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Joshua V. Rosenberg
Leah G. Traub

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Abstract

In this paper, we compare price discovery in the foreign exchange futures and spot markets during a period in which the spot market was less transparent but had higher volume than the futures market. We develop a foreign exchange futures order flow measure that is a proxy for the order flow observed by Chicago Mercantile Exchange pit traders. We find that both foreign currency futures and spot order flow contain unique information relevant to exchange rate determination. When we measure contributions to price discovery using the methods of Hasbrouck (1995) and Gonzalo and Granger (1995), we obtain results consistent with our order flow findings. Taken together, our evidence suggests that the amount of information contained in currency futures prices in 1996 is much greater than one would expect based on relative market size. Using data from 2006, we obtain quite different results, perhaps because of an increase in spot market transparency. In particular, we find in our more recent sample that the spot market has the dominant information share.

Key words: price discovery, exchange rates, order flow, futures, microstructure, foreign exchange

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Rosenberg: Federal Reserve Bank of New York. Traub: Lord Abbett Quantitative Research. Address correspondence to Joshua V. Rosenberg (e-mail: joshua.rosenberg@ny.frb.org). The authors thank Torben Andersen, Bruno Biais, Michael Fleming, Joel Hasbrouck, John Kambhu, Pamela Moulton, Christopher Neeley, Clara Vega, and seminar participants at the Federal Reserve Bank of New York and the Board of Governors of the Federal Reserve System for helpful comments.

1. Introduction

The relatively small size of the currency futures market compared to the over-the-counter (OTC) spot market suggests that the futures market might not play an important role in price discovery.[1] According to the 2004 BIS Triennial survey, average daily volume in exchange-traded currency products totaled 23 billion compared to 1,345 billion in over-the-counter products.[2] It is possible that price discovery in foreign exchange occurs exclusively in the OTC spot market and that futures prices quickly adjust to spot price changes through covered interest parity without adding significant information in the price determination process.

However, the foreign currency futures market's role might be larger than its relative size would indicate. The wide range of futures market participants (from hedge funds to corporate hedgers), centralized location, anonymity of counterparty identity, and high level of price transparency suggest that futures trading could potentially aggregate a rich source of private information. In this paper, we investigate the importance of the futures market in exchange rate determination, focusing on the information content of futures order flow and the role of the futures market in foreign currency price discovery.

Combining foreign currency spot and futures data for four major currencies in 1996, we find that futures order flow contains incremental information for spot returns above what is revealed in spot order flow. For this analysis, we use the same interdealer spot order flow data as Evans and Lyons (2002b) augmented with our own estimates of futures order flow.

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[1] Lyons (2001) states: "In FX, however, the futures market is much smaller than the spot market; it is unlikely that a significant share of price determination occurs there (Dumas 1996)." (p.113)

When we look at the short-term relationship of price changes across markets in our 1996 sample, we find that spot prices do not lead futures prices for any of the currencies studied, but British Pound and Swiss Franc futures prices lead their respective spot prices by up to 12 minutes. For foreign exchange price discovery over a longer horizon, we identify futures market information shares averaging between 80 and 90 percent using the approaches of Hasbrouck (1995) and Gonzalo and Granger (1995). Taken together, our evidence suggests that in 1996 the amount of information contained in currency futures prices is much greater than one would expect based on relative market size.[3] However, in 2006, the spot market has the dominant information share, reflecting perhaps the dramatic increase in spot market price transparency in recent years.

Why might a trading venue with lower market share have a disproportionate influence in price determination? The predominant answer given in the literature is because an alternative trading venue attracts a large share of informed traders. Specifically, informed traders may prefer a satellite market if it offers greater anonymity of trader identity or higher speed of transaction execution. Evidence along these lines is presented in Huang (2002), Barclay, Hendershott and McCormick (2003), Hasbrouck (2003), and Kurov and Lasser (2004). Informed traders might also favor a derivative security traded on a secondary venue if the derivative security has appealing characteristics, such as lower transactions costs or greater leverage. See, for example, Fleming, Ostdiek and Whaley (1996) and Easley, O'Hara and Srinivas (1998).

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[2] Results are similar using the 1996 BIS survey which corresponds more closely to our earlier sample period: 70 billion futures and 1.1 trillion spot.

[3] Consistent with this result, Hasbrouck (2004) reports a significant price impact for currency futures trades, and comments that "…the futures market may be serving as the primary forum of public price discovery (p. 321)." Along similar lines, in a recent paper, Mizrach and Neeley (2005) find that price discovery for Treasury bonds occurs in both the spot and futures market.

We are not able to offer direct evidence on the speed of execution in foreign currency futures versus spot markets. However, we do know that the institutional structure of the currency futures market preserves anonymity of the dealer's identity with the trade counterparty (when a dealer executes through a broker), while interdealer spot market does not. In the foreign exchange futures market, the counterparty to each side of a trade is the futures clearinghouse so trader identity is not revealed, even at settlement. By contrast, in the foreign exchange spot market, a dealer's identity is disclosed when a quote is requested or given (direct trading) or when the trade is complete (indirect trading).

Our results are compatible with foreign exchange traders choosing their trading venue based on trade type as documented in Bjonnes and Rime (2005).[4] A foreign exchange dealer might route the majority of information-based (proprietary trading desk) trades through the futures market and non-information-based (position rebalancing) trades through the spot market. Informed traders with more limited access to the OTC spot market, such as hedge funds, might more generally transact in the futures market instead of the spot market.

A second reason that a satellite market might be important in the price discovery process is a higher level of price transparency than the primary market. As noted in Madhavan (2000), "[Transparency] affects the informativeness of order flow and hence the process of price discovery. Greater transparency is generally associated with more informative prices (p. 241)."[5] However, informed traders may prefer to execute on a less

[4] Trading choice between more and less transparent markets is analyzed in Drudi and Massa (2005) using data on Italian Treasury bonds.
[5] Hendershott and Jones (2005) also show that Island's share of equity price discovery falls after it stops displaying its limit order book, which reduces price transparency. Island's share of price discovery increases when it redisplays its order book. Island is an Electronic Communication Network (ECN) on which Nasdaq shares are traded.

transparent primary exchange in order to extract greater profits from their private information as discussed in Bloomfield and O'Hara (1999) and Biais, Glosten and Spatt (2005).

In the context of foreign exchange, Rime (2003) points out the relatively low level of price transparency in interdealer direct trading (which is the market segment analyzed in Evans and Lyons (2002b)) prior to the emergence of electronic brokerage in the late 90's. The growth in trading on electronic brokerage systems, primarily Reuters Dealing 2000 and EBS, led to a dramatic increase in spot market transparency, since these systems report spot transactions prices in real time to participating dealers and also offer data feeds to other customers.

An additional contribution of our paper is the development of a direct measure of currency futures order flow as a proxy for the order flow observed by traders in the futures pits.[6] Because futures markets do not disseminate information on whether pit trades are buyer or seller initiated, we develop an extension of the quote rule trade-signing algorithm of Hasbrouck and Ho (1987) and Hasbrouck (1988). Since best bid and ask futures quotes are not consistently recorded by the futures exchange, we use forward quotes as a proxy for futures quotes. We then classify a currency futures transaction as buyer initiated if it is

[6] Hasbrouck (2004) implements a Markov chain Monte Carlo approach to infer a probability distribution over futures trade direction. His analysis focuses on the measurement of transactions costs across different futures contracts. Goodhart, Chang and Payne (1997) attempt to extract transaction types from Reuters quote data, but find that the performance of transaction generating algorithms is poor. Klitgaard and Weir (2004) analyze changes in the weekly net speculative futures position reported to the Commodity Futures Trading Commission. Their measure can be interpreted as futures order flow if speculators are trade initiators. Similarly, Rime (2001) uses a U.S. Treasury dataset of weekly changes in foreign currency positions held by large banks as a proxy for order flow. However, when using weekly position changes, it is difficult to distinguish trend-following behavior in which flows lag prices from a contemporaneous relationship between flows and prices.

above the corresponding currency forward midquote and as seller initiated if it is below the midquote.

Much of the existing theoretical and empirical microstructure literature on foreign exchange markets focuses on the interdealer direct market and, more recently, the interdealer electronically brokered market. Our work suggests that, perhaps, additional attention might be usefully directed at the futures market, since this market plays an important role in price discovery. Existing models of direct interdealer trade — e.g., Lyons (1996) and Evans and Lyons (2002b) — focus on the order flow that is seen by dealers. We posit that it may be important to also take account of the order flow directly observed by pit traders.

The remainder of the paper is organized as follows. In Section 2, we briefly describe our futures and spot data and the construction of futures order flow. Section 3 compares the information content in futures and spot foreign currency trading. Section 4 contains a full description of our futures trade-signing algorithm and describes several robustness checks. Section 5 concludes. The appendix provides additional empirical analyses of our constructed futures order flow over a long and recent sample.

2. Data

2.1 Currency futures market data

One of the most liquid foreign currency futures markets in the world is the International Monetary Market division of the Chicago Mercantile Exchange (CME). At the CME, futures are traded by open outcry on the floor of the exchange and also electronically on the Globex trading system. As transactions occur on the floor of the exchange in futures pits, market reporters relay transaction prices to computer operators. This information is nearly instantaneously transmitted worldwide via electronic quotation systems. For each futures contract, these transactions are the basis for the CME's Time and Sales record, which consists of a trade price, a trade time, and occasionally a supplementary informational code. Our futures dataset is constructed using these Time and Sales records.

One drawback of the Time and Sales record for our purposes is that this data does not include a trade sign indicator that can be used to calculate order flow. Therefore, to estimate futures order flow, we use a modified version of the quote rule. The quote rule is based on a stylized market in which a dealer sets bid and ask quotes and market participants transact at these quotes, e.g., Hasbrouck and Ho (1987) and Hasbrouck (1988). In this setting, buyer initiated trades occur at the ask, while seller initiated trades occur at the bid. Trade direction is inferred by comparing transactions prices and quotes. Hasbrouck (1991) generalizes this approach to deal with quotes inside or outside the spread. Trades above the quote midpoint are classified as buyer initiated, while trades below the midpoint are classified as seller initiated. Trades at the midpoint are not signed.

In open outcry futures trading, there is no official, publicly-available record of the best prevailing bid and offer.[7] This impedes application of the quote rule to futures trade signing. To overcome this problem, we exploit the tight linkage between forward and futures markets (see Section 4.2 for a discussion and tests of the futures-forward relationship). In particular, we use the observed forward midquote as an estimate of the

[7] In pit trading, a bid or offer is made by stating price and quantity and making a corresponding hand signal. New bids or offers can only be made if they improve on current prices. Bids and offers can be withdrawn at any time prior to acceptance. (CME rulebook, 521.A, 523).

futures midquote. A futures transaction is determined to be buyer initiated and assigned a value of +1 if it is above the midquote and seller initiated, with a value of -1, if it is below the midquote.[8] Daily order flow is equal to the sum of buyer and seller initiated trades over regular trading hours. Our approach is most applicable when there is a liquid futures and forward market for a given asset, and forward and futures prices are equal (at least in expectation). Section 4.1 explains our trade signing methodology in more detail.

Our primary sample covers the periods from May to August 1996 and from March to May 2006. The first subsample corresponds to the time period examined in Evans and Lyons (2002b), which allows us to use their spot data as a comparison. The second period is used for a more recent comparison of spot and futures market price discovery. The source for all Time and Sales data is the CME except the Deutsche Mark for the earlier period. That data is from the CQG DataFactory. Additionally, in our more recent sample, we collect time and sales data for electronically-traded currency futures on the CME's Globex trading system.

Since our dataset only includes transactions conducted on the floor of the CME, we analyze futures trades over CME Regular Trading Hours (RTH), which are between 7:20am and 2:00pm Central Time (CT). Trading only occurs on weekdays, excluding holidays. Trade prices are quoted in foreign currency per dollar. Our first subsample includes four currencies: Deutsche Mark, Japanese Yen, Swiss Franc and the Pound. In our second subsample, the Deutsche Mark is replaced with the Euro.

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[8] We delete futures trades that occur at exactly the forward price, while the Lee and Ready (1991) algorithm would sign these trades using the tick rule. In our dataset, these trades are exceptionally rare. The highest frequency of futures trades occurring at the matching forward price is only 1 out of 37,110 in the 1996 sample and 87 out of 1,093,992 (0.01%) in the longer 1999-2005 sample. Most of the misclassified equity trades identified in Odders-White (2000) and Ellis, Michaely and O'Hara (2000) occurred inside the spread or at the

While futures trading hours cover only about 1/3 of the trading day and account for about 1/4 to 1/3 of spot trades (see Table 1), this period of time overlaps with the releases all of the 25 U.S. major news announcements analyzed in Andersen, Bollerslev, Diebold and Vega (2007). The majority of these releases are at 8:30am, and the remainder are spread across the day with 5 releases at 10am and the remainder after 2:00pm. In terms of macroeconomic news headlines, futures regular trading hours account for 46% of headlines over the entire trading day, based on data from Evans and Lyons (2002c). Of the 46%, 30% of headlines are before 11am and 16% are after 11am.

2.2 Currency spot market data

The currency spot market data in our earlier sample (May to August 1996) is from the website of Martin Evans and is described extensively in Evans (1998).[9] This dataset is comprised of interdealer direct spot transactions from the Reuters Dealing 2000-1 system. Trades are recorded 24 hours a day. The vast majority of trading occurs on weekdays but there is occasionally some trading on the weekends. According to Evans and Lyons (2002b), this data accounts for about 50% to 60% of interdealer spot transactions over the sample period. The dataset consists of a time-stamped record of the transactions price, a bought or sold indicator (the trade sign) and a measure of cumulative dollar trading volume. Unlike with electronic brokerage, dealers trading on this bilateral system only see their own trades and cannot observe other transactions.

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exact midpoint of the prevailing quote. Excluding the trades at the midpoint may improve the accuracy of the signing algorithm.

[9] This is the same data used in Evans (2002) for the Deutsche Mark.

To create a spot order flow measure that is comparable with the futures order flow measure described above, we assign a value of +1 to each buy trade and -1 to each sell trade. Full-day spot order flow is then equal to the sum of the trade signs over a 24-hour period ending at 2:00pm Central Time. Since the spot transactions are recorded in British Summer Time, we subtract six hours from the trade time to match Central Time. For direct comparison with futures order flow over regular trading hours, we also calculate the amount of spot order flow each day from 7:20am to 2:00pm Central Time.

For the Deutsche Mark, Yen and Swiss Franc markets, spot transactions are in terms of dollars per foreign currency, which means that a positive value for spot order flow indicates a net purchase of dollars. The Pound and Euro spot transactions are quoted in terms of the foreign currency, as are all futures transactions. In our comparisons between the spot and futures market, we use the spot market conventions. This means that we take the negative of our futures order flow for the Deutsche Mark, Yen and Swiss Franc.

To provide a more recent comparison of spot and futures price discovery, we obtain spot market quotes from Bloomberg over the period from March to May 2006 for the Euro, Yen, and Pound. Bloomberg provides a continuously reported best mid-quote for each currency using indicative prices of a screened group of contributors (currently 83 dealers) who are required to produce “valid and current” prices. The current composite quote is the mid-point of the best bid and offer in the last 30 seconds. We download composite spot quotes at 1 minute intervals from an “Open Bloomberg” terminal using the Intraday Data Wizard.[10]

2.3 Comparison of futures and spot market characteristics

In Panel A of Table 1, we report measures of market share comparing Reuters spot direct-dealing with CME futures trading from May through August 1996.[11] In terms of the number of trades per day, we see many more in the spot market than futures market. However, when only comparing spot trades during regular futures trading hours (the column labeled Spot RTH), there are more futures trades than spot trades for all currencies except the Deutsche Mark. For example, on average, there are 1813 Yen spot trades over the full day, 463 Yen spot trades during futures regular trading hours, and 957 Yen futures trades during futures regular trading hours.

Table 1 Panel A also shows the average trade size in terms of millions of U.S. Dollars.[12] Although spot trades tend to be larger than futures trades, the futures trades are not too far behind. As an example, an average Deutsche Mark trade is about $3.5 million in the spot market compared to $2.7 million in the futures market. Market shares based on dollar volume show that over the full day, the spot market is dominant with shares ranging from 63% to 85%. However, over futures regular trading hours, the futures market share is greater than 50% for 3 of the 4 currencies we analyze. Note, however, that trading on

[10] We are grateful to Bloomberg L.P. for permitting us to use this data. Additional detail about this data is provided on the Bloomberg Currency QFX page.

[11] The fewer number of days with any trades recorded in the spot market reflects a feed interruption caused by a power failure that occurred at the end of June 1996 as noted by Evans (1998).

[12] The average dollars per futures trades is calculated by dividing Datastream daily futures contract volume by the average daily number of trades and multiplying by the closing exchange rate and futures contract size. The average dollars per spot trade is calculated using the cumulative dollar volume measure in the Evans (1998) dataset. This value is indicative of the amount of dollar sales that has occurred thus far in the trading day. We divide the average cumulative dollar volume at the end of the day by the average number of trades to get the average dollars per trade.

Reuters Dealing 2000-1 is only a fraction of total interdealer spot trading, so total spot would have a significantly larger market share than that reported in the table.[13]

Descriptive statistics for spot returns are given in Table 1 Panel B. Since futures regular trading hours end at 2pm CT, we use the log-difference of 2pm spot quotes to create daily returns. Characteristics of daily futures and spot order flow are shown in Panels C and D, respectively. We see that futures order flow is more volatile than spot order flow; this is what we expect given that futures order flow is estimated with error. We also see higher autocorrelation in spot order flow than futures order flow.

More importantly, futures and spot order flow are positively correlated with each other. Spot order flow over the full day and futures order flow over futures trading hours have a correlation coefficient from 0.38 to 0.65, as reported in the last column of Table 2, but when spot order flow is limited to futures regular trading hours the correlation increases to a range of 0.69 for the DM to 0.81 for the Yen. Figure 1 shows a scatter plot using futures and spot regular trading hours order flow from May through August 1996 that visually confirms this relationship. While spot and futures order flow clearly have a common component, they do not move together one-for-one.

3. Price discovery in the currency futures and spot market

3.1 Information content of futures and spot order flow

Evans and Lyons (2002b) measure the information content of interdealer spot currency order flow by regressing currency spot returns on order flow.[14] They find that

[13] Reuters Dealing 2000-1 is estimated to account for about 90% of direct interdealer trading, while direct interdealer trading is about 60% of total interdealer spot trading (Evans and Lyons, 2002, *fn*. 7).

order flow explains 63% of the variation in the daily Deutsche Mark spot returns. In their portfolio shifts model, interdealer order flow moves prices, since it is the mechanism through which nonpublic pricing-relevant information is revealed. We are interested in testing whether futures order flow can also move prices because customers or dealers with private information are implementing futures trading strategies using this information. Private information could result from proprietary information such as customer orders or superior analysis of the implications of public news releases. We follow the Evans and Lyons (2002b) order flow regression methodology as the basis for our analysis, but we use both spot and futures order flow to explain daily spot returns.

We note that it is possible that all price discovery in foreign exchange occurs in the spot market and that futures prices merely respond to spot prices via the covered interest parity (CIP) relationship.[15] If this is the case, then there is no reason for futures order flow to be correlated with spot exchange rate returns, and we would not find a statistically significant relationship when we regress spot returns on futures order flow. Or, futures order flow could simply represent the same information as spot order flow. In that case, we would initially see a significant relationship between futures order and spot returns, but once we control for spot order flow, this relationship would disappear.

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[14] They also include interest rate differentials and changes in interest rate differentials as controls. These variables are not found to be significant in most of their specifications.

[15] Covered interest parity is a no-arbitrage relation that sets the difference between the prices of a forward contract and the spot exchange rate equal to the foreign and domestic interest rate differential. Baum and Barkoulas (1996) point out that this relationship should also hold for the price of an identically timed futures contract on the foreign currency if daily mark-to-market effects are small. A number of papers have found the CIP relationship to be relatively well supported by currency forward contracts. Taylor (1987) and Taylor (1989) report that other than in periods of high market turbulence, the CIP condition was satisfied for the dollar-sterling and associated Eurodeposit rates over a variety of maturities and time periods. Rhee and Chang (1992) also find very few cases of profitable two-way arbitrage opportunities (breakdown of CIP) in the Pound, Mark, Yen and Swiss Franc.

To test these hypotheses, we estimate four sets of regressions of daily spot returns on order flow for each currency.[16] Results are shown in Table 2. First, in rows (i), (v), (ix), and (xiii) of Table 2, only the full-day spot order flow is used as the independent variable; this is the standard Evans and Lyons (2002b) regression. Our results are quite similar to those reported previously. For example, in row (i), the estimated coefficient on Deutsche Mark spot order flow implies that a day with 1000 more dollar purchases than sales increases the spot exchange rate by 2.2% compared to 2.1% in Evans and Lyons (2002b).

In the second set of regressions, spot order flow is divided into futures regular trading hours (7:20am – 2pm CT) and non-regular trading hours components. This helps to control for possible differences in liquidity over the trading day, e.g., Danielsson and Payne (2002). Looking at rows (ii), (vi), (x), and (xiv) in Table 2, we see higher coefficients on spot order flow over futures regular trading hours than for the rest of the day, which may indicate that there is more information production for these exchange rates during the U.S. business hours than European and Asian business hours. As shown by the increases in adjusted R-squareds from the first set of regressions, breaking spot order flow into these two components does seem to add additional information for spot returns, especially for the less liquid currencies, the Pound and Swiss Franc.

For the third set of regressions, we regress daily spot returns on futures order flow. This is our preliminary test of the importance of the futures market for spot price discovery. In rows (iii), (vii), (xi), and (xv) of Table 2, we find a positive, statistically significant effect of futures order flow on spot exchange rate returns. This confirms that there is

[16] The spot market conventions are used so that order flow is measured in terms of dollars the Deutsche Mark, Yen, and Swiss Franc, and the spot exchange rate is the foreign currency price of one dollar. Pound order flow is in terms of Pounds and the exchange rate is Dollars per Pound.

market relevant information in futures order flow. Furthermore, for the Pound and Swiss Franc, futures order flow has a larger explanatory power for spot returns than spot order flow. In the next table we explore whether this result could be due to a potential errors in variables issue.

Since futures and spot order flow are correlated, it is possible that the information in futures order flow is the same as that in spot order flow. To test this possibility, our fourth set of regressions in rows (iv), (viii), (xii), and (xvi) of Table 2, includes spot and futures order flow. We see that futures order flow remains positive and statistically significant for all four currencies, which indicates that there is indeed different information in the futures market that contributes to price discovery in the spot market.

In these regressions, coefficients on spot RTH and futures RTH order flow decline when both variables enter at the same time, since they are capturing a common effect to some extent. For the Yen, Swiss Franc and Pound, the coefficient on spot RTH order flow declines so much as to become insignificant or barely significant at the 5% level, indicating that almost all of the information over futures regular trading hours comes through futures trading instead of spot trading. If we focus on price discovery over futures regular trading hours rather than the full day (not shown), price impact coefficients on futures order flow remain significant for all four currencies. Also, with returns only over regular trading hours, futures order flow makes spot order flow insignificant in the Yen and Swiss Franc models.

We next re-estimate our Table 2 models using two-stage least squares to correct for possible regression coefficient bias due to futures order flow estimation error. The instrument we use is futures order flow obtained using the tick rule, which we expect would not be correlated with the estimation error in futures order flow based on the quote rule. In the tick rule, a futures trade is signed a buy if it occurs at a higher price than the previous trade and a sell if it occurs at a lower price. Order flow is then calculated as the sum of the signed trades over regular trading hours. Results of these instrumental variable regressions are shown in Table 3.

We see that when futures order flow is included by itself in the spot return regressions, the estimated coefficients remain positive and statistically significant. There is no change in the order flow coefficient for the DM, while the order flow coefficients increase for the other three currencies. The adjusted R-squared increases for the DM but falls for the other currencies. Comparing this regression to the ones in the first two rows of Table 2 for each currency, we see that now the explanatory power of spot order flow is greater than futures order flow when each market is included separately in the regression. Thus, the quote rule seems to be causing a small, positive spurious relationship between spot returns and futures order flow for the three less liquid currencies. When we include spot order flow in the regression, again we see an increase in the R-squared, as compared to the Table 2, for the DM, but a decrease for the other currencies. Spot order flow is now highly significant over both regular and non-regular trading hours for all currencies and futures order flow remains positive and statistically significant.

3.2 Short-term price discovery in currency futures and spot markets

Previous papers have examined short-term price discovery in the foreign exchange market by comparing correlations of intraday leads and lags of Reuters FXFX indicative quotes with either currency futures prices or over-the-counter spot transactions prices.[17] In this section, we focus on short-term price discovery as revealed by the relationship between spot and futures transactions prices.

To compare the role of the futures and spot markets in price discovery, we use the same three month period in 1996 as analyzed in Section 3.1 as well as a three month period in 2006. Spot prices are from interdealer direct spot transactions on the Reuters 2000-1 system for the older period or from Bloomberg for the more recent period, and futures prices are from the CME Time and Sales reports. We take log differences of the first and last transaction prices in each 3-minute interval to create a series of spot and futures returns over futures regular trading hours. This is the smallest time period over which most intervals in our sample contain at least one trade.[18]

We then compute the correlations of the 3-minute spot return with leads and lags of the 3-minute futures return. Our results for the 1996 sample are shown in Figure 2. In this figure, the correlation at zero is for contemporaneous spot and futures returns, correlations to the left of zero are for futures returns that lead spot returns, and correlations to the right of zero are for spot returns that lead futures returns.

For all four currencies, we find evidence that futures returns lead spot returns by up to 12 minutes. We can see this from the positive and statistically significant correlations to the left of zero. For example, as shown in Panel B, a Yen spot return has a correlation of

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[17] Martens and Kofman (1998) show that Reuters FXFX indicative quotes lag futures transaction prices by about 3 minutes. Danielsson and Payne (2002) find that Reuters FXFX indicative quotes lag transactions prices on Reuters D2002-2 by up to 3 minutes. Hutcheson (2003) analyzes the lead-lag relationship between GLOBEX Euro-FX prices and Reuters Dollar-Euro spot quotes using intraday data over a two-week period in 2002 and finds that the spot returns lead futures returns by five minutes. This type of analysis is also closely related to Garbade and Silber (1979) and Garbade and Silber (1983).

[18] We repeated our analysis using a 1-minute interval. Due to the large number of intervals with a zero return, the results were noisier than those presented here, but still fairly consistent.

about 0.12 with a futures return three minutes earlier. These correlations decline, but are still statistically significant, for Yen futures returns as much as 9 minutes before the Yen spot return.

We find little evidence, however, that spot returns lead futures returns. Looking at points in these graphs to the right of zero, few correlations are statistically significant. Since this pattern is similar for all four currencies, the futures market appears to dominate in terms of short-term price discovery over the 1996 period. We also note that there will be some cross-sectional variation in spot prices available to different dealers at any point in time. Therefore, the predictability of spot returns calculated from transactions data for multiple dealers does not necessarily imply that prices that a particular dealer faces are predictable.

Interestingly, over the more recent period in 2006 (Figure 3), the results are quite different. Looking at the correlations of spot returns with floor-traded futures returns (solid line) or electronically-traded futures returns (dashed line), we see that the spot and futures market have become more tightly linked. Contemporaneous spot and futures correlations in the earlier period were in the range of 0.25 to 0.35, but, in the more recent period these correlations increase to nearly 1.0.

In 2006, there also seems to be more price discovery in spot trading than futures pit trading, but less price discovery in the spot trading than in electronic futures trading. In particular, DM and Pound spot returns lead floor-traded futures returns as indicated by the black circles at plus 3 minutes with correlations above 0.20. Floor returns lead spot returns only for the Euro (black circle at minus 3 minutes in Panel A), and the correlation is less than 0.05. In comparison to Figure 2, these results suggest that there may have been a change in market structure that increased the information content of spot trades relative to floor-traded futures.

In addition, our findings are consistent with a shift of information-based futures trading from the pit to the Globex electronic trading system. Specifically, Globex futures returns lead spot returns by 3 minutes for all three currencies (solid triangles at -3 minutes). The correlations, however, are low. Spot returns do not lead Globex returns for any of the currencies.

3.3 Long-term price discovery in currency futures and spot markets

Hasbrouck (1995) proposes using a vector error correction model to measure contributions to long-term price discovery across markets. In this section, we follow his approach and estimate a model containing three lags of both the 3-minute currency spot and futures prices (the minimum number of lags needed to eliminate serial correlation in the residuals). One model is estimated for each day and currency in our sample. The length of our samples (4 months in 1996 and about 2 months in 2006) is relatively similar to a number of other papers that use a VECM approach to measure price discovery. For example, Hasbrouck (1995) and Hasbrouck (2003) both analyze samples that are 3 months long.

Covered interest parity predicts that the difference between the spot and future price will vary over time in response to changes in domestic and foreign interest rates. Like Hasbrouck (2003), our VECM specification is includes a constant in the error correction term. Because the model is estimated daily, this setup allows the basis to vary from day to day.

The estimated coefficients on the cointegrating term and the residual covariance matrix are used to construct upper and lower bounds for the Hasbrouck information share. The upper bound of the futures (spot) information share is calculated by putting the futures (spot) price first in the Cholesky ordering and the lower bound is calculated by putting the futures (spot) price last in the ordering. The formulas we use to construct the upper and lower bounds of the Hasbrouck information share are given in Baillie (2002). Using the vector error correction coefficient estimates, we also calculate the Gonzalo and Granger (1995) common factor component weights.[19]

In Table 4 Panel A, we show summary statistics for information shares using averages of daily estimates for the 1996 sample. According to the Hasbrouck method, the Deutsche Mark 3-minute spot transactions price only contributes 4% to 9% of the total price information in both the futures and spot markets, while the 3-minute futures price contributes the remaining 91% to 96%. The common factor weight for the Deutsche Mark spot market is 11% versus 89% for the futures market.

Looking at all of the currencies, the highest information share for the spot market is for the Pound at 22% to 31%. The lowest spot information share is 4% to 8% for the Yen. These results suggest that the currency futures market plays a dominant role in price discovery over futures regular trading hours in 1996.

These results are essentially reversed for the 2006 sample as shown in Panel B of Table 4. The spot market has the most important role in price discovery for the Euro, Yen, and Pound. GG common factor weights for the spot market are 89%, 89%, and 83%, and

[19] Let a_1 denote the estimated coefficient on the cointegrating term in the spot equation and a_2 denote the estimated coefficient on the cointegrating term in the futures equation. The Gonzalo-Granger common factor

Hasbrouck information share upper bounds are 96%, 94%, and 95%. Not surprisingly, perhaps, our findings on long-run price discovery show the same shift of information from the futures to spot market that we saw for short-run price discovery in the previous section. When we compare electronic futures trading to spot trading, we see that the futures market information shares generally increase, but the spot market still retains its dominance.

4. Signing currency futures trades

4.1 Methodology

Section 2.1 briefly outlined our use of the quote rule to sign futures trades, while this section describes our methodology in detail. We choose the quote rule over alternative trade signing algorithms, because the quote rule has been found to be the most reliable classification technique in several empirical comparisons.[20] However, there have been no tests of these algorithms conducted specifically on futures data, perhaps due to the absence of data on the actual futures trade sign.

Since regularly reported best bid and ask quotes are not available for the futures market, we implement the quote rule using forward quotes to sign futures trades. There are two adjustments we need to make to match the maturity and timing of the forward quotes to futures trades. Futures contracts typically have standardized maturity dates (e.g. the third

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weight for the futures market is then equal to $1 / (1 + a_2/a_1)$. The common factor weight for the spot market is one minus the futures share.

[20] Lee and Ready (1991) (LR) classify trades inside the spread using the tick test (sign a trade as a buy [sell] if the transaction price is higher [lower] than the preceding transaction price) and other trades using the quote rule. Ellis, Michaely and O'Hara (2000) develop an algorithm that uses the quote rule for trades occurring at the bid or ask quote and the tick test for all others. Odders-White (2000) finds that the quote rule misclassifies only 9% of NYSE trades compared to 21% for the tick test, and 21% for Lee and Ready algorithm. Savickas and Wilson (2003) calculate the percentage of option trades signed correctly by the quote rule, tick test, and LR algorithm as 83%, 59%, and 80%, respectively. Moreover, both of these papers find that the LR algorithm performs worse for trades inside the spread, exactly when the tick test is used rather than the quote rule.

Wednesday of March, June, September, and December) while forward contracts have standardized maturity lengths (e.g., 1 month, 3 months, 6 months, 9 months). Previous studies that compare futures and forward prices tend to throw out dates with non-matching maturities.

To avoid loss of significant amounts of data, we create a matching maturity forward contract for any outstanding futures contract by taking the weighted average of the prices of the two forward contracts with the closest maturities to the futures contract, using the difference in maturities as weights. More complicated approaches based on fitting non-linear functions to the forward term structure are also possible. In the next section, we perform several robustness checks with regard to the construction of the forward premium.

For the purpose of applying the quote rule, one would ideally observe an active quote just before the trade occurs (Lee and Ready, 1991). In a continuous market, trade data is characterized by irregular observation frequency since a trade can occur at any time. By contrast, forward quotes are sometimes measured at regular intervals as a snapshot of the state of the market. For example, in our data we observe forward quotes every fifteen minutes. So, to implement the quote rule, we compare the transactions price to the quoted price at the beginning of each fifteen minute interval. We investigate the sensitivity of our results to the timing of the forward quote in the next section.

4.2 Tests of the futures trade signing algorithm

In this section, we run tests to ensure that using a forward quote up to fifteen minutes prior to the futures transaction does not affect our results. To explore whether there

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However, Ellis, Michaely and O'Hara (2000) find that NASDAQ trades tend to be classified most accurately is a persistent forward versus futures price differential that could influence our results, we re-estimate the futures trade sign using an adjusted forward quote. Specifically, we subtract the average futures-forward price differential in our sample from each forward quote and then sign the futures trade using the adjusted quote.[21] Order flow is constructed by summing the trade signs over futures regular trading hours.

Repeating the regressions from Table 2 using this modified futures order flow, we find very similar results. The adjusted R-squareds decrease by at most 6% (for the DM) and the order flow coefficients fall marginally. The correlation between order flow using adjusted forward quotes and the order flow using the original forward quotes ranges from 0.98 to nearly 1 for the four currencies. Thus, a futures-forward price differential does not appear to be driving our order flow results.

Because we observe forward quotes at regular intervals, we have to use quotes that either lag or lead our futures price by from 0 to 15 minutes. Our algorithm matches the futures price to the forward quote at the beginning of the 15 minute interval containing the trade. In our first test to determine the impact of stale forward quotes, we replace the actual futures transactions time stamp with a time stamp that is five minutes later. This is equivalent to lagging the forward quote time by an additional five minutes, so that the quote is now between 5 and 20 minutes before the futures trade.

As shown in Table 5, increasing the lag between the quote and trade price (or using a quote that is stale) does not significantly alter our results; futures order flow still has a positive impact on spot returns. The order flow coefficients and adjusted R-squareds

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by the LR algorithm with a success rate of 81%, compared to 76% for the quote rule and 78% for the tick test.

[21] The average difference between the synthetic forward quote (modified to match the maturity of the futures trade) and the futures price is 0.70 pips for the DM, 5.73 pips for the Yen, -2.1 pips for the Swiss Franc and -

decline slightly from those shown in Table 2. For instance, the DM order flow coefficient only declines from 0.0014% (row iii of Table 2) to 0.0013% (first row of Table 5), while the adjusted R-squared goes from 38% to 25%. The differences for the other three currencies are smaller.

In another test for the potential effect of stale quotes on our results, we restrict our futures sample to those trades occurring within two minutes of each forward quote. Thus, if the timing of the quote and trade are accurate, the quote occurs only up to two minutes before the trade, instead of 15 minutes as our current algorithm uses. Note that this restricts the number of trades in the sample substantially; for example there are 59,426 futures trades in the DM sample that is reduced to 7,509 when restricted to those two minutes after each quote.

The results of the regression of daily spot returns on this restricted futures order flow are shown in the third and fourth columns of Table 5. Although the adjusted R-squared decreases substantially for the DM, the results for the other currencies are basically unchanged from those in Table 2. The order flow coefficients are larger in these regressions due to the smaller order flow values in the restricted sample. Therefore, it seems that stale quotes may matter for the DM (although the main result of a positive and statistically significant impact on spot returns remains), but not for the three other currencies.

Our next test of the signing algorithm measures the impact of quotes that lag transactions prices on *spot* order flow, which we expect would be quite similar to the impact on futures order flow. We create estimated spot order flow using the quote rule with spot transactions prices from Evans (1998). These are compared to the Reuters spot mid-

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9.7 pips for the Pound. A pip is the smallest unit prices are quoted in and equals $0.0001 for the European quote at the beginning of each 15 minute interval to form estimated daily spot order flow. This is approach is analogous to our futures trade signing algorithm, so it is likely to produce similar estimation error.

In addition, when we use Reuters spot data to sign spot trades, the spot mid-quotes are intended to approximate the mid-point of the bid and ask available to all dealer pairs at that point in time. Heterogeneity in mid-quotes across dealers at the same point in time – e.g., Peiers (1997) and Huang and Masulis (1999) – will tend to weaken the relationship between estimated spot order flow using the quote rule and actual spot order flow.

In Table 6, we see that much of the actual trade sign information is preserved using trade signs determined with the quote rule and beginning of interval quotes. Correlations for estimated and actual spot order flow range from 0.50 for the Deutsche Mark to 0.29 for the Yen. Using estimated flow from the quote rule does cause explanatory power and regression coefficients to decline — the DM order flow coefficient drops from 0.0022% to 0.0006% — as would be expected when some noise is added to the independent variable. Notably, for all four currencies, the coefficient on order flow remains positive and statistically significant in all of the regressions even when the quotes lag trades by up to 15 minutes.

The regressions shown in the second half of Table 6 underscore the importance of using a quote that lags the trade price, as opposed to one that leads it, in trade signing. This point was made in Lee and Ready (1991). Using a quote that follows the trade causes there to be a negative relationship between order flow and spot returns since the quote is affected by the trade price. For example, a buyer-initiated trade occurs at a higher price than the

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currencies and $0.000001 for the Yen.

previous quote, which typically causes the next quote to be higher than the trade price. Signing the trade using the succeeding quote would result in the incorrect determination that the trade is seller-initiated. We see in Table 6 that the correlation between actual spot order flow and estimated spot order flow using the end of the interval quote ranges from -0.54 for the DM to -0.14 for the Pound.

4.3 Futures order flow estimated using audit trail data

One characteristic of the Time and Sales data is that it is not a full transaction record. Only trades at prices different from the previous trade price or trades that follow a quote are reported. In addition, bid and ask quotes are only reported if they reflect an apparent change in the price level without a corresponding transaction, i.e., a bid higher than the last trade or ask lower than the last trade.[22] In this section, we examine what effect, if any, the missing trades have on our order flow regressions. For this analysis, we obtained the full record of futures transactions — usually referred to as the audit trail or CTR data — from the Commodity Futures Trading Commission from January 1999 to September 2002. We compare order flow from this dataset to order flow constructed from the Time and Sales reports over the same time period.

The audit trail data can be considered to be common knowledge to pit traders because they observe all trades on the floor, but not necessarily to the market as a whole. To the extent that there is useful information in trades that do not generate price changes, order flow constructed using the audit trail data will explain more variation in spot returns

[22] Despite these reporting rules, our dataset does contain a very small number of no-price-change trades: 0.21% of Euro trades, 0.38% of Yen trades, 0.19% of Swiss Franc trades and 0.31% of Pound trades. All quotes are excluded from our dataset.

than order flow constructed using Time and Sales data. Several papers, such as Locke and Sayers (1993) and Manaster and Mann (1996), have used audit trail data along with the Time and Sales reports for empirical analysis.[23]

We reconstruct a measure of futures order flow using audit trail data. The audit trail data includes a separate record for the buy and sell side of the same transaction (but does not indicate whether a given trade was buyer or seller initiated). Therefore, before applying our trade-signing algorithm to audit trail data, we discard all buy-side transactions to avoid double counting. Even after doing so, the number of trades in the audit trail is almost two and a half times the number of trades in the Time and Sales reports. We then use the quote rule with forward quotes to estimate the trade sign for each transaction and sum up the estimated trade signs to obtain daily order flow over futures regular trading hours.

As shown in Table 7, including trades with no price change does not seem to significantly alter the overall pattern of daily order flow. The last column shows that the correlation between audit trail and Time and Sales order flow is between 0.98 and 0.99 for all currencies.

Table 7 also reports results from order flow regressions using audit trail and Time and Sales data. The dependent variable is the spot return over futures regular trading hours. We see that audit trail order flow and Time and Sales order flow have similar explanatory power, but the exclusion of trades that occur at the same price in the Time and Sales data does seem to add a positive bias to our regression coefficients. Order flow coefficients estimated using Time and Sales data are almost double those estimated using audit trail

[23] A disadvantage of the audit trail data is that there is some question about the accuracy of the time stamp. Each trade in the audit trail is assigned a fifteen minute time bracket. The exact minute of the trade is

data. This result is not surprising, because futures trades that move futures prices are also more likely to correspond to changes in spot prices than futures trades with no price change. Overall, our results suggest that order flow constructed using Time and Sales data is a good proxy for the order flow based on all trades (audit trail data).

5. Alternative explanations for the order flow regression results

It is possible that order flow is correlated with returns without price discovery. For example, in Pasquariello (2007) (and see references therein) information asymmetries can cause order flow to cause price movements when there is no change in fundamental value. These price movements occur when uninformed traders make incorrect inferences about the signal received by informed traders. The uninformed mimic the trades of the informed which results in a change in the equilibrium price that does not reflect fundamentals. However, Evans and Lyons (2004) show that foreign exchange flows forecast future macroeconomic variables, which suggests that flows (at least on average) contain private information about future fundamentals.

In addition, order flow might cause temporary price movements due to inventory effects rather than permanent price changes due to private information. As explained in Hendershott and Seasholes (2007), an empirical implication of dealer compensation for inventory risk is that inventories are negatively correlated with contemporaneous returns and positively correlated with future returns. Brandt and Kavajecz (2004) look for exactly this type of effect by regressing Treasury returns on current and lagged order flow. We

constructed afterwards using an algorithm known as computerized trade reconstruction (CTR) that uses each trader's independently reported sequence of trades as well as the Time and Sales data.

follow their approach using regressions of currency returns on contemporaneous and lagged spot and futures order flow, which are shown in Table 8.

Out of the 16 coefficients on lagged flow, only three are significant and of these three only one is negative. We interpret this as evidence that, at least at a daily frequency, the order flow regression results predominantly reflect private information being incorporated into prices rather than inventory effects. To further explore this issue, we check whether most of the explanatory power for our order flow regressions is on days with low liquidity, when one might expect inventory effects to dominate. In additional regressions (results not shown), we find that the order flow coefficients for high liquidity days (when the closing spot bid-ask spread is above the median) tend to be higher but not statistically different from those for low liquidity days. This finding indicates that our results on the relationship between order flow and spot returns are independent of liquidity and, combined with the results in Table 8, does not support the inventory effects explanation.

Finally, it is possible that futures order flow is a proxy for spot order flow not reported in the Reuters dataset. For example, one might reasonably expect some price discovery to occur through voice brokers. There is also evidence that order flows across multiple currencies contribute to price discovery, e.g. Evans and Lyons (2002a). Therefore, an alternative interpretation of our order flow results is that there is significant evidence of price discovery from trading outside of the Reuters direct dealing system.

6. Conclusions

Despite the dominance of the foreign exchange spot market in terms of total trading volume, we find that the foreign exchange futures market also plays an important role in price formation in 1996. This conclusion is supported by analyses of the information content of order flow, short-term price dynamics, and long-term price dynamics. One possible reason for the key role of the futures market in price determination is its much higher level of transparency compared to direct interdealer spot trading.[24]

Previous research has also pointed out that a secondary market can take on a essential role in price discovery when that market offers greater anonymity, faster execution, or lower transactions costs, e.g., Huang (2002), Barclay, Hendershott and McCormick (2003), Hasbrouck (2003), and Kurov and Lasser (2004). Over a more recent period in 2006 which is characterized by higher spot market transparency, we see that the spot market dominates price discovery.

[24] This explanation is also given in Hasbrouck (2004).

References

Andersen, T. G., T. Bollerslev, F. X. Diebold, and C. Vega, 2007, "Real-time Price Discovery in Global Stock, Bond and Foreign Exchange Markets," *Journal of International Economics* 73, 251-277.

Baillie, R. T., 2002, "Price Discovery and Common Factor Models," *Journal of Financial Markets* 5, 309-321.

Barclay, M. J., T. Hendershott, and D. T. McCormick, 2003, "Competition among Trading Venues: Information and Trading on Electronic Communications Networks," *Journal of Finance* 58, 2637-2666.

Baum, C. F., and J. Barkoulas, 1996, "Time-Varying Risk Premia in the Foreign Currency Future Basis," *Journal of Futures Markets* 16, 735-755.

Biais, B., L. Glosten, and C. Spatt, 2005, "Market Microstructure: A Survey of Microfoundations, Empirical Results, and Policy Implications," *Journal of Financial Markets* 8, 217-264.

Bjonnes, G. H., and D. Rime, 2005, "Dealer Behavior and Trading Systems in Foreign Exchange Markets," *Journal of Financial Economics* 75, 571-605.

Bloomfield, R., and M. O'Hara, 1999, "Market Transparency: Who Wins and Who Loses?" *Review of Financial Studies* 12, 5-35.

Brandt, M. W., and K. A. Kavajecz, 2004, "Price Discovery in the U.S. Treasury Market: The Impact of Orderflow and Liquidity on the Yield Curve," *Journal of Finance* 59, 2623-2654.

Danielsson, J., and R. Payne, 2002, "Real Trading Patterns and Prices in Spot Foreign Exchange Markets," *Journal of International Money and Finance* 21, 203–222.

Drudi, F., and M. Massa, 2005, "Price Manipulation in Parallel Markets with Different Transparency," *Journal of Business* 78, 1625–1658.

Easley, D., M. O'Hara, and P. S. Srinivas, 1998, "Option Volume and Stock Prices: Evidence on Where Informed Traders Trade," *Journal of Finance* 53, 431-465.

Ellis, K., R. Michaely, and M. O'Hara, 2000, "The Accuracy of Trade Classification Rules: Evidence from Nasdaq," *Journal of Financial and Quantitative Analysis* 35, 529-552.

Evans, M. D. D., 1998, The Microstructure of Foreign Exchange Markets.

Evans, M. D. D., 2002, "FX Trading and Exchange Rate Dynamics," *Journal of Finance* 57, 2405-2447.

Evans, M. D. D., and R. K. Lyons, 2002a, "Informational Integration and FX Trading," *Journal of International Money and Finance* 21, 807-831.

Evans, M. D. D., and R. K. Lyons, 2002b, "Order Flow and Exchange Rate Dynamics," *Journal of Political Economy* 110, 170-180.

Evans, M. D. D., and R. K. Lyons, 2002c, "Time-varying Liquidity in Foreign Exchange," *Journal of Monetary Economics* 49, 1025-1051.

Evans, M. D. D., and R. K. Lyons, 2004, Exchange Rate Fundamentals and Order Flow.

Fleming, J., B. Ostdiek, and R. E. Whaley, 1996, "Trading Costs and the Relative Rates of Price Discovery in Stock, Futures and Options Markets," *Journal of Futures Markets* 16, 353-387.

Garbade, K. D., and W. L. Silber, 1979, "Dominant and Satellite Markets: A Study of Dually-Traded Securities," *Review of Economics and Statistics* 61, 455-460.

Garbade, K. D., and W. L. Silber, 1983, "Price Movements and Price Discovery in Futures and Cash Markets," *Review of Economics and Statistics* 65, 289-297.

Gonzalo, J., and C. Granger, 1995, "Estimation of Common Long-Memory Components in Cointegrated Systems," *Journal of Business and Economic Statistics* 13, 27-35.

Goodhart, C. A. E., Y. Chang, and R. G. Payne, 1997, "Calibrating an Algorithm for Estimating Transactions from the FXFX Exchange Rate Quotes," *Journal of International Money and Finance* 16, 921-930.

Hasbrouck, J., 1988, "Trades, Quotes, Inventories, and Information," *Journal of Financial Economics* 22, 229-252.

Hasbrouck, J., 1991, "The Summary Informativeness of Stock Trades: An Econometric Analysis," *Review of Financial Studies* 4, 571-595.

Hasbrouck, J., 1995, "One Security, Many Markets: Determining the Contributions to Price Discovery," *Journal of Finance* 50, 1175-99.

Hasbrouck, J., 2003, "Intraday Price Formation in U.S. Equity Index Markets," *Journal of Finance* 58, 2375-2400.

Hasbrouck, J., 2004, "Liquidity in the Futures Pits: Inferring Market Dynamics from Incomplete Data," *Journal of Financial and Quantitative Analysis* 39, 305-326.

Hasbrouck, J., and T. S. Y. Ho, 1987, "Order Arrival, Quote Behavior, and the Return-Generating Process," *Journal of Finance* 42, 1035-1048.

Hendershott, T., and C. M. Jones, 2005, "Island Goes Dark: Transparency, Fragmentation, and Regulation," *Review of Financial Studies* 18, 743-793.

Hendershott, T., and M. S. Seasholes, 2007, "Market Maker Inventories and Stock Prices," *American Economic Review* 97, 210.

Huang, R. D., 2002, "The Quality of ECN and Nasdaq Market Maker Quotes.," *Journal of Finance* 57, 1285-1319.

Huang, R. D., and R. M. Masulis, 1999, "FX Spreads and Dealer Competition across the 24-Hour Day," *Review of Financial Studies* 12, 61-93.

Hutcheson, T., 2003, Lead-lag Relationship in Currency Markets.

Klitgaard, T., and L. Weir, 2004, "Exchange Rate Changes and Net Positions of Speculators in the Futures Market," *Federal Reserve Bank of New York Economic Policy Review* 10, 17-28.

Kurov, A., and D. J. Lasser, 2004, "Price Dynamics in the Regular and E-Mini Futures Market," *Journal of Financial and Quantitative Analysis* 39, 365-384.

Lee, C. M. C., and M. J. Ready, 1991, "Inferring Trade Direction from Intraday Data," *Journal of Finance* 46, 733–746.

Locke, P. R., and C. L. Sayers, 1993, "Intra-Day Futures Price Volatility - Information Effects and Variance Persistence," *Journal of Applied Econometrics* 8, 15-30.

Lyons, R. K., 1996, "Optimal Transparency in a Dealer Market with an Application to Foreign Exchange," *Journal of Financial Intermediation* 5, 225-254.

Lyons, R. K., 2001, *The Microstructure Approach to Exchange Rates*, MIT Press, Cambridge.

Madhavan, A., 2000, "Market Microstructure: A Survey," *Journal of Financial Markets* 3, 205-258.

Manaster, S., and S. C. Mann, 1996, "Life in the Pits: Competitive Market Making and Inventory Control," *Review of Financial Studies* 9, 953-975.

Martens, M., and P. Kofman, 1998, "The Inefficiency of Reuters Foreign Exchange Quotes," *Journal of Banking and Finance* 22, 347-366.

Mizrach, B., and C. J. Neeley, 2005, The Microstructure of Bond Market Tatonnement.

Odders-White, E. R., 2000, "On the Occurrence and Consequences of Inaccurate Trade Classification," *Journal of Financial Markets* 3, 259-286.

Pasquariello, P., 2007, "Imperfect Competition, Information Heterogeneity, and Financial Contagion," *Review of Financial Studies* 20, 391-426.

Peiers, B., 1997, "Informed Traders, Intervention, and Price Leadership: A Deeper View of the Microstructure of the Foreign Exchange Market," *Journal of Finance* 52, 1589-1614.

Rhee, S. G., and R. P. Chang, 1992, "Intra-Day Arbitrage Opportunities in Foreign Exchange and Eurocurrency Markets," *Journal of Finance* 47, 363-379.

Rime, D., 2001, U.S. Exchange Rates and Currency Flows.

Rime, D., 2003, "New Electronic Trading Systems in Foreign Exchange Markets," in D. C. Jones, ed., *New Economy Handbook*, Elsevier.

Savickas, R., and A. J. Wilson, 2003, "On Inferring the Direction of Option Trades," *Journal of Financial and Quantitative Analysis* 38, 881-902.

Taylor, M. P., 1987, "Covered Interest Parity: A High-frequency, High-quality Data Study," *Economica* 54, 429-438.

Taylor, M. P., 1989, "Covered Interest Arbitrage and Market Turbulence," *Economic Journal* 99, 376-391.

Table 1. Descriptive Statistics for Currency Futures and Spot Markets May – August 1996

Panel A: Market shares

Currency	Days			Average Number of Trades per Day			Average Trade Size ($Mil)		Market Shares			
	Spot Full	Spot RTH	Futures	Spot Full	Spot RTH	Futures	Spot	Futures	Spot Full	Futures Full	Spot RTH	Futures RTH
DM	83	80	86	3080	1205	691	3.49	2.65	85%	15%	70%	30%
Yen	83	80	86	1813	463	957	4.12	2.48	76%	24%	45%	55%
Swiss Franc	83	80	86	811	348	1031	3.31	1.44	64%	36%	44%	56%
Pound	83	80	86	624	233	432	3.13	2.65	63%	37%	39%	61%

Panel B: Daily spot return

Currency	Number of Obs	Mean	Standard Deviation	Skewness	Kurtosis	Maximum	Minimum	Autocorr
DM	87	-0.04%	0.41%	-1.54	10.17	0.81%	-2.14%	-0.07
Yen	87	0.04%	0.46%	-0.21	3.54	1.04%	-1.24%	-0.10
Swiss Franc	87	-0.05%	0.53%	-1.61	9.85	0.91%	-2.75%	0.01
Pound	85	0.05%	0.32%	0.79	5.35	1.18%	-0.77%	0.10

Panel C: Daily futures order flow

Currency	Number of Obs	Mean	Standard Deviation	Skewness	Kurtosis	Maximum	Minimum	Auto corr
DM	86	413.99	160.02	0.74	3.11	2031	-910	-0.07
Yen	86	582.67	369.13	0.87	2.96	1825	-1699	-0.00
Swiss Franc	86	539.99	406.31	0.32	1.91	2645	-1298	-0.06
Pound	86	-182.21	169.75	-0.92	3.55	1063	-587	0.10

Panel D: Daily spot order flow

Currency	Number of Obs	Mean	Standard Deviation	Skewness	Kurtosis	Maximum	Minimum	Auto corr
DM	83	1.00	142.68	0.09	3.78	403	-442	0.02
Yen	83	35.72	108.07	0.15	3.22	314	-233	0.13
Swiss Franc	83	-17.66	69.33	-0.92	4.38	103	-265	0.20
Pound	83	-12.78	51.12	0.14	4.20	156	-140	0.29

Notes: This table reports descriptive statistics for currency spot and futures markets over the period from May through August 1996. Futures trades are from the Chicago Mercantile Exchange (CME) Times and Sales reports and cover futures regular trading hours (RTH) from 7:20am – 2pm Central Time. Spot trades are interdealer direct transactions on the Reuters Dealing 2000-1 system described in Evans (1998) and available from http://www.georgetown.edu/faculty/evansm1. Since these trades occur 24-hours a day, we separate out those that occurred during futures regular trading hours (spot RTH) in Panel A. The average dollars per futures trade is calculated by dividing Datastream's daily futures contract volume by the average daily number of trades and multiplying by the average exchange rate and contract size. The Evans (1998) dataset contains an estimate of dollar volume cumulated over each day. This average volume is divided by the average number of trades per day to calculate the average dollars per spot trade. Market shares are calculated by multiplying the average number of trades by the average dollars per trade in each spot and futures market and dividing by the sum of the two. Panel B reports descriptive statistics for the daily spot return, which is calculated as the log change in the Reuters spot quotes taken at 2pm Central Time. Panel C reports descriptive statistics for daily futures order flow, which is the sum of signed currency futures trades (see Sections 2.1 and 5.1 for additional detail) over futures regular trading hours. Panel D shows the same statistics for full-day spot order flow, calculated by summing the Evans (1998) signed trade data (+1 for a buy, -1 for a sell) over the 24-hour period ending at 2pm Central Time.

Table 2. Currency Futures and Spot Order Flow Regressions
May – August 1996

Dependent variable: Daily spot return

			Coefficients					Price Impact				Corr
		Num Obs	Spot Full	Spot RTH	Spot Non-RTH	Futures RTH	Adjusted R^2	Spot Full	Spot RTH	Spot Non-RTH	Futures RTH	Full Spot & Futures RTH
(i)	DM	77	0.0022%				56%	0.63%				0.38
			(9.93)									
(ii)		77		0.0028%	0.0019%		58%		0.81%	0.53%		
				(7.83)	(7.07)							
(iii)		77				0.0014%	38%				0.53%	
						(6.88)						
(iv)		77		0.0013%	0.0019%	0.0010%	69%		0.37%	0.54%	0.38%	
				(2.99)	(8.17)	(5.00)						
(v)	Yen	77	0.0029%				44%	0.70%				0.50
			(7.85)									
(vi)		77		0.0049%	0.0021%		49%		1.19%	0.50%		
				(6.21)	(4.64)							
(vii)		77				0.0005%	48%				0.21%	
						(8.48)						
(viii)		77		0.0003%	0.0020%	0.0004%	62%		0.06%	0.50%	0.18%	
				(0.23)	(5.26)	(5.01)						
(ix)	Swiss Franc	77	0.0054%				50%	1.64%				0.57
			(8.83)									
(x)		77		0.0080%	0.0032%		56%		2.43%	0.96%		
				(8.24)	(3.52)							
(xi)		77				0.0005%	61%				0.37%	
						(11.06)						
(xii)		77		0.0020%	0.0034%	0.0004%	72%		0.59%	1.03%	0.29%	
				(1.59)	(4.71)	(6.42)						
(xiii)	Pound	76	0.0043%				46%	1.36%				0.65
			(7.98)									
(xiv)		76		0.0073%	0.0020%		58%		2.33%	0.65%		
				(9.26)	(3.08)							
(xv)		76				0.0008%	70%				0.31%	
						(13.28)						
(xvi)		76		0.0021%	0.0013%	0.0006%	73%		0.66%	0.43%	0.24%	
				(1.99)	(2.46)	(6.36)						

Notes: This table shows results from regressions of currency spot returns on futures and spot order flow. The sample is from May 1, 1996 through August 31, 1996, excluding weekends, holidays and a data feed interruption in the spot transactions data. Except for the Pound regressions, the dependent variable is the daily spot return measured in dollars per foreign currency using 2pm Central Time Reuters spot exchange rates. The Pound spot return is in terms of pounds per dollar. Futures order flow is the sum of signed futures trades, which are estimated using the methodology described in Sections 2.1 and 5.1. Spot order flow is the sum of signed trades from interdealer direct currency spot transactions on the Reuters Dealing 2000-1 system as described in Evans (1998). Spot order flow is separated into two components: flow over futures regular trading hours (RTH) and flow over the rest of the day (non-RTH). Each regression includes an intercept (not shown). Robust t-statistics are in parentheses. Price impact is the change in the exchange rate due to $1 billion net purchases of dollars (for the DM, Yen and Swiss Franc) or Pounds. This is calculated using the average trade size shown in Table 1 Panel A. The last column shows the Pearson correlation coefficient between full-day spot order flow and futures regular trading hours order flow.

Table 3: Currency Futures and Spot Order Flow Instrumental Variable Regressions May – August 1996

Dependent variable: Daily spot return

Currency	Num Obs	Spot RTH	Spot Non-RTH	Futures RTH	Adjusted R^2	1st Stage R^2
DM	77			0.0022%	50%	50%
				(8.73)		
	77	0.0011%	0.0017%	0.0016%	72%	
		(2.74)	(7.73)	(6.20)		
Yen	77			0.0006%	39%	62%
				(7.07)		
	77	0.0023%	0.0021%	0.0004%	59%	
		(2.53)	(5.19)	(4.36)		
Swiss Franc	77			0.0007%	48%	47%
				(8.43)		
	77	0.0045%	0.0032%	0.0004%	65%	
		(3.84)	(4.02)	(4.39)		
Pound	76			0.0009%	40%	46%
				(7.20)		
	76	0.0050%	0.0023%	0.0004%	62%	
		(4.77)	(3.65)	(3.04)		

Notes: This table repeats the last two regressions for each currency from Table 2 using instrumental variables regression to correct for possible errors-in-variables bias due to futures order flow estimation error. Daily futures order flow calculated using the tick rule instruments for futures order flow calculated using the quote rule. The dependent variable is the spot return over the full day. Actual spot order flow is from Evans (1998). Robust t-statistics are in parentheses. The first-stage R-squared is from a regression of futures order flow calculated using the quote rule on futures order flow calculated using the tick rule.

Table 4. Daily Information Shares for Currency Spot and Futures Markets
Averages across all days

Panel A: May – August 1996

			Hasbrouck Information Share		
		Days	Upper Bound	Lower Bound	GG Common Factor Weights
DM	Spot	78	9%	4%	11%
	Futures	78	96%	91%	89%
Yen	Spot	78	7%	4%	8%
	Futures	78	96%	93%	92%
Swiss Franc	Spot	78	12%	7%	16%
	Futures	78	93%	88%	84%
Pound	Spot	77	31%	22%	31%
	Futures	77	78%	69%	69%

Panel B: March – May 2006

			Hasbrouck Information Share		
		Days	Upper Bound	Lower Bound	GG Common Factor Weights
Floor Traded Futures					
Euro	Spot	45	96%	62%	89%
	Futures	45	38%	4%	11%
Yen	Spot	46	94%	70%	89%
	Futures	46	30%	6%	11%
Pound	Spot	46	95%	71%	83%
	Futures	46	29%	5%	17%
Globex Traded Futures					
Euro	Spot	45	96%	19%	69%
	Futures	45	81%	4%	31%
Yen	Spot	45	97%	22%	72%
	Futures	45	78%	3%	28%
Pound	Spot	45	98%	20%	75%
	Futures	45	80%	2%	25%

Notes: Panel A reports information shares of the currency spot and futures market over the period from May through August 1996. The spot and futures data are 3-minute interdealer spot transactions prices from the Evans (1998) dataset and 3-minute futures transaction prices from CME Time and Sales Reports. Spot and futures returns are calculated over futures regular trading hours. A vector error-correction model with 3 lags is estimated for each currency and day in the sample. The Hasbrouck information share is calculated using the estimated coefficients on the cointegrating term and the correlation between spot and futures innovations, as specified in Baillie et. al. (2002). The residual covariance matrix is made lower-triangular using the Cholesky decomposition. Putting the price first in the Cholesky ordering creates the upper bound of the information share, while putting the price last creates the lower bound of the information share. The Gonzalo-Granger (GG) common factor weights only use the ratio of coefficients on the cointegrating terms (See Gonzalo and Granger 1995). Panel B reports the same measures for the Euro, Yen and Pound over the period from March 17 – May 22, 2006. The first set of results compares spot to floor traded futures returns using the CME Pit-traded Time and Sales Reports. The second set compares spot to electronically traded futures returns over futures regular trading hours using the CME GLOBEX Time and Sales Reports. The spot returns data uses Bloomberg composite spot quotes. Both panels show the average of the information shares over all days in the sample.

Table 5. Test of the Trade Signing Algorithm: Stale Forward Quotes

Dependent Variable: Daily spot return

Currency	Futures, 5-minute lead order flow coefficient	Futures, only trades 2 min after quote order flow coefficient	Adjusted R^2	Correlation with unadjusted futures order flow	Correlation with actual spot order flow
DM	0.0013%		25%	0.94	0.33
	(5.12)				
		0.0062%	11%	0.76	0.22
		(3.27)			
Yen	0.0005%		49%	1.00	0.50
	(8.53)				
		0.0038%	44%	0.98	0.45
		(7.85)			
Swiss Franc	0.0005%		61%	1.00	0.57
	(10.86)				
		0.0039%	58%	0.99	0.54
		(10.21)			
Pound	0.0008%		70%	1.00	0.65
	(13.34)				
		0.0061%	68%	0.98	0.64
		(12.65)			

Notes: The first set of regression results in the above table shows results from re-estimating the Table 2 regressions (third row for each currency) of currency spot returns on futures order flow, adjusting the timing of futures prices. Order flow is estimated using forward quotes that are at least 5 minutes earlier than the futures transaction time. In the second set of regressions, the sample is restricted to those futures trades that occur within 2 minutes of the forward quote. All other variables are the same as in Table 2. Each regression includes an intercept (not shown), and robust t-statistics are given in parentheses.

Table 6. Estimated Spot Order Flow

Dependent Variable: Daily Spot Return, May – August, 1996

	Spot, 15-minute lead order flow coefficient	Spot, 15-minute lag order flow coefficient	Adjusted R^2	Correlation with actual spot order
DM	0.0006%		24%	0.50
	(5.05)			
		-0.0009%	43%	-0.54
		(-7.78)		
Yen	0.0006%		11%	0.29
	(3.18)			
		-0.0009%	20%	-0.35
		(-4.47)		
Swiss Franc	0.0028%		38%	0.48
	(6.86)			
		-0.0029%	22%	-0.40
		(-4.78)		
Pound	0.0021%		28%	0.46
	(5.56)			
		-0.0017%	9%	-0.14
		(-2.89)		

Notes: The table reports the effects of estimation error induced by estimating the trade sign for spot trades. The quote rule is applied to interdealer Evans (1998) spot data. The spot data is available on the website of Martin Evans. The first set of order flow coefficients is for estimated spot order flow calculated using the beginning of interval quotes, which are up to 15 minutes before spot trade prices. The second set of results is for estimated spot order flow calculated using end of interval quotes, which are up to 15 minutes after spot trade prices. The last column reports the correlation between estimated and actual spot order flow. Each regression includes an intercept (not shown), and robust t-statistics are given in parentheses.

Table 7. Currency Order Flow Regressions using Time and Sales Data and Audit Trail Data

	Audit Trail Data			Time and Sales Data			
	Num Obs	Order Flow	Adj. R^2	Num Obs	Order Flow	Adj. R^2	Correlation Coefficient
Euro	912	0.0018%	50%	912	0.0017%	54%	0.99
T-statistic		(30.16)			(32.77)		
Yen	910	0.0008%	26%	910	0.0008%	30%	0.98
T-statistic		(17.89)			(19.53)		
Swiss Franc	910	0.0020%	46%	910	0.0020%	50%	0.99
T-statistic		(27.98)			(30.16)		
Pound	910	0.0025%	57%	910	0.0028%	65%	0.98
T-statistic		(34.42)			(40.75)		

Notes: This table compares currency order flow regression results using two measures of daily futures order flow. The first order flow measure signs futures transactions recorded in the Time and Sales data, while the second signs futures transactions reported in the Audit Trail data. Audit trail data contains a complete record of all futures transactions, while Time and Sales data only includes transactions at a new price. The methodology for futures order flow estimation is described in Sections 2.1 and 5.1. Audit trail data is from the Commodities Futures Trading Commission (CFTC), and Time and Sales data is from the CME. For further details on the audit trail data, see the Section 5.5 and Manaster and Mann (1996). The dependent variable is the daily foreign exchange spot return taken, measured in foreign currency per dollars, over futures regular trading hours. Each regression includes an intercept (not shown), and robust t-statistics are in parentheses. The last column of the above table shows the correlation coefficient between the two order flow measures. The sample period for all regressions is from January 1, 1999 through September 30, 2002, which matches the audit trail data availability.

Table 8. Order Flow and Dealer Compensation for Inventory Risk
May – August, 1996

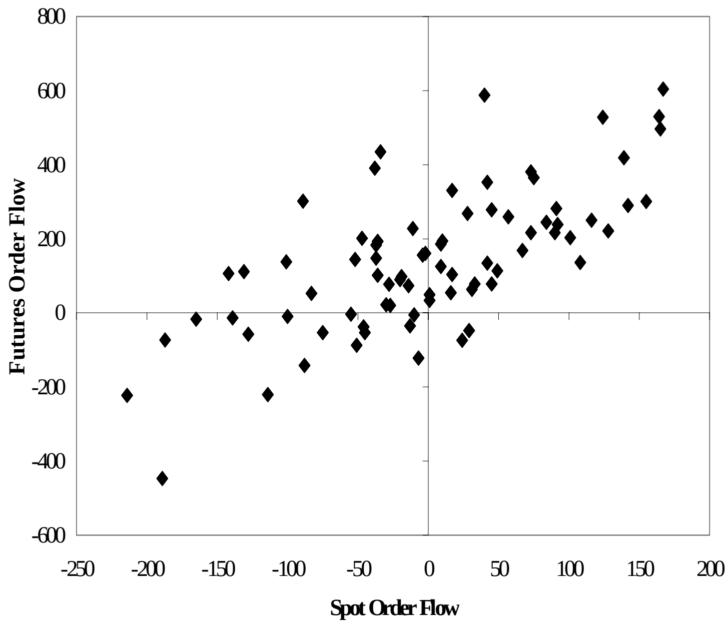
Dependent Variable: Spot Return over Futures Regular Trading Hours

	Obs	Futures Order Flow	Lagged Futures Order Flow	Spot Order Flow, RTH	Lagged Spot Order Flow, RTH	Adj Rsq
DM	73	0.00132%	-0.00003%			66%
		(11.86)	(-0.24)			
	73			0.00261%	0.00054%	52%
				(8.93)	(1.78)	
	73	0.001013%	-0.00026%	0.00101%	0.00090%	73%
		(7.26)	(-1.84)	(3.24)	(2.95)	
Yen	73	0.00045%	-0.00001%			81%
		(17.82)	(-0.32)			
	73			0.00493%	-0.00001%	56%
				(9.47)	(-0.01)	
	73	0.00033%	-0.00056%	0.00043%	0.00002%	81%
		(0.57)	(-0.97)	(9.74)	(0.55)	
Swiss Franc	73	0.00035%	0.00003%			68%
		(12.54)	(1.13)			
	73			0.00529%	0.00035%	45%
				(7.75)	(0.51)	
	73	0.00033%	0.00001%	0.00058%	0.00040%	68%
		(7.21)	(0.31)	(0.70)	(0.48)	
Pound	73	0.00043%	-0.00009%			54%
		(9.14)	(-1.88)			
	73			0.00323%	-0.00099%	23%
				(4.82)	(-1.44)	
	73	0.00053%	-0.00008%	-0.00146%	0.00003%	54%
		(7.00)	(-1.05)	(-1.74)	(0.04)	

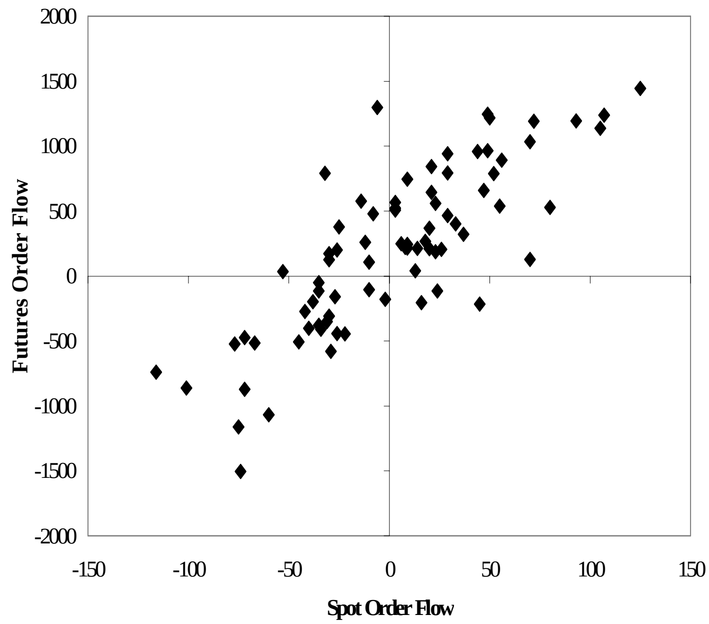
Notes: This table provides a test for whether the relationship between order flow and returns is being driven by dealer compensation for inventory risk (See Section 5 for details). The one-day lagged futures and interdealer spot order flows are added to the regressions shown in Table 2 to pick up the return reversals that would be expected if dealers are compensated for taking on undesired inventory by future price appreciation. The spot data is described in Evans (1998) and is available on Martin Evans website. The dependent variable is the spot return over futures regular trading hours, 7:20 am – 2pm Central Time. An intercept is included in each regression (not shown), and robust t-statistics are in parentheses.

Figure 1. Daily Currency Futures and Spot Order Flow, May – August 1996

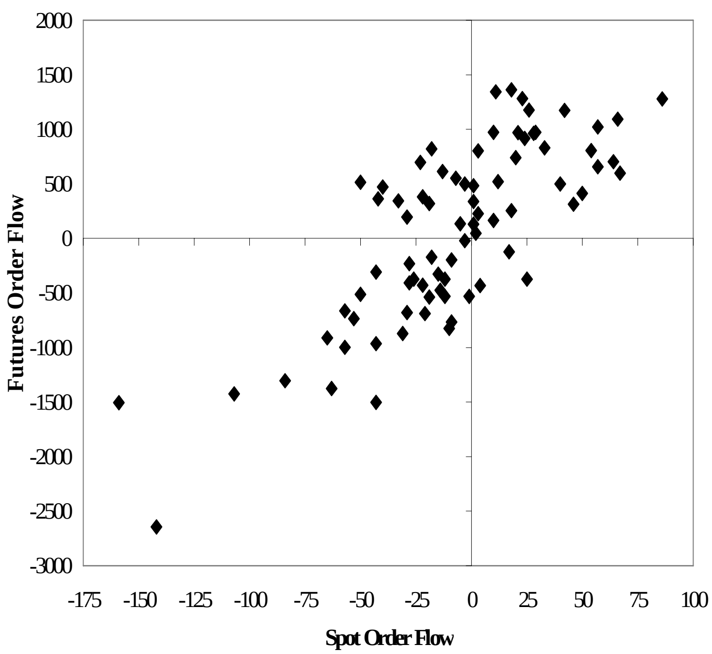
Panel A: Deutsche-Mark



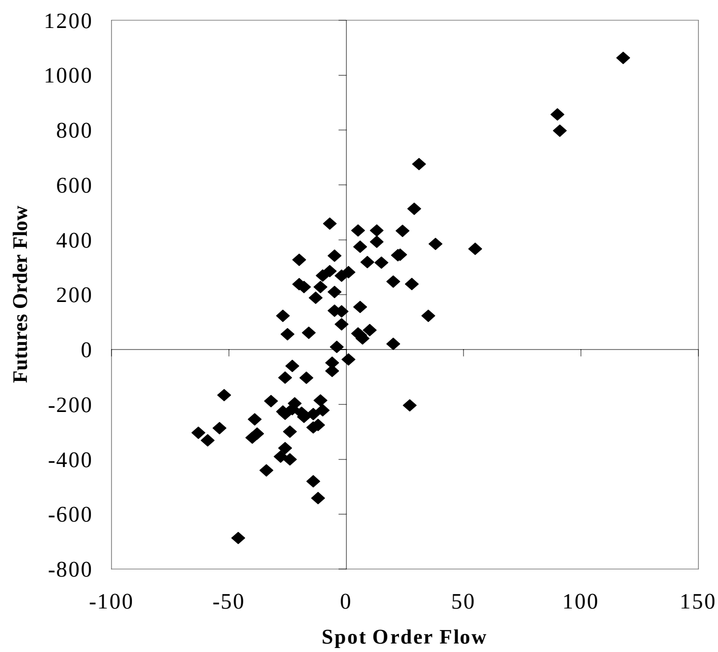
Panel B: Yen



Panel C: Swiss Franc

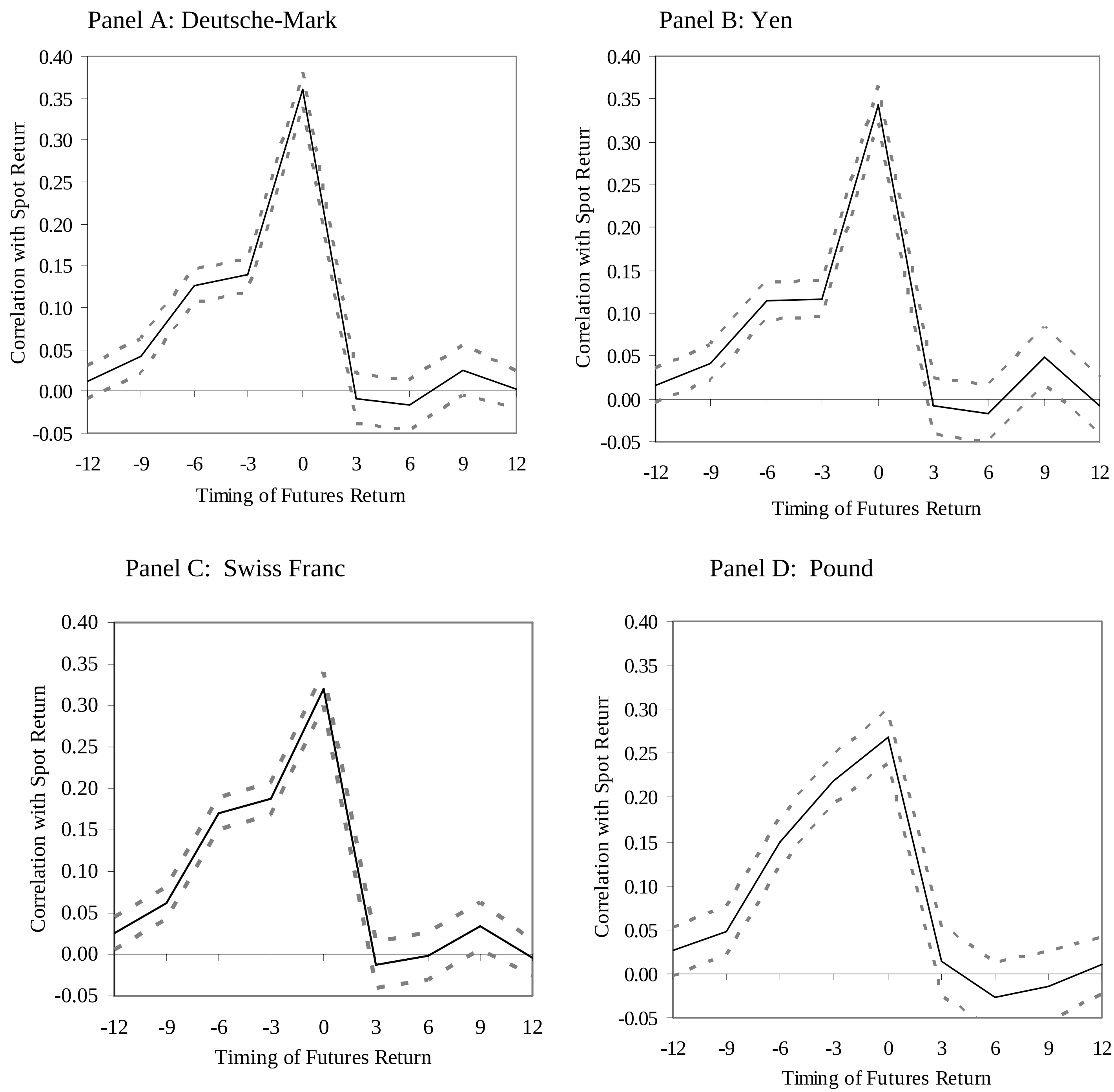


Panel D: Pound



Notes: These graphs show the relation between daily currency spot and futures order flow over the period from May 1996 through August 1996. Futures order flow is the daily sum of signed currency futures trades estimated using the methodology described in Sections 2.1 and 5.1. Spot order flow is the daily sum of signed trades from interdealer direct currency spot transactions on the Reuters Dealing 2000-1 system as described in Evans (1998). Both order flow measures are calculated over futures regular trading hours. A positive (negative) number indicates a net purchase (sale) of dollars for all currencies except the Pound. A positive (negative) number for Pound order flow indicates a net purchase (sale) of Pounds.

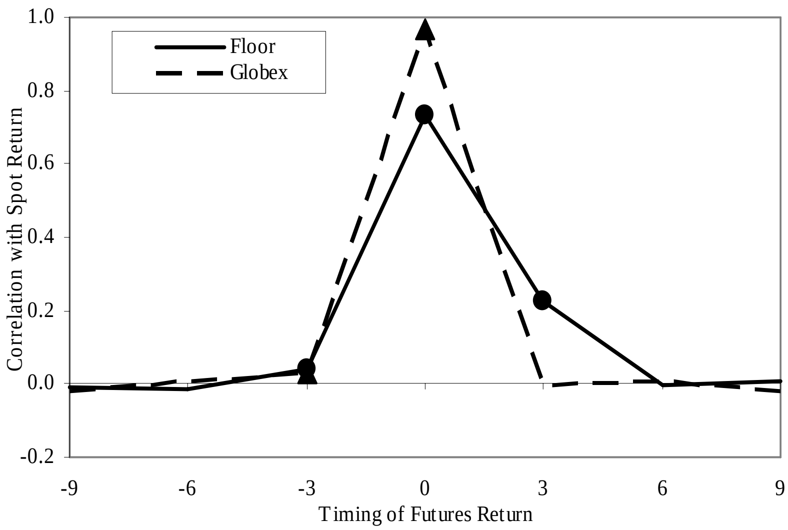
Figure 2. Cross Correlations of 3-Minute Currency Spot Returns with Futures Returns, May – August 1996



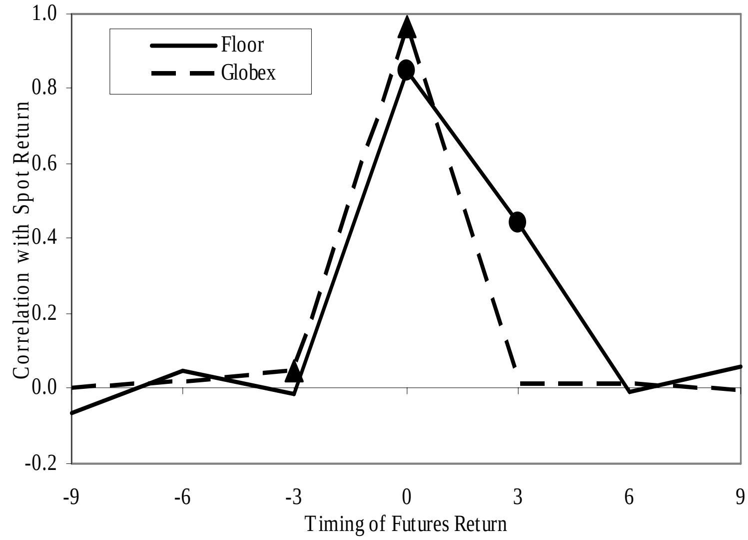
Notes: These graphs show correlations (solid lines) between current 3-minute spot returns with leads and lags of 3-minute futures returns over the period from May 1, 1996 through August 31, 1996. Standard error bands are also shown (dashed lines). Spot returns are from interdealer spot transactions prices described by Evans (1998) and available from the website of Martin Evans. Futures returns are from futures prices recorded in CME Time and Sales reports. Returns are log differences between 3-minute prices over futures regular trading hours. Positive values to the left of zero indicate that futures prices predict changes in spot prices.

Figure 3. Cross Correlations of 3-Minute Currency Spot Returns with Futures Returns, March – May 2006

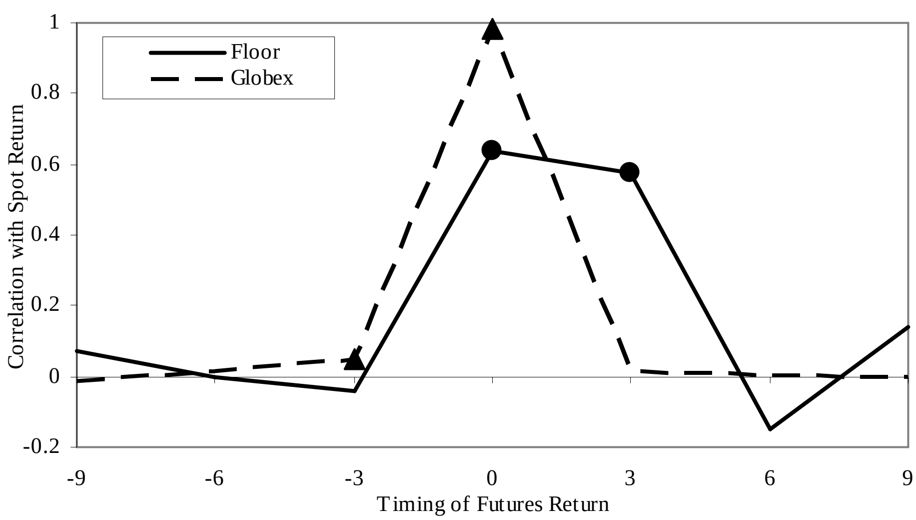
Panel A: Euro



Panel B: Yen



Panel C: Pound



Notes: These graphs show correlations between current 3-minute spot returns with leads and lags of 3-minute floor traded (solid lines) and Globex electronically traded (dashed lines) futures returns over the period from March 17, 2006 through May 22, 2006. The dotted (triangle) points represent correlations between floor (Globex) futures and spot returns that are statistically significant at a 5% significance level. Spot returns are from Bloomberg composite spot quotes. Both floor and electronically traded futures returns are from futures prices recorded in CME Time and Sales reports. Returns are log differences between 3-minute prices over futures regular trading hours. Positive values to the right of zero indicate that spot prices predict changes in futures prices, while those to the left of zero indicate that futures prices predict changes in spot prices.