline" half-spread, meaning the spread that would apply before adjustment for trade size or existing inventories. The model also implies that $\beta_1 = |\beta_2|/\phi > |\beta_2| > 0 > \beta_2$, where $0 < \phi < 1$ is a model-derived parameter that captures the extent to which dealers rely on their priors rather than the current trade in updating their estimate of the currency's true value. According to the model, the intercept, α, should be zero if the dealer's desired inventory is zero, as is typically true in FX. If the dealer shades prices in response to inventories then $\gamma_2 = |\gamma_1|/\phi > |\gamma_1| > 0 > \gamma_1$. In FX, dealers typically rely on the interbank market to manage their inventory (Bjønnes and Rime (2005)), rather than shading prices, which implies that both γ_1 and γ_2 should be insignificant.

Since large trades in the model sometimes reflect a big gap between the asset's true value and the dealer's quote, the dealer's spread rationally rises with trade size and the coefficient on trade size, δ, is expected to be positive. A positive coefficient on trade size could also, however, capture an inventory effect noted in Ho and Stoll (1981): larger trades leave market makers with higher inventory and thus greater inventory risk, so larger trades should carry wider spreads. Adverse selection and this inventory effect, which we will refer to as a "prospective" inventory effect, are observationally equivalent here.

Since adverse selection and inventory shading are integral features of the Madhavan-Shmidt (1991) model, one might wonder whether the model can be used if neither feature actually influences the market.

Fortunately, the parameters associated with adverse selection and inventory shading do not influence the coefficient on lagged direction, so our estimates of the baseline half-spread should be reliable.

We follow standard practice and estimate the model using generalized method of moments (GMM) with Newey-West correction for heteroskedasticity and autocorrelation (e.g., Yao (1998); Bjønnes and Rime (2005)). Since the model operates on transaction time and involves transactions in which the dealer sets the price, our dependent variable is the sequence of prices on transactions initiated by customers (or equivalently, "incoming" transactions). We exclude the few transactions over $25 million because such trades essentially represent a distinct market: customers hire dealers to manage such trades by breaking them up into smaller interbank transactions.[9] Interbank and customer trades may not strictly be comparable, given the structural differences between quote- and order-driven markets, so we exclude interbank transactions for our baseline regressions.

We include three robustness tests for all our main results. First, we rerun the regressions excluding inventories, since existing inventories appear to have no influence on spreads. Second, we rerun the regressions using only spot transactions. Forward transactions account for 20 percent of all trades, so their inclusion could impede direct comparisons with earlier papers, which focus exclusively on spot trades. Finally, we also rerun the regressions including interdealer transactions. This provides comparability with Bjønnes and Rime (2001), where customer transactions (as a single category) and interbank transactions are included in the main regressions. Our results consistently prove robust.

B. Bilateral Relationships

This subsection shows how spreads vary with trade size and, separately, across customer types; the next examines the simultaneous variation of spreads across size and customer type.

Trade size: Market participants tell us that they informally divide normal-sized customer transactions into three categories: regular trades, which vary from €1 million to about €25 million; modest trades; and tiny trades. Though the line between the latter two categories is ambiguous, their treatment can vary substantially: tiny trades are often spread by formula rather than by dealers' discretion, and a one percent spread is not considered unreasonable on tiny trades. For estimation purposes we distinguish the following size ranges: Large trades: $\{|Q_{jt}| \in [€1 \text{ million}, € 25 \text{ million})\}$; medium trades: $\{|Q_{jt}| \in [€0.5 \text{ million}, €1 \text{ million})\}$; and small trades: $\{|Q_{jt}| \in (€0, € 0.5 \text{ million})\}$. To examine the bilateral relationship between trade size and spreads we interact the five spread determinants of the Madhavan-Smidt (1991) model with dummies for large (*LG*), medium (*MD*), and small trades (*SM*).

The results of this analysis are presented in Table IV. As expected, the constant term is insignificant, implying that our dealer's preferred inventory level is zero, and the coefficients on current and lagged inventory are insignificant as well, consistent with our dealer's preference for managing his inventory through the interbank trades rather than price shading. As predicted by the model, the coefficient on current direction exceeds the absolute value of the coefficient on lagged direction for all size categories.

The results suggest that adverse selection has little influence over customer spreads in this market. The coefficient on trade size is never statistically different from zero, and is actually negative in one case. Furthermore, estimated baseline half-spreads on small, medium, and large trades are 11.5 pips, 4.5 pips, and 1.6 pips, respectively. Wald chi-squared tests indicate that these differences are statistically significant. The statistics are 23.52 for the small-medium comparison and 122.54 for the small-large comparison, both of which have marginal significance below 0.0001. The statistic is 3.97 for the medium-large comparison, which has marginal significance below 0.05. These results thus imply a negative relation between trade size and spreads, inconsistent with adverse selection.

The conclusion that trade size and FX customer spreads are negatively related is statistically and economically strong and is sustained across three robustness tests. It is also consistent with the negative relationship between trade size and spreads observed in other quote-driven markets. Such a relationship characterizes U.S. bond markets. In the municipal bond market spreads average 2.23 percent for small trades and 0.10 percent for large trades (Harris and Piwowar (2004)). In the U.S. corporate bond market spreads for BBB-rated bonds average $2.37 per $100 face value for trades involving ten bonds or less but only $0.37 per $100 face value for trades involving over 1,000 bonds (Goldstein *et al.* (2006)). A negative relationship has also been documented in the London Stock Exchange (Hansch *et al.* (1999)), where average quoted spreads range from 165 basis points for the smallest stocks to 112 basis points for the largest stocks (similar results are provided in Bernhardt *et al.* (2004)). By contrast, spreads are apparently positively related to transaction size, as predicted by adverse selection, on the order-driven NYSE (see, for example, Harris and Hasbrouck (1996); Bernhardt and Hughson (2002); Peterson and Sirri (2003)).

The negative relationship between trade size and FX customer spreads does not extend to the FX interbank market. The earliest study using interbank transaction data, Lyons (1995), finds a positive relationship between trade size and spreads, and subsequent studies find little or no relationship (Yao (1998), Bjønnes and Rime (2005)). The absence of any such relationship in recent years presumably reflects the fact that interbank trades are consistently small so their size is uninformative.[10]

Customer Type: To examine the bilateral relationship between spreads and customer type we interact the key variables of the Madhavan-Smidt (1991) model with dummies for transactions with financial customers (*FC*) and commercial customers (*CC*). The results, which are presented in Table V, indicate that the baseline half-spread for financial customers is only 4.2 pips while the baseline half-spread for commercial customers is 10.8 pips. The Wald chi-squared test statistic for this difference is 21.82, with p-value below 0.0001, which indicates that the difference between these figures is highly significant. As usual, inventories do not appear to influence dealer quotes and our qualitative conclusions do not change if we exclude inventories, if we consider only spot trades, or if we include incoming interbank trades (*IB*). Thus it appears that FX dealers distinguish sharply between commercial and financial customers but not in the manner predicted by adverse selection.

Adverse selection has been found to provide a good guide to dealer behavior in other non-anonymous markets, however. The theory works well, for example, in explaining the pattern of price discrimination among specialists on the non-anonymous Frankfurt Stock Exchange. As shown by Thiessen (2003), those specialists provide price improvement when adverse selection costs are lowest and adjust quotes the most after trades that did not get price improvement.

According to our correspondents at large dealing banks, the correct customer disaggregation is between small commercial customers, on the one hand, and financial customers and large multinational (commercial) corporations, on the other. Though we cannot technically distinguish large multinationals from other commercial customers, large multinationals are unlikely to do much business with a small bank. Thus the counterparty-based tiering identified here should be roughly accurate for our bank.

C. Joint Influence of Trade size and Counterparty Type

We now run the Madhavan-Smidt (1991) regressions interacting the key variables with dummies for both transaction size {*LG*, *MD*, *SM*} and counterparty type {*FC*, *CC* }. The results of this analysis, reported in Table VI, reveal that currency spreads are influenced by both trade size and counterparty type. The tiering of spreads by trade size is most pronounced for commercial customers, for which estimated baseline half-spreads are 12.7 pips on small trades, 7.2 pips on medium trades, and 2.1 pips on large trades. Wald tests indicate that the large-small and large-medium comparison are both statistically significant, while the small-medium comparison is not. This may reflect the lower power of this test, as each trade category has fewer observations than in the bilateral tests reported above. For example, only five percent of the commercial-customer trades in our sample are medium sized.

For financial customers, estimate baseline half-spreads are 6.6 pips on small trades and roughly half that size – and insignificantly different from zero – for medium and large trades. Wald tests are not able to detect statistically significant differences within the financial-customer spreads, which could once again be due to a lack of power since our bank primarily serves commercial customers. However, Wald tests indicate that financial-customer spreads are indeed smaller than commercial-customer spreads for small trades (marginal significance 0.0002) and medium trades (marginal significance 0.03). Wald tests detect no significant difference between spreads on large trades for financial and commercial customers, which is not surprising since the spreads themselves were insignificant in this size category for both types of customers. The qualitative conclusions that spreads are higher for commercial than financial customers, and that spreads are inversely related to trade size are sustained across our three robustness tests.[11]

Lyons (2001) and Marsh and O'Rourke (2005) suggest, based on a negative correlation between commercial order flow and exchange rates in daily data, that commercial trades may have a negative price impact. If so, our analysis suggests that the price impact is certainly not instantaneous, since we find that spreads are positive for both commercial and financial customers. Marsh and O'Rourke (2005) also suggest that the negative relationship may instead reflect feedback trading, and provide evidence that commercial-customer trades are indeed influenced by lagged returns. Our evidence provides a further indication that the feedback-trading interpretation is more likely to be correct.

D. The Huang and Stoll Model

Bjønnes and Rime (2005) find no evidence for adverse selection using the Madhavan-Smidt model but do find such evidence when they adopt (a modified version of) the Huang and Stoll regression framework (1997). We close this section by showing that, when the trades of our dealer are disaggregated by customer type and size, the Huang and Stoll model does not support adverse selection though it does support the overall pattern of customer spreads identified above.

Huang and Stoll (1997) observes that trade size is relatively unimportant for pricing in markets, like foreign exchange, where large trades are routinely broken up into multiple smaller transactions. Even in such markets, however, the risk of trading with a better informed counterparty remains. Thus, Huang and Stoll's model assumes that prices are determined by a trade's direction and the market maker's existing inventories, but not by a trade's size.

In this model, dealer *i* sets his price, P_{it}, as $P_{it} = \mu_{it} + \frac{S}{2} D_t - \theta \frac{S}{2} I_{it} + \upsilon_t$. Once again, μ_{it} represents dealer *i*'s conditional expectation of the asset's fundamental value. The baseline half-spread is $S/2$ and the effect on price of existing inventory (through price shading) is $\theta S/2$. Dealer *i* updates his expectation of the asset's fundamental value in light of the private information revealed by the direction of the previous trade as well as public news: $\mu_{it} - \mu_{it-1} = (\lambda S/2)D_{t-1} + \varepsilon_t$. The term $\lambda S/2$ captures the information effect of trade direction and ε_t is a serially uncorrelated public information shock. Combining the pricing and updating rules gives the following expression for price changes between incoming transactions:

$$\Delta P_{it} = \frac{S}{2}(D_t - D_{t-1}) + \lambda \frac{S}{2} D_{t-1} - \theta \frac{S}{2} \Delta I_{it} + e_t, \quad (2)$$

where $e_t \equiv \varepsilon_t + \Delta \upsilon_t$. We follow Huang and Stoll (1997) in estimating the model separately for various size categories. We also disaggregate trades according to counterparty. As earlier we use GMM with Newey-West standard errors. The results, shown in Table VII, broadly confirm our earlier findings: baseline spreads are wider for small trades than for large trades and are generally wider for commercial customers than for financial customers; also, spreads are little influenced by existing inventories.

Consistent with our earlier analysis, however, the estimates of the adverse-selection coefficient, λ, suggest that adverse selection is not influential in this market. The theory predicts that λ should be larger for financial customers than commercial customers, but this is only true for the point estimates in one of the three size categories and that difference is not statistically significant. The theory also predicts that λ should be largest for large trades, but the estimated coefficients for large trades are statistically insignificant for both financial and commercial customers.

III. Operating Costs, Market Power, and Strategic Dealing

The cross-sectional pattern of currency spreads just documented is not consistent with adverse selection, despite the widespread acceptance of that hypothesis in the FX microstructure literature. This section examines possible alternative explanations for the pattern of spreads.

We begin by considering the components of the standard paradigm beyond adverse selection, which are: monopoly power, inventory risk, and operating costs. Pure monopoly power is unlikely to be important in FX, where hundreds of dealers compete intensely. Inventory risk can also be ruled out as a determinant of our pattern, since the prospective inventory effect implies a positive relationship between spreads and trade size (Ho and Stoll (1981)), rather than the negative relation we observe. In addition, inventory risk is invariant across customers, so this element cannot explain the relationship between spreads and customer type.

The remaining component of the standard paradigm is operating costs. In discussing the negative relationship between spreads and trade size on the London Stock Exchange, Angel (1996) and Hansch *et al.* (1999) note that such a relationship could arise if per-unit processing costs are smaller for large trades. This occurs with fixed costs, which certainly exist in FX and, in conversation, foreign exchange dealers themselves suggest that they are relevant. However, the relationship between costs and customer type seems unable to explain the smaller spreads paid by financial customers: fixed costs do not vary strongly by customer type, and marginal costs are, if anything, higher for asset managers, who often require the proceeds of a large trade to be "split" among numerous individual funds. In short, the standard paradigm can explain the relationship between FX customer spreads and trade size but not the relationship between spreads and customer type.

One might wonder whether the customer-based differences in spreads could result merely from differences in the intraday pattern of trading. If commercial customers trade more intensely during hours when spreads are widest, they will naturally pay larger spreads on average. Interdealer spreads (the only spreads for which intraday patterns are available) are widest during the London morning and during the FX market's "overnight" period, which lasts for a few hours after about 5 pm London time (Payne (2003)). Financial-customer trades tend to be concentrated during the London morning hours (Figure 2A,B), while commercial-customer trades are more evenly distributed across the trading day. In consequence, intraday trading patterns predict variation in customer spreads opposite to that just documented.

The rest of this section highlights two mutually consistent theories of dealing under asymmetric information that might have more success in explaining why FX spreads vary across counterparty types. One theory suggests that information about current market conditions provides market power which, in turn, affects spreads. The other theory suggests that dealers strategically vary spreads across customers in an attempt to gather private information about near-term exchange-rate returns.[12] It is our view that both of these information-based forces operate simultaneously with operating costs.

A. Market Power

Green *et al.* (2004) shows that variations in market power between dealers and their customers may explain why spreads are inversely related to trade size in the U.S. municipal bond market. That paper points out that dealership markets are opaque due to the dispersion of trading, so current market conditions – meaning real-time mid-quotes, spreads, volatility and the like – are hard to ascertain. The customers who make smaller municipal bond trades tend to know the least about current market conditions, so they have the least market power relative to the dealers and are charged the widest spreads.

The market-power hypothesis can be applied directly to explain why commercial FX customers pay wider spreads than financial customers. Currency markets are also dealership markets with dispersed information. What little market information is available to customers is expensive. Financial customers typically purchase real-time information and hire professional traders who know how to interpret it. By contrast, most commercial customers do not purchase that information and do not hire sophisticated traders, so their traders are usually considered relatively uninformed about market conditions.

Information about market conditions is not the only potential source of financial customers' market power. In discussing the NYSE, Angel (1996) notes that

> a dealer knows that an unsophisticated individual who places a small order may have higher search costs per share and is not in a good position to monitor the quality of a broker's execution. The broker has little incentive to spend time negotiating or shopping around for a better deal for a small order. Thus, a dealer may take advantage of this by quoting a wider market for small orders (p. 4).

Duffie *et al.* (2004) develops this insight into a formal model and shows that bargaining power in OTC markets partly reflects the alternatives to trading immediately, alternatives that are determined by the relative costs and benefits of further search. In currency markets, the benefits to search are smaller for commercial customers than for financial customers.[13] FX traders at commercial firms are not always rewarded for finding better prices; for them, trading is typically just one of many administrative responsibilities. By contrast, FX traders at financial customers are often explicitly evaluated on execution quality. Since FX traders at financial firms perceive greater benefits to search, they are more likely to keep at it until they find a narrow spread. Knowing this, dealers may not even try to quote them a wide spread. Financial customers' market power may also come from their tendency to undertake large trades (see Table III). As shown in Bernhardt *et al.* (2004), customers who regularly provide a dealer with substantial amounts of business may receive better spreads as dealers compete for their business.

B. Strategic Dealing

The counterparty-based tiering of currency spreads may also reflect "strategic dealing," in which the dealers adjust their pricing so as to extract private information from their customers. Order flow at large banks includes information about upcoming high-frequency currency returns, as documented by Evans and Lyons (2004) and Daníelsson *et al*. (2002). Evidence from equity markets confirms that access to real-time order flow information can provide an informational advantage (Anand and Subramanyam (2005)). Thus it seems logical that FX dealers might try to capture a larger share of the most informative order flow, since the information could help increase returns and/or lower risk through better inventory management, better pricing on upcoming trades, and better speculative positioning.[14]

Our own small bank's order flow need not be hugely informative for strategic dealing considerations to influence its customer spreads. As noted earlier, dealers' dominant concern when setting FX spreads is conforming to standard practice (Cheung and Chinn (2001)), so strategic dealing will (at least) indirectly influence spreads at small banks so long as it directly influences spreads set at large banks.[15] It is also noteworthy that dealers need not know exactly which customers are informed for strategic dealing to be influential. Strategic dealing can arise even if, as is true in FX, dealers discriminate only according to a customer's likelihood of being informed.

The insight that market makers might strategically manipulate spreads to increase the information value of order flow is not new. Leach and Madhavan (1992, 1993) use equity-market inspired models to demonstrate that market makers may adjust prices early in a trading session to enhance later profitability. This general insight motivates the empirical tests of Hansch and Neuberger (1997), which "provide[s] evidence that dealers [on the London Stock Exchange] do act strategically, and that they deliberately accept losses on some trades in order to make superior revenues on others" (p. 1). Evidence for this type of strategic dealing in an experimental market which shares many properties with the FX interdealer market is presented in Flood *et al.* (1999).

Our evidence, however, concerns cross-sectional variation in spreads rather than variation across time. An equity-inspired strategic dealing hypothesis that overlaps more substantially with our own is presented in Naik *et al.* (1997), whose analysis of a two-tier market indicates that customer spreads will be narrower for more informed customers, consistent with the pattern we document for FX. The motivation for this conclusion is similar to the first two outlined above: after gleaning the information included in the current customer trade, dealers can profit more in subsequent trading. However, the Naik *et al.* model also concludes that customer spreads vary positively with trade size, while our data fits the opposite pattern.

Consistent with the Naik *et al.* (1997) model, Reiss and Werner (2004) report that "[d]uring the period of our sample, London [Stock Exchange] dealers were known to solicit large customer orders, even if the terms were unfavorable. The explanation most often given for this behavior was that dealers were 'purchasing' information …" (p. 625). In the context of the FX market we hypothesize that information content is not only inversely related to trade size, as on the London Stock Exchange, but it is typically higher for financial customers than commercial customers. Evidence that financial transactions in FX carry information for high-frequency exchange-rate returns is provided in Froot and Ramadorai (2005). Evidence that the information in financial transactions tends to exceed the information in commercial transactions, at least information about high-frequency dynamics, is provided in Fan and Lyons (2003) and Carpenter and Wang (2003).

Further evidence consistent with strategic dealing in FX is presented in Ramadorai (2005), which analyzes the FX transactions of the customers of a major global custodian and thus focuses on how spreads vary across financial customers. This paper shows that spreads are narrower for asset managers that produce higher (risk-adjusted) FX returns, as predicted by the strategic dealing hypothesis.

There is a sense in which the strategic dealing hypothesis mirrors the market power hypothesis. In the game between dealers and their commercial customers, dealers gain market power from their knowledge of market conditions, on the basis of which they extract wider spreads. In the game between dealers and their financial customers, both sides are well informed about market conditions but financial customers also have private information relevant to near-term exchange-rate dynamics. Financial customers view themselves as exploiting the market power associated with their private information to extract smaller spreads. Dealers simultaneously view themselves as strategically setting small spreads to increase their business with privately informed customers and learn their information. Both sides are right.

IV. Price Discovery in Foreign Exchange

The evidence presented so far shows that spreads in the FX customer market are inversely related to a deal's information content, the opposite of the pattern predicted by adverse selection. But, if adverse selection is not the basis for price discovery in currency markets, what is? This section provides an alternative interpretation of the price discovery process in FX and summarizes existing evidence in support of that interpretation. Asymmetric information is the centerpiece of our story, as it must be, but we suggest that information influences inventory management and order choice in the interdealer market rather than spreads in the customer market. Our interpretation thus reflects institutional features of the FX market, such as its two-tiered structure and the importance of the interdealer market for inventory management, that distinguish FX from the simpler market structures assumed in adverse-selection models.

Our interpretation differs in a key way from the familiar "portfolio shifts" model of the FX market articulated in Evans and Lyons (2002). In that model, dealers first absorb inventory from end users, then trade that inventory among themselves, and finally sell the inventory to other end users. The exchange rate moves to reflect information only during the customer trading of round three. If one were to graft our price discovery framework to the Evans and Lyons model, however, one would conclude that the exchange rate moves to reflect information during the interbank trading of round two. Nonetheless, our interpretation creates a coherent picture from disparate stylized facts from FX microstructure.

A. The Mechanism

Our suggested mechanism involves dealers' interbank trading in response to customer trades. We focus on the interbank market because the evidence presented above implies that a given trade's potential information content is not embedded in customer prices. We infer that price discovery does not happen in the customer market and must therefore happen in the interdealer market.[16] Interdealer markets are crucially important for inventory management in FX (Lyons 1996) as in other two-tier markets (Manaster and Mann (1996), Reiss and Werner (1998), Lyons (1997)).

Consider a dealer whose inventory rises abruptly in response to an incoming customer call. Since FX dealers prefer to have zero inventory (this is documented for our dealer in the Appendix and for large dealers in Bjønnes and Rime (2005)), our dealer will most likely try to offload the new inventory to another dealer. In FX the dealer must choose between "indirect" trading in the order-driven broker market or "direct" trading in the regular quote-driven market.

Assume for now that our dealer chooses to trade through an interdealer broker, in which case he must decide whether to submit a market sell or a limit sell. Harris (1998) and Foucault (1999) highlight a central trade-off: market orders provide immediate execution with certainty while limit orders provide better prices with uncertain execution. Since FX dealers can identify their customers, this order choice could depend on the customer providing the inventory (Reiss and Werner (2004)).

Suppose the customer is informed. In this case the dealer has three incentives to exploit the immediacy offered by market orders: He has information, he has inventory with its inherent risk, and his information indicates that his inventory could soon bring a loss. Our dealer therefore seems likely to place a market sell order and earn the lower bid price. Suppose instead the customer is uninformed. In this case the dealer has only one incentive to place a market order: the inherent riskiness of his inventory. Thus our dealer might be more likely to place a limit order which, if executed, would earn him the higher offer price. In short, we suggest that dealers using the brokers market to manage inventory will have a stronger tendency to place market orders after informed customer trades than after uninformed customer trades.[17]

The connection to price discovery is direct: brokered interdealer prices will tend to move in the direction indicated by informed trades.

If our dealer chooses to trade directly, a modified version of this cost-benefit analysis still applies. Calling another dealer produces a quick, certain trade at a relatively undesirable price, like placing a market order; waiting for someone else to call could bring a better price but could instead bring no trade at all, like placing a limit order. Thus, a dealer who chooses the direct interdealer market has strong incentives to call another dealer after trading with an informed customer and may be more likely to wait for incoming calls after trading with an uninformed customer.

The overall conclusion is consistent regardless of whether a dealer chooses to manage his inventory via brokered or direct trades. After trades with informed customers, a dealer will be more likely to make a (parallel) outgoing trade than after trades with uninformed customers. As a result, interdealer prices will tend to move in the direction required by the information contained in customer trades. (Note that our discussion of price discovery does not assume a priori that informed dealers place outgoing/market orders, but instead derives that outcome.)[18]

In equilibrium, trading might cease entirely if (a) customer identity were the only factor determining whether a dealer makes an outgoing trade and (b) customer identity were a reliable indicator of whether the customer is informed at a given point in time. Under this combination of circumstances dealers would only place market orders after informed-customer trades, so placing a limit order would be a recipe for losing money and the market might cease to exist. In reality, however, customer identity is imperfectly correlated with a given customer's private information at any point in time. Furthermore, the decision to make an outgoing trade depends on more than just customer identity, as shown below.[19]

B. Explaining the Stylized Facts

Our analysis of dealer order choice in FX predicts a number of the stylized facts in FX microstructure. For example, it predicts that financial order flow, which dealers assert is relatively informed, will be positively related to exchange-rate returns. Evidence for this positive relationship is provided in Evans and Lyons (2004), Bjønnes *et al.* (2005), and Marsh and O'Rourke (2005). Our analysis also predicts that this relationship between financial order flow and exchange rates is substantially permanent, evidence for which is provided in Lyons (2001) and in Bjønnes *et al.* (2005).

Our analysis predicts a positive and largely permanent relationship between exchange rates and interdealer order flow, which is defined as buy-initiated interdealer transactions minus sell-initiated transactions. (In the order-driven or brokered portion of the interdealer market, the initiator of a transaction is considered to be the dealer placing the market order; in the quote-driven or direct dealing portion of that market, the initiator is the dealer that calls out. In both cases the initiator makes an "outgoing trade.") Consistent with this prediction, substantial evidence indicates a strong and positive contemporaneous correlation between interdealer order flow and exchange-rate returns at the daily and weekly horizons (see Lyons (1995), Payne (2003), Evans (2002), Evans and Lyons (2002), Killeen, Lyons, and Moore (2002), and Daníelsson *et al.* (2003), *inter alia*). Furthermore, a substantial portion of this relationship is permanent (Evans and Lyons (2002), Payne (2003), Killeen *et al.* (2005), Bjønnes *et al.* 2005).

C. New Evidence

Our interpretation of price discovery in FX has three additional testable implications. First, it predicts that interdealer prices are the best measure of "the market" at any instant. Abundant institutional evidence confirms this implication. Most critically, dealers universally base their customer quotes on the interdealer market's current best bid and offer. In a large dealing room, salespeople construct the quote actually given to a customer from a preliminary quote provided at that moment by the relevant interdealer trader. Those preliminary quotes are in turn anchored on the best bid and offer in the interdealer market. In electronic communication networks (e.g., Currenext, FXAll) the connection between interdealer prices and customer quotes is programmed directly into the pricing algorithm.

Beyond these observations, our conjecture also has the testable implication that dealers should be more likely to make outgoing interbank transactions after trades with financial customers than after trades with commercial customers. Finally, our conjecture implies that dealers should also be more likely to make outgoing interbank transactions after larger trades, since large trades apparently carry more information than small ones.

We test these last two implications via a probit analysis of the conditional probability that a given transaction is outgoing in the interbank market:

$$Prob(Trade_t{=}IB^{out}) = P(FC_{t\text{-}1},\ CC_{t\text{-}1},\ 10mio_{t\text{-}1}, |I_{it}|,\ I_{it}^2,\ |Q_{jt}|)\ . \qquad (4)$$

Our hypothesis concerns the first three variables, dummy variables for lagged financial-customer trades, $FC_{t\text{-}1}$, lagged commercial customer trades, $CC_{t\text{-}1}$, and a dummy set to one if the previous transaction was worth €10 million or more, $10mio_{t\text{-}1}$. Our conjecture suggests that the coefficient on the financial dummy will be higher than the coefficient on commercial dummy, and the coefficient on $10mio_{t\text{-}1}$ will be positive.

The last three terms in equation (4) capture other factors relevant to the decision to place a market order. The coefficient on absolute inventory, $|I_{it}|$, should be positive since higher inventory brings higher inventory risk.[20] Following Bjønnes and Rime (2005) we include squared inventory, I_{it}^2, to capture potential nonlinearities in this relationship. The absolute size of the current transaction, $|Q_{jt}|$, is included because our dealer's customer transactions are often smaller than the $1 million minimum size for brokered trades. Since our dealer prefers to carry out interbank trades on EBS, a broker, rather than by dealing directly, he seems likely to collect inventory from small customer transactions and then square his position by submitting one relatively large market order.

The results of estimating Equation (4), shown in Table VIII, support our view that the likelihood of an outgoing interbank transaction is higher when the most recent transaction is considered informed. Outgoing interbank transactions are statistically significantly more likely when the previous transaction involves a financial customer than when it involves a commercial customer. They are also statistically significantly more likely after big trades, meaning those over €10 million. The results are economically meaningful, as well. After a moderate-sized commercial trade the estimated probability of an outgoing interbank transaction is 9.5 percent; after a similarly-sized financial trade that probability is roughly twice as large, at 18.5 percent. After commercial trade over €10 million the probability of an outgoing interbank transaction is 25.4 percent. After a similarly-sized financial trade this probability reaches a lofty 40.2 percent. (In these calculations, all other independent variables are taken at sample means.) As indicated by the three robustness tests, these results, like our earlier results, are not sensitive to whether inventories are included as an independent variable or to whether the data include spot trades or interdealer trades.

The rest of the results from estimating Equation (4) also make sense. The likelihood of an outgoing trade rises with the absolute value of existing inventory and the relationship is concave. As noted above, the importance of inventory level for dealer order choice helps the market avoid no-trade equilibria and maintain low interbank spreads by reducing the signal/noise ratio associated with outgoing interbank trades. Importantly, the significance of inventory levels eliminates one alternative possible explanation for the influence of trade size on order choice. Specifically, it appears that large trades are not significant in our regression because of the inventory risk they bring, since the influence of inventory level per se is already accounted for. The positive relationship between absolute trade size and the likelihood that the trade itself is outgoing indicates that outgoing brokered transactions tend to be larger than the dealer's average incoming transaction, as expected.[21]

To summarize: This section suggests a mechanism through which price discovery may occur in FX. We first note that price discovery must happen in the interdealer market since customer spreads vary inversely with a trade's likely information content. We then show both conceptually and empirically that dealers are more likely to make outgoing interbank trades after trading with informed customers than after trading with uninformed customers. This could be the force that drives interdealer prices in the direction consistent with information brought to the market by informed customers.

V. CONCLUSIONS

This paper investigates the process through which information becomes embedded in exchange rates. Our data comprise the complete USD/EUR trading record of a bank in Germany over four months in 2001. These data have the advantage of distinguishing between transactions with financial and commercial customers.

The paper's first contribution is to show that spreads on normal-sized currency trades vary inversely with trade size and are wider for commercial customers than for financial customers. Both components of the pattern are inconsistent with the hypothesis that adverse selection dominates currency spreads, since FX dealers consider large trades to be more informative than small trades and financial customers to be more informed than commercial customers. One potentially important implication of the pattern is that a customer trade's immediate price impact is not a good measure of its information value.

The paper's second contribution is to highlight three hypotheses that help explain the cross-sectional pattern of currency spreads. We first note that operating costs are largely fixed in FX, which could help explain the negative relationship between trade size and spreads. The customer-based variation in spreads could be explained by Green *et al.*'s (2004) market-power hypothesis. This hypothesis asserts that spreads in quote-driven markets vary positively with a dealer's market power relative to a given customer, and that such market power derives in part from knowledge of market conditions. Commercial customers tend to know the least about current market conditions, so this theory predicts they will pay the widest spreads, as they do. The customer-based variation in spreads could also reflect dealers' attempts to strategically gather information about near-term returns (Leach and Madhavan (1992), (1993), Naik *et al.* (1997)). Dealers may subsidize trades with informed customers in order to learn the information embedded in their trades. Dealers consider financial order flow to be relatively informative, so financial customers pay the narrowest spreads.

The paper's third contribution is to create a coherent picture of the FX price discovery process by fusing existing empirical evidence on FX microstructure, including our own, with insights from mainstream microstructure. We first note that, since customers' information is not immediately reflected in the prices they pay, price discovery must take place entirely in the interdealer market. We focus our analysis, therefore, on dealer behavior in the interdealer market, a market that is important for inventory management (Lyons (1997)). The key mechanism behind our suggested price discovery process involves the dealer's response to individual customer trades. We suggest that after transactions with informed customers, dealers will tend to make parallel outgoing interdealer trades – placing a market order in the order-driven component of the market, for example – motivated by their inventory as well as by their newly-acquired information. In this way the information from customer trades will be reflected in interdealer prices. After transactions with uninformed customers, by contrast, dealers will be relatively likely to place parallel limit orders or to wait for incoming calls.

Our theory predicts that dealers should be more likely to place outgoing interdealer trades after informed customer trades, and we provide evidence that this is true for our dealer. Our theory also predicts some key stylized facts in FX: the positive and substantially permanent relation between cumulative interdealer order flow and exchange rates, as well as the positive and substantially permanent relation between financial order flow and exchange rates. Future research could be productively directed to further tests of our proposed price discovery mechanism as it applies to the foreign exchange market. It could also be fruitful to evaluate whether that proposed mechanism applies in other liquid two-tier markets.

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Appendix: Small Banks and Large Banks Behave Similarly

This Appendix documents that our small-bank dealer behaves very similarly to large-bank dealers in terms of pricing and inventory management. The analysis is based on the Madhavan-Shmidt model outlined in Section II, with customers aggregated into one category for comparability with earlier studies.

Baseline spreads: As shown in Table AI, our bank's average baseline half-spread for interbank transactions is about 1.5 pips, which is similar to estimates from other studies. For example, Goodhart *et al.* (2002) finds that the average spread for USD/EUR transactions on the Electronic Brokerage Service (EBS, one of the two major electronic brokerage systems for interbank trading) was 2.8 pips about one year after the euro was introduced. Our bank's average half-spread for customer trades, 9.2 pips, is much higher than its average interdealer spread of 1.6 pips. Customers are also quoted sharply higher spreads than other dealers by Bjønnes and Rime's (2001) NOK/DEM dealer. These figures imply that currency spreads average less than 0.1 percent; for comparison, average municipal bond spreads were 180 basis points in 2003 (Harris and Piwowar (2004)) and average spreads on the London Stock Exchange were 110 basis points in 1991 (Reiss and Werner (2004)).

Influence of existing inventories: Our results indicate that existing inventories have no influence on the prices our dealer quotes to other dealers, consistent with recent studies of large banks (Yao (1998), Bjønnes and Rime (2005)). Survey-based evidence confirms that inventories are of minimal importance when dealers set spreads, and that the dominant concern is whether spreads conform to market convention (Cheung and Chinn (2001)). Lyons (1995) provides evidence that his dealer did engage in inventory-based price shading towards other dealers in 1992. This may reflect the unusual character of Lyons' dealer who, as a jobber, dealt exclusively with other dealers at extremely high frequency. Yao (1998) claims that his dealer avoided such shading because it would reveal information about his inventory position.

Bjønnes and Rime (2005) argue that any shift away from inventory-based price shading in recent years may reflect the interbank market's rapid shift to a heavy reliance on electronic brokerages after their introduction in the mid-1990s (Melvin and Wen (2003)). Our dealer reports that for interbank trades he generally uses EBS because it is less expensive and faster than direct interbank dealing.[22] Together, these observations imply that our dealer controls inventories via interbank trading instead of price shading, a conclusion we support empirically later in this section. Studies from other markets also show that dealers in two-tier markets with access to brokerage services prefer to manage their inventory through interdealer transactions (Reiss and Werner (1998)).

The estimates in Table AI seem to provide slight evidence of inventory-based price shading in the "wrong" direction with respect to transactions with customers. Reassuringly, this can be traced to one trade carried out in the first month of our sample period. If that trade is excluded, the coefficients on inventory are insignificant.

Trade size and spreads: The coefficient on trade size is statistically insignificant for interbank trades, suggesting that neither information asymmetries nor prospective inventories cause large interbank trades to be priced less attractively than small ones. This is consistent with the large dealing bank examined in Bjønnes and Rime (2004), for which spreads on brokered interbank transactions seem independent of trade size. That paper also finds that spreads rise with trade size for direct interbank transactions, a distinction that makes economic sense. Dealers have limited control over the relationship between trade size and spread for brokered transactions, but they have full control for direct trades. Notably, the earliest studies of currency dealers (Lyons (1995), Yao (1998)), which did not control for the distinction between direct and brokered trades, found that interbank spreads do rise with trade size, consistent with standard models. This could reflect the fact that interbank trading was mostly carried out through direct transactions until the late 1990s.

The coefficient on trade size is also insignificant for customers in our baseline regression. Note that this coefficient is negative and significant when inventories are excluded: Section II showed that the overall relationship between spreads and trade size is indeed negative for customer transactions.

2. *Inventory Management*

Our dealer's tendency to keep inventories close to zero (Figure 1) is itself similar to inventory management practices at large banks. As Table I shows, currency dealers of all sizes tend to keep minimal inventories. A more rigorous description of our dealer's approach to inventory management comes from estimating the following regression:

$$I_t - I_{t-1} = \omega + \rho I_{t-1} + \varepsilon_t. \qquad \text{(A1)}$$

If the dealer instantly eliminates unwanted inventories, then $\rho \approx -1$. If the dealer allows his inventory to change randomly, then $\rho = 0$. The time subscript corresponds to transaction time, and only incoming transactions, for which our dealer quotes the price, are included (giving 2,858 observations). Results from estimating Equation (A1), once again using GMM with Newey-West standard errors, confirm that our small bank strives to keep inventories close to zero. Our point estimate of $\rho = -0.20$ has a standard error of 0.008 and is thus highly statistically significant. The dealer on average eliminates 20 percent of an inventory shock in the next trade, which implies a median inventory half-life of 19 minutes.

Our estimated inventory half-life is quite close to the 18-minute median inventory half-life for Bjønnes and Rime's (2004) NOK/DEM dealer. The speed of adjustment is faster in futures markets, where dealers eliminate almost half of any inventory shock in the next trade (Manaster and Mann 1994). Adjustment speeds are also faster of the large DEM/USD dealers at the bank studied by Bjønnes and Rime, for which inventory half-lives range from 0.7 to 3.7 minutes. Nonetheless, our dealer's adjustment speed is lightning fast, and differs little from the others just reported, when compared with inventory adjustment lags in other markets. On the NYSE these lags average over a week (Madhavan and Smidt (1993)) and can extend beyond a month (Hasbrouck and Sofianos (1993)). Even on the London Stock Exchange, which is a dealership market like FX, inventory half-lives average 2.5 trading days (Hansch *et al.* (1998)).

Overall, this analysis shows that the dealer from which we take our data behaves much like large dealers despite his small volume.

Table I. Descriptive statistics, currency dealing at a small bank in Germany

The table shows the complete USD/EUR trading activity of a small bank in Germany, except preferred customer trades, over the 87 trading days between July 11th, 2001 and November 9th, 2001.

A. All Business

	All Transactions	Interbank	Customer		
			All	Financial	Commercial
Number of Transactions	3,609	1,919	1,690	171	1,519
(percent)	(100)	(44)	(56)	(5)	(42)
Of Which, Forward	646	114	532	60	472
Value of trades (€ mil.)	4,335	2,726	1,609	405	1,204
(percent)	(100)	(61)	(39)	(9)	(28)
Of Which, Forward	999	87	912	226	686
Mean Size (€ mil.)	1.20	1.42	0.95	2.37	0.79
Mean Size, Forwards (€ mil.)	1.55	0.76	1.71	3.77	1.45

Table II. Comparison of small bank studied here with larger banks studied in other papers.

The table shows the complete USD/EUR trading activity of a small bank in Germany, except preferred customer trades, over the 87 trading days between July 11th, 2001 and November 9th, 2001. For comparison purposes we focus on statistics based exclusively on the small bank's spot trades.

	Small Bank in Germany	B.I.S. (2002) per Bank	Lyons (1995)	Yao (1998)	Bjønnes and Rime (2004)		
					Four Dealers, Range	DEM/USD Dealer	NOK/DEM Dealer
	87 Trading Days in 2001[a]	April 2001	5 Trading Days in 1992	25 Trading Days in 1995	5 Trading Days in 1998		
Transactions per Day	**40 (51)**	---	267	181	58 - 198	198	58
Transaction value per Day (in $ millions)	**39 (52)**	50 - 150	1,200	1,529	142 - 443	443	270
Value per Transaction ($ mil.)	**1.0**	---	4.5	8.4	1.6 - 4.6	2.2	4.6
Customer Share of Transaction value (in percent)	**23 (39)**	33	0	14	0 – 18	3	18
Average Inventory Level (in € or $ millions)	**3.4**		11.3	11.0	1.3 – 8.6	4.2	8.6
Average Transaction Size (in € or $ millions)	**1.2**		3.8	9.3	1.5 – 3.7	1.8	3.7
Average Price Change Btwn. Transactions (in pips)	**11**		3	5	5 - 12	5	12

[a] Values in parentheses refer to the data set including outright-forward transactions.

Table III. Size distribution of individual trades

The table shows the size distribution of all USD/EUR spot and forward transactions, except those for preferred customers, at a small bank in Germany over the period July 11, 2001 through November 9, 2001.

	Interbank Trades	Financial Customer Trades	Commercial Customer Trades
Number	1,872	171	1,492
Share (%)			
Below € 0.1 million	7%	15%	54%
€ 0.1 – 0.5 million	9	26	32
€ 0.5 – 1.0 million	7	14	5
€ 1.0 – 20 million	77	44	8
€ 20 million and above	0	1	1

Table IV: Spread variation across trade size categories

We estimate this equation: $\Delta P_{it} = \alpha + \beta_1 D_t + \beta_2 D_{t\text{-}1} + \gamma_1 I_{it} + \gamma_2 I_{it\text{-}1} + \delta Q_{jt} + \varepsilon_t$.

The dependent variable is the change in price between two successive incoming trades measured in pips. D_t is an indicator variable picking up the direction of the deal, positive for purchases (at the ask) and negative for sales (at the bid); I_{it} is the dealer's inventory at time *t,* and Q_{jt} is order flow measured in millions of euros. These variables are interacted with dummy variables for the three trade size categories, large trades (*LG*), medium trades (*MD*), and small trades (*SM*). Data include all incoming customer USD/EUR spot and forward trades of a small bank in Germany, except those with preferred customers, during the period July 11, 2001, through November 9, 2001. Estimation uses GMM and Newey-West correction. Significance at the 1, 5 and 10 percent levels indicated by ‡, † and *, respectively. Estimates of the (negative of the) baseline half spread are highlighted in bold.

	Baseline Regression		Robustness Tests		
			No Inventories	Spot Trades Only	Interbank Trades Included
	Coefficient	*Std. Error*	Coefficient	Coefficient	Coefficient
Constant	0.378	*0.31*	0.461	1.194‡	-0.333
Direction					
$SM \times D_t$	12.250‡	*0.74*	12.245‡	10.275‡	11.367‡
$SM \times D_{t-1}$	**-11.519‡**	*0.59*	**-11.557‡**	**-10.154‡**	**-9.903‡**
$MD \times D_t$	17.455‡	*6.70*	17.548†	12.258	13.165†
$MD \times D_{t-1}$	**-4.463‡**	*1.55*	**-4.424‡**	**-6.275‡**	**-3.739‡**
$LG \times D_t$	3.726‡	*1.37*	4.839‡	0.789	4.404‡
$LG \times D_{t-1}$	**-1.560†**	*0.66*	**-1.526†**	**-0.928**	**-1.358‡**
Inventory					
$LG \times I_{it}$	0.436	*0.43*		-0.128	0.612†
$LG \times I_{it-1}$	-0.454	*0.44*		0.442	-0.688†
$MD \times I_{it}$	-2.098	*2.52*		-0.030	-2.142
$MD \times I_{it-1}$	1.856	*2.58*		-0.052	2.145
$SM \times I_{it}$	1.008*	*0.53*		-0.014	-0.200
$SM \times I_{it-1}$	-1.079†	*0.53*		-0.047	0.164
Trade size					
$LG \times Q_{jt}$	0.158	0.47	-0.248	0.127	0.348
$MD \times Q_{jt}$	-13.163	9.59	-11.724	1.291	-9.980
$SM \times Q_{jt}$	4.968	3.45	3.807	7.841*	-2.329
Adjusted R^2	0.29		0.29	0.30	0.16
Observations	1,640		1,640	1,125	2,848

Table V. Spread variation across counterparty types

We estimate this equation: $\Delta P_{it} = \alpha + \beta_1 D_t + \beta_2 D_{t-1} + \gamma_1 I_{it} + \gamma_2 I_{it-1} + \delta Q_{jt} + \varepsilon_t$.

The dependent variable is the change in price between two successive incoming trades measured in pips. D_t is an indicator variable picking up the direction of the deal, positive for purchases (at the ask) and negative for sales (at the bid); I_{it} is the dealer's inventory at time *t,* and Q_{jt} is order flow measured in millions of euros. These variables are interacted with dummy variables for both counterparty groups, financial customers (*FC*) and commercial customers (*CC*). Data include all incoming customer USD/EUR spot and forward trades of a small bank in Germany, except those with preferred customers, during the period July 11, 2001, through November 9, 2001. Estimation uses GMM and Newey-West correction. Significance at the 1, 5 and 10 percent levels indicated by ‡, † and *, respectively. Estimates of the (negative of the) baseline half spread are highlighted in bold.

	Baseline Regression		Robustness Tests: No Inventories	Robustness Tests: Spot Trades Only	Robustness Tests: Interbank Trades Included
	Coefficient	*Std. Error*	Coefficient	Coefficient	Coefficient
Constant	0.031	*0.32*	0.159	0.718*	-0.597†
Direction					
$FC \times D_t$	6.902‡	*1.48*	6.814‡	7.936‡	5.619‡
$FC \times D_{t-1}$	**-4.175‡**	*1.32*	**-4.216‡**	**-5.586‡**	**-2.090***
$CC \times D_t$	11.876‡	*0.56*	12.278‡	11.137‡	12.386‡
$CC \times D_{t-1}$	**-10.758‡**	*0.57*	**-10.982‡**	**-10.183‡**	**-10.170‡**
$IB \times D_t$					2.987‡
$IB \times D_{t-1}$					**-1.578‡**
Inventory					
$FC \times I_{it}$	-0.255	*0.52*		-0.019	1.082
$FC \times I_{it-1}$	0.168	*0.54*		-0.071	-1.150
$CC \times I_{it}$	1.167†	*0.42*		-0.059	1.113‡
$CC \times I_{it-1}$	-1.277†	*0.42*		-0.050	-1.259‡
$IB \times I_{it}$					-0.274
$IB \times I_{it-1}$					0.169
Trade size					
$FC \times Q_{jt}$	-0.366	0.59	-0.151	-0.645	0.656
$CC \times Q_{jt}$	0.221	0.42	-0.919‡	-0.536†	0.076
$IB \times Q_{jt}$					-0.217
Adjusted R^2	0.33		0.33	0.33	0.24
Observations	1,640		1,640	1,125	2,848

Table VI. Spread variation across trade sizes and counterparty types

We estimate this equation: $\Delta P_{it} = \alpha + \beta_1 D_t + \beta_2 D_{t-1} + \gamma_1 I_{it} + \gamma_2 I_{it-1} + \delta Q_{jt} + \varepsilon_t$.

The dependent variable is the change in price between two successive incoming trades, measured in pips. D_t is an indicator variable picking up the direction of the deal, positive for purchases (at the ask) and negative for sales (at the bid); I_{it} is the dealer's inventory at time *t,* and Q_{jt} is order flow measured in millions of euros. These variables are interacted with dummy variables for financial customers (*FC*) and commercial customers (*CC*). They are also interacted with dummies for trade size: *Lg.* = $\{Q_{jt} \in [1,\infty)\}$; *Med.* = $\{Q_{jt} \in [0.5,1)\}$; *Sm.* = $\{Q_{jt} \in (0,0.5)\}$. Data include all incoming customer USD/EUR spot and forward trades of a small bank in Germany, except those with preferred customers, over the period July 11, 2001, through November 9, 2001. Estimation uses GMM and Newey-West correction. Significance at 1, 5 and 10 percent levels indicated by ‡, † and *, respectively. Estimates of the (negative of the) baseline half spread are highlighted in bold.

	Baseline Regression		Robustness Tests		
			No Inventories	Spot Trades Only	Interbank Trades Included
	Coefficient	*Std. Error*	Coefficient	Coefficient	Coefficient
Constant	0.094	*0.31*	0.174	0.799	-0.272
Direction					
FC X D_t X Sm.	10.456‡	*2.58*	10.419‡	12.924‡	9.034‡
FC X D_{t-1} X Sm.	**-6.615‡**	*2.39*	**-6.935‡**	**-13.236‡**	**-5.420‡**
FC X D_t X Med.	3.921	*2.69*	3.905	5.574	3.364
FC X D_{t-1} X Med.	**-2.972**	*2.99*	**-2.930**	**-4.679**	**-0.895**
FC X D_t X Lg.	2.397	*2.93*	2.788	4.013	-0.164
FC X D_{t-1} X Lg.	**-3.622***	*2.02*	**-3.100**	**-0.065**	**0.343**
CC X D_t X Sm.	13.329‡	*0.61*	13.327‡	11.403‡	12.934‡
CC X D_{t-1} X Sm.	**-12.681‡**	*0.64*	**-12.729‡**	**-11.100‡**	**-11.469‡**
CC X D_t X Med.	12.618‡	*1.56*	12.473‡	13.945‡	14.570‡
CC X D_{t-1} X Med.	**-7.199‡**	*1.86*	**-7.161‡**	**-5.607‡**	**-8.492‡**
CC X D_t X Lg.	4.682†	*2.31*	4.721†	1.010	6.296‡
CC X D_{t-1} X Lg.	**-2.064**	*1.76*	**-1.715**	**0.001**	**-3.189†**
IB X D_t X Med.+Sm.					2.027
IB X D_{t-1} X Med.+Sm.					**-3.757†**
IB X D_t X Lg.					3.450‡
IB X D_{t-1} X Lg.					**-1.122†**
Inventory					
FC X I_{it}	-0.464	*0.59*		-0.234	1.119
FC X I_{it-1}	0.365	*0.60*		0.169	-1.180
CC X I_{it}	**1.052†**	*0.41*		0.029	**1.012†**
CC X I_{it-1}	**-1.087‡**	*0.42*		-0.036	**-1.097‡**
IB X I_{it}					-0.263
IB X I_{it-1}					0.198
Trade size					
FC X Q_{jt}	0.121	0.73	0.435	-0.263	1.597
CC X Q_{jt}	0.773*	0.47	-0.240	0.311	0.522
IB X Q_{jt}					-0.347
Adjusted R^2	0.33		0.33	0.32	0.24
Observations	1,640		1,640	1,125	2,848

Table VII. Modified Huang and Stoll (1997) model

We estimate this model: $\Delta P_{it} = \frac{S}{2}(D_t - D_{t-1}) + \lambda \frac{S}{2} D_{t-1} - \theta \frac{S}{2} \Delta I_{it} + e_t$.

ΔP_{it} is the change in price between two successive incoming trades measured in pips. D_t is +1 for buy-initiated trades and –1 for sell-initiated trades. I_{it} is the dealer's inventory, measured in EUR millions. These variables are interacted with dummy variables for trades with financial customers (*FC*) and trades with commercial customers (*CC*). They are also interacted with dummies for trade size: *Lg.* = $\{|Q_{jt}| \in [1,\infty)\}$; *Med.* = $\{|Q_{jt}| \in [0.5,1)\}$; *Sm.* = $\{|Q_{jt}| \in (0,0.5)\}$. Data include all incoming USD/EUR spot and forward trades of a small bank in Germany, except those with preferred customers, over the period July 11, 2001, through November 9, 2001. Estimation uses GMM and Newey-West correction. Significance at 1, 5 and 10 percent levels indicated by ‡, † and *, respectively. Constant term suppressed. Estimates of the baseline half spread are highlighted in bold.

	Baseline Regression		Robustness 1: No Inventories	Robustness 2: Spot Trades Only	Robustness 3: Interbank Trades Included
	Coefficient	**Std. Error**	**Coefficient**	**Coefficient**	**Coefficient**
Half-Spread, *S*/2					
S/2 X *FC* X *Sm.*	**10.538‡**	*2.55*	**10.606‡**	**7.807‡**	**9.304‡**
S/2 X *FC* X *Med.*	**5.354†**	*2.39*	**4.125**	**2.763**	**4.918†**
S/2 X *FC* X *Lg.*	**4.202†**	*1.94*	**4.214†**	**0.998**	**1.597**
S/2 X *CC* X *Sm.*	**13.478‡**	*0.59*	**13.436‡**	**11.346‡**	**12.805‡**
S/2 X *CC* X *Med.*	**11.621‡**	*2.74*	**12.298‡**	**13.561‡**	**12.963‡**
S/2 X *CC* X *Lg.*	**3.804†**	*1.65*	**3.480†**	**6.505†**	**4.478‡**
S/2 X *IB* X *Sm.+ Med.*					0.817
S/2 X *IB* X *Lg.*					**3.934‡**
Adverse Selection					
λ X *FC* X *Sm.*	0.319	*0.21*	0.333*	0.529*	0.391†
λ X *FC* X *Med.*	0.457	*0.52*	0.330	-0,395	0.802*
λ X *FC* X *Lg.*	0.266	*0.57*	0.346	-3.360	1.965
λ X *CC* X *Sm.*	0.056†	*0.02*	0.048†	0.197‡	0.101‡
λ X *CC* X *Med.*	0.393†	*0.18*	0.426‡	0.614‡	0.348†
λ X *CC* X *Lg.*	0.513	*0.46*	0.534	0.489	0.364
λ X *IB* X *Sm.+ Med.*					-2.729
λ X *IB* X *Lg.*					0.717‡
Inventory					
θ X *FC* X *Sm.*	0.038	0.18		0.116	0.18
θ X *FC* X *Med.*	-0.512	0.42		-1.315	0.42
θ X *FC* X *Lg.*	0.003	0.05		0.152	0.05
θ X *CC* X *Sm.*	-0.078*	0.04		-0.002	0.04
θ X *CC* X *Med.*	0.081	0.27		-0.003	0.27
θ X *CC* X *Lg.*	-0.011	0.02		-0.017	0.02
θ X *IB* X *Sm +Med..*					4.814
θ X *IB* X *Lg.*					-0.077
Adjusted R^2	0.33		0.33	0.35	0.23
Observations	1,651		1,651	1,129	2,859

Table VIII. Probit regression of choice of outgoing interbank trades

We estimate this equation, $Prob(Trade_t{=}IB^{out}) = P(FC_{t-1}, CC_{t-1}, |I_{it}|, I_{it}^2, |Q_{jt}|)$, as a probit regression.

Incoming (outgoing) interbank trades are coded 0 (1). FC_{t-1} is a dummy coded 1 if the previous counterparty was a financial customer, CC_{t-1} and IB_{t-1} are defined similarly for commercial customers and other banks. I represents inventories, in millions of euros; $|Q_{jt}|$ represents the absolute size of the current deal, measured in EUR millions; $10\ mio_{t-1}$ is a dummy set to one if the size of the previous transaction was €10 million or larger. Significance at the 1, 5 and 10 percent levels indicated by ‡, † and *, respectively.

	Baseline Regression			Robustness Tests	
				Spot Trades Only	Interbank Trades Included
	Coefficient	Std. Error	z-Statistic	Coefficient	Coefficient
Constant	-0.875‡	*0.044*	-19.92	-0.893‡	-0.728‡
FC_{t-1}	-0.116	*0.116*	-1.00	-0.091	-0.256*
CC_{t-1}	-0.531‡	*0.055*	-9.60	-0.409‡	-0.672‡
IB_{t-1}					-0.214‡
$10\ mio_{t-1}$	0.650‡	*0.190*	3.43	0.770‡	0.657‡
$\|I_{it}\|$	0.030‡	*0.011*	2.85	0.051‡	0.028‡
I_{it}^2	-0.001‡	*0.000*	-2.64	-0.002‡	-0.001†
$\|Q_{jt}\|$	0.029‡	*0.008*	3.58	0.070‡	0.028‡
McFadden's R^2		0.041		0.044	0.044
Observations		3,534		2,894	3,534

Figure 1. Overall inventory position (EUR millions)

Plot shows the evolution of a currency dealer's inventory position in EUR millions over the period July 11, 2001 through November 9, 2001. Data come from a small bank in Germany and include all USD/EUR spot and forward trades. The horizontal axis is transaction-time. Vertical lines indicate the end of each calendar week.

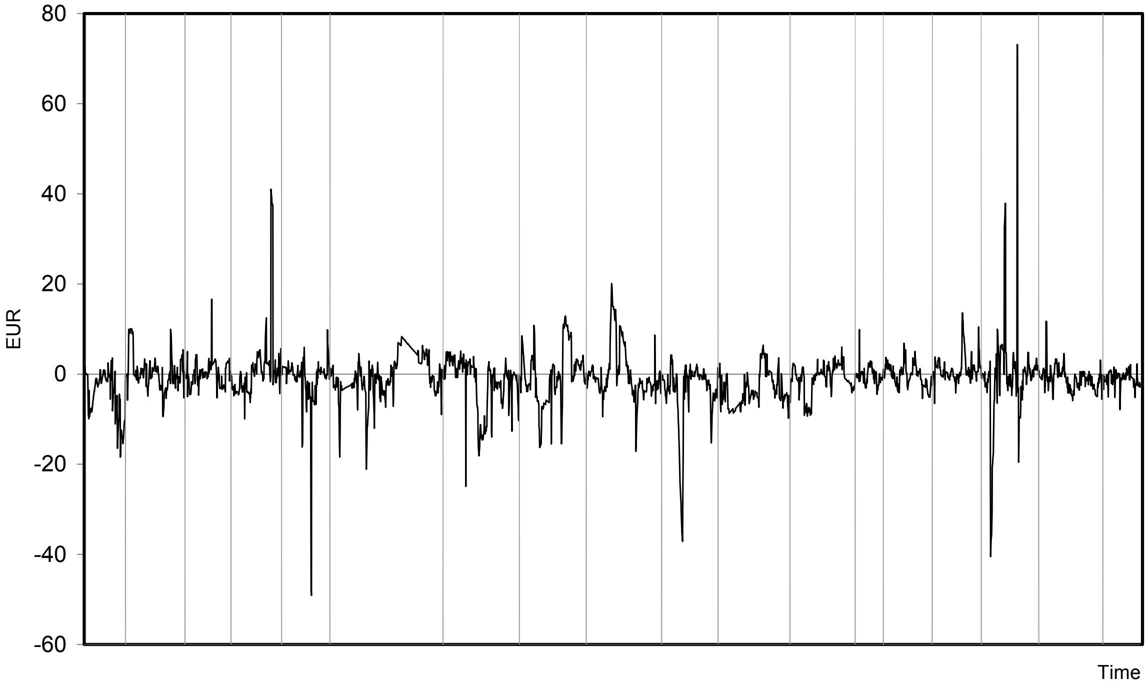

Figure 2: Intraday distribution of trades

The charts below show the average number of trades during each five-minute period of the trading day. Data come from a small bank in Germany and include all USD/EUR spot and forward trades during four months in 2001.

2A: Financial-customer trades

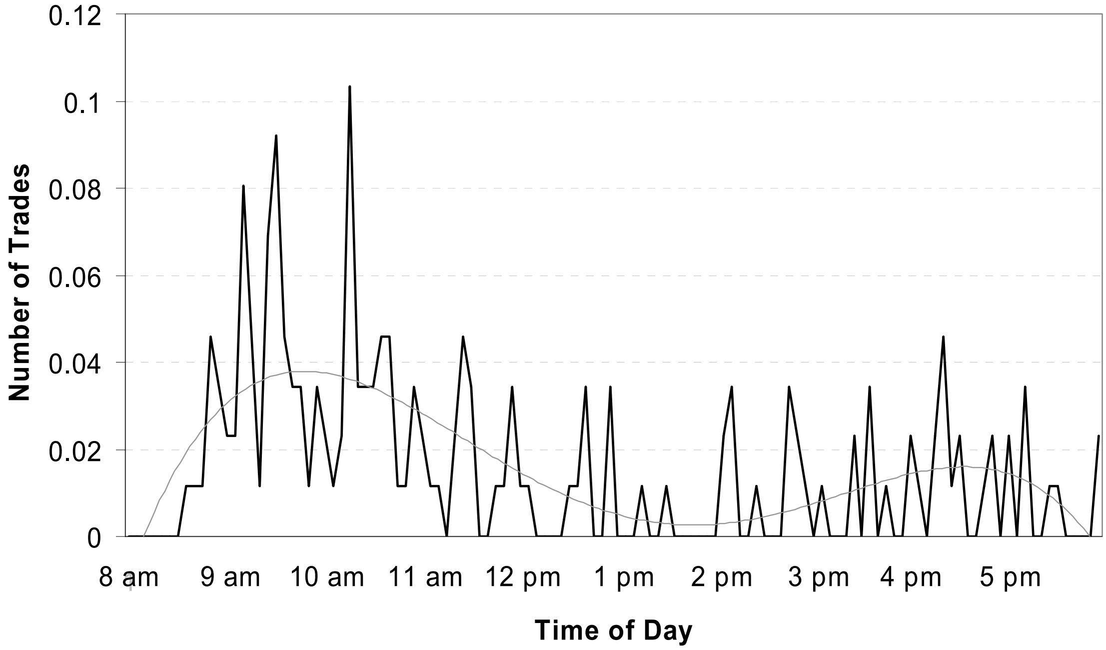

Figure 2B: Commercial-customer trades

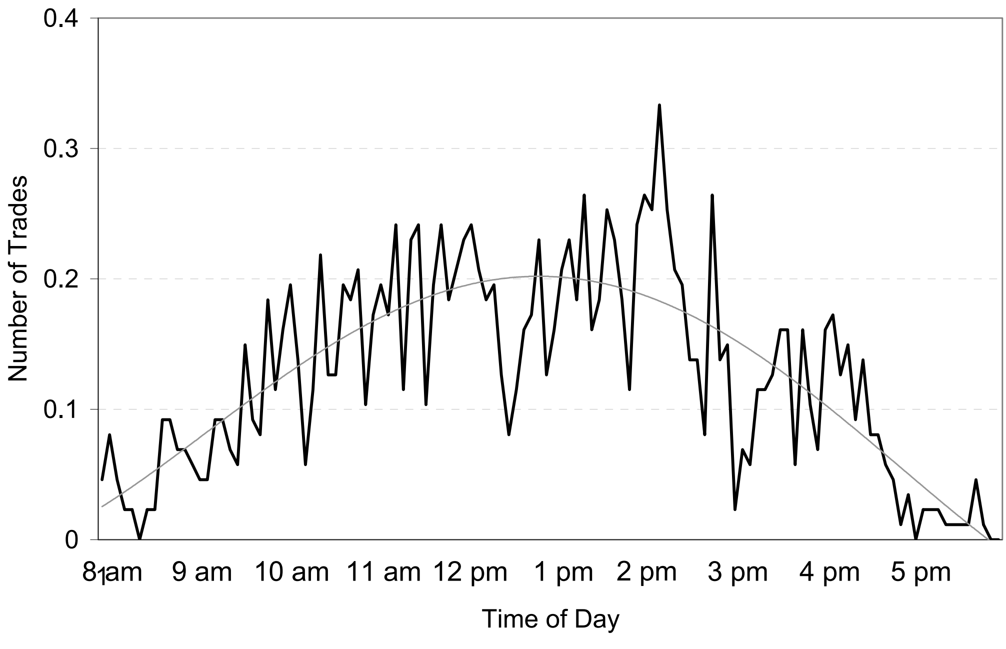

Table AI. Baseline Madhavan-Smidt model

We estimate this equation: $\Delta P_{it} = \alpha + \beta_1 D_t + \beta_2 D_{t-1} + \gamma_1 I_{it} + \gamma_2 I_{it-1} + \delta Q_{jt} + \varepsilon_t$.
The dependent variable is the change in price between two successive incoming trades measured in pips. Q_{jt} is order flow measured in EUR millions, I_{it} is the dealer's inventory at time *t,* and D_t is an indicator variable picking up the direction of the trade, positive for purchases (at the ask) and negative for sales (at the bid). These variables are interacted with dummy variables for the two counterparty groups, other dealers (*IB* for "interbank") and all customers (*CU*). Data include all incoming customer USD/EUR spot and forward trades of a small bank in Germany, except those with preferred customers, over the period July 11, 2001 through November 9, 2001. Estimation uses GMM and Newey-West correction. Significance at the 1, 5 and 10 percent levels indicated by ‡, † and *, respectively. Numbers in bold can be interpreted as the (negative of the) baseline half-spread.

	Baseline Regression		Robustness Tests		
			No Inventories	Spot Trades Only	Interbank Trades Excluded
	Coefficient	*Std. Error*	Coefficient	Coefficient	Coefficient
Constant	-0.590†	*0.23*	-0.426*	-0.383	0.070
Direction					
$CU \times D_t$	11.467‡	*0.50*	11.327‡	10.988‡	11.548‡
$CU \times D_{t-1}$	**-9.206‡**	*0.45*	**-9.186‡**	**-8.864‡**	**-10.025‡**
$IB \times D_t$	2.817‡	*0.69*	2.753‡	0.706	
$IB \times D_{t-1}$	**-1.579‡**	*0.48*	**-1.555‡**	**-1.025†**	
Inventory					
$CU \times I_{it}$	1.125‡	*0.38*		-0.064	0.855†
$CU \times I_{it-1}$	-1.264‡	*0.38*		-0.046	-0.974†
$IB \times I_{it}$	-0.259	*0.35*		-0.191	
$IB \times I_{it-1}$	0.133	*0.35*		0.187	
Trade size					
$CU \times Q_{jt}$	0.126	*0.39*	-1.001‡	-0.840‡	-0.001
$IB \times Q_{jt}$	-0.152	*0.40*	0.055	0.590	
Adjusted R^2	0.23		0.23	0.23	0.32
Observations	2,848		2,848	2,212	1,640

NOTES

[1] Our definition of a "customer" follows the market definition as any counterparty that is not another dealer.

[2] We show in Section IV that a similar analysis applies if the dealer uses direct trades to unwind his inventory.

[3] Electronic brokerages were not introduced until the early 1990s, so their dominance dates only from the late 1990s.

[4] The time stamp indicates the time of data entry and not the moment of trade execution, which will differ slightly. Nevertheless, there is no allocation problem because all trades are entered in a strict chronological order.

[5] Inventory calculations are based on all trades for all tests, including those in which our statistical analysis is restricted to subsets of the data.

[6] We exclude trades with "preferred customers", typically commercial customers with multi-dimensional relationships with the bank, because these customers' spreads may reflect cross-selling arrangements and because their trades are typically very small (average size EUR 0.18 million). We also exclude a few trades with tiny volumes (less than EUR 1,000) or with apparent typographical errors.

[7] The large mean absolute change in transaction price between successive trades, 10.7 pips, presumably reflects the relative infrequency of transactions at our bank as well as the high proportion of small commercial customer trades, which tend to have wide spreads (as we document below).

[8] It is also not possible to estimate spreads from matched pairs of trades. This technique is commonly used in analyzing bond markets (e.g., Goldstein *et al.* (2006), Green *et al.* (2004)), where trades can be identified by the amount traded, as in FX, and also by the particular bond.

[9] Fewer than ten of the customer trades in our sample exceeded $25 million. These trades were not excluded when calculating inventory levels.

[10] According to market participants, interbank trades on the electronic brokerages that now dominate that market are almost always $1, $2, $3, or $5 million.

[11] Market participants, whom we have questioned extensively, strongly support our qualitative conclusions here. Indeed, they assert that the pattern just identified approximates common knowledge within the FX market: The pattern is known by virtually everyone who trades, and virtually everyone who trades knows that virtually everyone else who trades knows it, etc. Only rank beginners might find the pattern unfamiliar, they claim.

[12] Huang and Stoll (1997) propose yet another explanation for the negative relationship between adverse selection costs and transaction size in their analysis of equity market spreads. We pass over this explanation since it relies on the special properties of block trades. We exclude all trades over $25 million from our regression analyses, so this explanation cannot explain our results. Further, the management of large trades is carried out quite differently in FX than in equity markets.

[13] As interpreted here, asymmetric information has two roles in the Duffie et al. (2004) model. First, dispersed/asymmetric information about current prices generates the need to search in OTC markets. Second, information asymmetries determine the agency relationships within customer firms, between management and their traders, that in turn determine whether execution is rewarded.

[14] Strategic dealing may be more relevant in FX than the municipal or corporate bond markets, since most such bonds trade relatively infrequently so the information value of any trade may be negligible.

[15] This pre-occupation with standard practice may bring to mind the issues of collusion on the NASDAQ raised in Christie and Schultz (1994). However, since there are literally hundreds of dealers in the major currency pairs, and they are spread across the globe, it seems highly unlikely that collusion could maintain FX spreads for decades.

[16] We are not the first to note that some price discovery happens in the interdealer market (Evans and Lyons 2006), but to our knowledge we are the first to note that price discovery *cannot* happen in the customer market, and that therefore *all* price discovery must happen in the interdealer market.

[17] The choice between limit and market orders will also hinge on market conditions, such as the width of the bid-ask spread and the depth of the book (Biais *et al.* (1995), Goettler *et al.* (2005), Lo and Sapp (2005)).

[18] Our conclusion that dealers will place outgoing/market orders after trading with "informed" customers is consistent with the finding of Bloomfield et al. (2005) that informed traders "take (provide) liquidity when the value of their information is high (low)." In their experimental setting information is most valuable when it is new. In FX markets, information is newest right after a dealer trades with an informed customer, which corresponds to the time we suggest the dealer will place the outgoing/market order.

[19] Though it would be ideal to develop a formal model of this price discovery mechanism, space constraints preclude presenting a fully articulated model in this paper. Indeed, the influence of information on order choice has only begun to be analyzed theoretically (Kaniel and Liu (2004)), in part because such models are of necessity extremely complex. These complexities will multiply when information is incorporated into a two-tier market structure.

[20] A more general framework would replace $|I_{it}|$ with $|I_{it}-I^*_t|$, the gap between actual and desired inventory. However, currency dealers' desired inventory is usually zero.

[21] These inventory management practices are consistent with practices at large banks (Bjønnes and Rime (2004)). Further extensive parallels between our bank's behavior and that of large banks are documented in the Appendix.

[22] This preference is supported by the transactions data. Our dealer's mean interbank transaction size was only €1.42 million (Table 1), the maximum interbank trade size was only € 16 million, and the standard deviation of these trade sizes was only €1.42. These small values are consistent with heavy use of EBS, where the mean USD/EUR transaction size in August 1999 was €1.94 million and the standard deviation of (absolute) transaction sizes was €1.63 million. By contrast, interbank trades averaged closer to $4 million prior to the emergence of electronic brokerages (Lyons (1995)).