

The Components of Electronic Inter-Dealer Spot FX Bid-Ask Spreads

FRANK MCGROARTY, OWAIN AP GWILYM AND STEPHEN THOMAS*

Abstract: This paper applies an established bid-ask spread decomposition model to the inter-dealer spot foreign exchange market. In addition, the paper presents and tests a modified decomposition model which is specifically adapted to the features of order-driven markets and which is found to produce more plausible results than the original model. Price clustering is introduced as a new explanatory factor within this framework and is shown to be vitally important in understanding the composition of bid-ask spreads in this market.

Keywords: high frequency data, foreign exchange, market microstructure, bid-ask spreads, order driven

1. INTRODUCTION

Bid-ask spreads are an important transaction cost in financial markets and are inversely associated with liquidity. Consequently, much prior research has investigated the components of bid-ask spreads. This paper extends this literature in three specific ways. First, it sheds light on bid-ask spread composition and liquidity in the world's largest financial market, the foreign exchange (FX) market. Second, we revise the specification of the bid-ask spread decomposition model to take account of particular features of electronic order driven markets. This is because existing bid-ask spread decomposition models were developed around the US equity markets and do not match the structure of the electronic order driven spot FX market that we study. Third, we find a new explanatory factor to be important, namely price clustering.

Bjornes and Rime (2005) previously explored the components of spot FX bid-ask spreads but their perspective is very different from ours. Contrasting our study with Bjornes and Rime (2005) highlights the fact that bid-ask spreads are not uniform across the whole of the spot FX market. Cai, Hudson and Keasey (2004) demonstrated that different trading mechanisms can produce different bid-ask spreads within the

*The authors are respectively Lecturer in Finance, School of Management, University of Southampton; Professor of Finance, School of Management & Business, University of Wales, Aberystwyth; and Professor of Finance, Cass Business School, City University, London. They are grateful for comments received from the editor, an anonymous referee, participants at the Midwest Finance Association 2006 conference, Chicago and the Forecasting Financial Markets 2006 conference, Aix en Provence. They thank EBS for providing the data for this study. (Paper received January 2006, revised version accepted March 2007. Online publication July 2007)

Address for correspondence: Frank McGroarty, Lecturer in Finance, School of Management, University of Southampton, SO17 1BJ, UK.
e-mail: F.J.McGroarty@soton.ac.uk

same market. The spot FX market has a two-tier structure and bid-ask spreads are very different in each tier. The popular perception of bid-ask spreads in the spot FX market is the bid-ask spreads paid by consumers, corporations and investment institutions to the FX banks. Bjonnes and Rime's (2005) bid-ask spreads are mostly of this type, as their data comes from four spot FX dealers working for a Scandinavian bank. Our bid-ask spreads are very different, as they come from the other tier of the spot FX market.

At the heart of the spot FX market is the inter-dealer market which, in recent years, including the period for which we have data, was primarily electronically traded. According to Lyons (2001), approximately two-thirds of total spot FX trading volume is traded between dealers via the inter-dealer market, while only one-third of all trades involve customers. In addition, the highly liquid and transparent electronic inter-dealer market sets the mid-price on which FX banks base their spot FX quoted prices to customers (see McGroarty, ap Gwilym and Thomas, 2006, for a detailed description). In the electronic inter-dealer market, the bid-ask spread arises as the difference between the best limit order bid price and the best limit order ask price facing a trader who wishes to trade. Unlike customer bid-ask spreads, inter-dealer bid and ask prices usually come from different dealers and are generally much narrower than customer bid-ask spreads. Hau, Killeen and Moore (2002) stoked much controversy when they suggested that an increase in these electronic inter-dealer bid-ask spreads was responsible for a post-EMU dip in global spot FX trading volumes. It is the composition of these bid-ask spreads that we study in this paper.

A common focus for previous studies on the bid-ask decomposition model is the New York Stock Exchange (NYSE), e.g. Glosten and Harris (1988), Madhavan, Richardson and Roomans (1997), Huang and Stoll (1997) and Van Ness, Van Ness and Warr (2002). A major difference between the NYSE and the electronic inter-dealer spot FX market is the absence of market makers on the latter market. Market makers, or 'specialists', are central to the structure of the NYSE. While they sometimes match incoming market orders with existing limit orders, they also frequently step up directly as the counterparty for a trade. By contrast, the electronic inter-dealer spot FX market permits market participants two ways to execute a trade. They can either submit a market order which engages a pre-existing limit order posted earlier by another trader, or they can advertise their own willingness to trade by submitting a limit order. Traders place limit orders or market orders in the electronic inter-dealer market in order to achieve their desired holdings of currencies, rather than as a service to others. There is no evidence that any electronic inter-dealer spot FX market participants consistently provide simultaneous two-way prices (i.e. bid limit orders and ask limit orders) in order to earn the bid-ask spread.

Using a simulated electronic trading room experiment, Bloomfield, O'Hara and Saar (2005) found that informed traders prefer to place limit orders most of the time. A recent microstructure theory paper by Goettler, Parlour and Rajan (2005) reached the same conclusion. Bloomfield et al. (2005) also found that when price deviates greatly from fair value, informed traders favour market orders. These findings also agree with earlier theoretical predictions of Angel (1994) and Harris (1998). This insight leads us to redefine certain technical elements of the bid-ask spread decomposition model used by previous researchers. Comparison of results from the original model with results from our revised model overwhelmingly vindicates this approach.

Huang and Stoll (1997) identify three components of the bid-ask spread. The first relates to private information whereby informed traders move the price and it does not

return to its pre-trade level. From a market maker's point of view, this carries the risk of being adversely selected by a trader who knows more about the true price than the market maker does. Gregoriou, Ioannidis and Skerratt (2005) link this risk to the range of disparity in traders' future returns expectations. The second component is related to temporary imbalances between buying and selling volumes that recover their pre-trade levels fairly quickly. From a market maker's perspective, these trades give rise to inventory which absorbs capital and which needs to be managed. The third component is the residual bid-ask spread after the first two components have been accounted for. It is linked to order processing and administration costs borne by market makers in providing their services.

The private information and temporary buy-sell imbalance components of Huang and Stoll's (1997) model still make economic sense as bid-ask spread determinants in an electronic order-driven market. However, the market maker reaction to these factors must be set aside. Additionally, in our view, the order processing component seems out of place in an electronic order-driven market setting. There is no evidence to suggest that limit order traders require any more infrastructure or need to pay any more processing costs in the electronic inter-dealer spot FX market than market order traders do. On the other hand, one factor that has been independently shown to be important for bid-ask spreads is price clustering. McGroarty et al. (2006) examined the distribution of trading volume across the final digits of trade prices. They found price clustering to be important in explaining the observed increase in bid-ask spreads after EMU. Based on this, we feel that it is more appropriate to classify the residual component of our bid-ask spread model as price clustering than as order processing. This gives us three potentially important components of electronic inter-dealer bid-ask spreads: private information, temporary buy-sell imbalances and price clustering.

The remainder of the paper is organised as follows. Section 2 reviews the established theoretical model for bid-ask spread decomposition. Section 3 presents our original modified trade indicator model which reflects the order driven nature of the electronic inter-dealer spot FX market under investigation in this paper. Section 4 describes the data and methodology, Section 5 presents the empirical results and Section 6 concludes.

2. BID-ASK SPREAD DECOMPOSITION: THE TRADE INDICATOR MODEL

Trade indicator models relate time series of returns to the 'side' of trades, i.e. whether a given trade is transacted near the prevailing bid quote or the prevailing ask quote. Because trades oscillate between bid side and ask side, the bid-ask spread can be deduced and its components can be measured. Glosten and Harris (1988) developed the seminal trade indicator model, using the trade indicator sequence to separate returns into an 'adverse selection' component associated with permanent price shifts and informed trading, and a 'transitory' component comprising order processing and inventory management costs. Madhavan et al. (1997) extend the analysis to intra-day NYSE data to study the changing structure of the bid-ask spread over the course of the day. Huang and Stoll (1997) develop a general approach to bid-ask spread decomposition using the trade indicator model.

Since Huang and Stoll's (1997) form of the model is the most general, we follow their notation here. In this model, the trade indicator variable, denoted as Q_t , can

take on only three distinct values, +1 when the transaction is initiated by the buyer (i.e. where the transaction price is above the mid-quote), -1 when the transaction is initiated by the seller (i.e. where the transaction price is below the mid-quote) and 0 where neither party can be identified as the initiator (i.e. where the transaction price exactly equals the mid-quote). The prevailing bid and ask quotes, which make up the mid-quote, are defined as those which pre-exist each trade and must be no more than one minute old.

Equation (1) is the basic Huang and Stoll (1997) model:

$$\Delta P_t = \frac{S}{2} Q_t + (\lambda - 1) \frac{S}{2} Q_{t-1} + e_t. \quad (1)$$

This model is equivalent to the original Glosten and Harris (1988) model. The left hand side variable is return defined as the change in traded price, while on the right hand side, the $S/2$ is the half-spread and λ represents the combined adverse selection and inventory management components. The half-spread is assumed constant. λ can take values between 0 and 1, where 1 means that adverse selection and inventory management together account for all of the bid-ask spread. The part of the bid-ask spread that is not accounted for by adverse selection and inventory management, i.e. $(1 - \lambda)$, is deemed due to order processing costs. The error term, e_t , combines public information releases which perturb prices with random deviations in the bid-ask spread. Public information releases or news are assumed to occur randomly.

The second Huang and Stoll (1997) model is more advanced and it contains an additional lag of the trade indicator variable to the above equation as follows:

$$\Delta P_t = \frac{S}{2} Q_t + (\alpha + \beta - 1) \frac{S}{2} Q_{t-1} - \alpha \frac{S}{2} (1 - 2\pi) Q_{t-2} + e_t \quad (2)$$

$(\alpha$ plus $\beta)$ equals λ in the previous equation. $(1 - 2\pi)$ indicates the conditional expectation of Q_{t-1} given Q_{t-2} , where π is the probability that a trade is of the opposite sign to the previous one. The second model also requires that $(1 - 2\pi)$ be simultaneously estimated along with the extended regression equation, using (3):

$$Q_t = (1 - 2\pi) Q_{t-1} + u_t. \quad (3)$$

Both Huang and Stoll's (1997) basic model (equation (1)) and their more elaborate model (equations (2) and (3) together) are built on the assumption of a NYSE-like, market-maker-centric setting. Since the electronic inter-dealer spot FX market does not conform to that ideal, it is necessary to expose the assumptions underlying these models to see where they might conflict with the actuality of a different market structure.

Huang and Stoll (1997) explain that three separate but co-existing variables linked to price underpin these models. These are: (1) the fundamental valuation, V_t , (2) the mid-quote value between the bid and the ask, M_t , and (3) the transaction price, P_t . Fundamental valuations evolve as follows:

$$V_t = V_{t-1} + \alpha \frac{S}{2} Q_{t-1} + \varepsilon_t. \quad (4)$$

Order flow drives the fundamental value in equation (4), (e.g., Glosten and Milgrom, 1985) reflecting the influence of both informed trading, α , and the random release of public information, ε_t .

By contrast, the mid-quote is driven by accumulated market maker inventory (e.g., Ho and Stoll, 1981):

$$M_t = V_t + \beta \frac{S}{2} \sum_{i=1}^{t-1} Q_i. \quad (5)$$

And, finally, combining the above, transaction price is given by (6):

$$P_t = V_t + \beta \frac{S}{2} \sum_{i=1}^{t-1} Q_i + \frac{S}{2} Q_t + \eta_t. \quad (6)$$

Taking the first difference of equation (6) allows the change in price to be related to the sign indicator sequence of past trades, as presented in equation (1).

Although equations (1) and (2) appear very similar in structure, the latter, more advanced, model taps into a separate tradition of bid-ask spread model, namely, covariance models. The new term π , which denotes the probability that each successive trade will be of the opposite sign to its predecessor, is using the serial correlation of the trade flow to reveal the components of the bid-ask spread. In other words, it infers the bid-ask spread from bid-ask bounce. This covariance approach to bid-ask spread modelling was instigated by Roll (1984). While Roll's (1984) original model is valid only where the bid-ask spread consists entirely of order processing costs, later innovations by Choi, Salandro and Shastri (1988) and by George, Kaul and Nimalendran (1991) allowed for informed trading and inventory effects in the covariance model framework. Huang and Stoll (1997) utilise the covariance model approach within the trade indicator model framework in order to separate the inventory management and adverse selection effects from each other.

3. THE NEW MODIFIED TRADE INDICATOR MODEL

While the focus of much market microstructure research to date has been on market-maker-centric markets like the NYSE, there is a smaller but nevertheless well established literature on order-driven markets. These papers provide insights into the nature of order-driven market bid-ask spreads. Cohen, Maier, Schwartz and Whitcomb (1981) showed that order-driven bid-ask spreads are endogenously determined by risk of limit orders not executing. When the risk of non-execution is low and the bid-ask spreads is wide, traders will submit limit orders in preference to market orders, which will narrow the bid-ask spread. In an order-driven market, non-execution of orders is unlikely when volume is high and volatility is low. Parlour (1998) found that greater depth at the best price also contributes to non-execution risk because new limit orders may be crowded out. Confirming this link between order-driven bid-ask spreads and non-execution risk, Foucault, Kadan and Kandel (2001) found that bid-ask spreads and times-to-execution are jointly determined in equilibrium. However these papers, like other key papers in the order-driven market microstructure literature, including Rock (1990), Glosten (1994) and Seppi (1997) rely on a crucial but questionable assumption. They all assume that informed traders would choose to submit market orders in preference to limit orders.

Experimental work by Bloomfield et al. (2005) found that informed traders are more likely to submit limit orders than market orders. The authors argue that this is because only informed traders know the true value of the underlying asset and they can

extract profit using this knowledge to sell high and buy low around the true value. This insight completely redefines one of the key fundamentals of the trade indicator model, the determination of fundamental value, V . If informed traders are setting prices, the notion of the uninformed market maker learning by 'vote-counting' no longer applies, i.e. order flow (Q_{j-1}) no longer revises the fundamental valuation. Instead, the evolution to V would be solely determined by public information shocks, ε :

$$V_t = V_{t-1} + \varepsilon_t. \quad (7)$$

In an order-driven market context, the definition of the mid-quote, M , in equation (5) is misleading, since it contains the implied suggestion that price-setting market makers adjust their mid-quote to accommodate inventory imbalances. This cannot happen in order-driven markets with no market makers. However, there is no dispute that aggregate imbalances between supply and demand will disturb V , insofar as downward sloping aggregate demand curves require price concessions for the excess to be held. As such, an interim variable representing the disturbed value of V seems more consistent with the mechanisms of order-driven markets. We use the term V^* to represent V disturbed by a buy-sell imbalance:

$$V_t^* = V_t + \beta \frac{S}{2} \sum_{i=1}^{t-1} Q_i. \quad (8)$$

The mid-quote, M , can now be defined as a function of V^* . However, given the insight of Bloomfield et al. (2005) that informed traders submit limit orders in order-driven markets, informed traders must set M . The information they release can be captured by the following relationship for the mid-quote:

$$M_t = V_t^* - \alpha \frac{S}{2} Q_t. \quad (9)$$

Previously, in the quote-driven model, Q_t acted as a vote counter, registering aggressive market order trading (order flow) from informed traders. In an order-driven market trade indicator model, Q_t is the first opportunity to record the information released at M_t in the trade flow. In order-driven regimes, liquidity based trading endowments are exogenous. The choice facing every trader is whether to submit a limit order or a market order. Using the Bloomfield et al. (2005) insight, what was aggressive buying or selling by an informed trader in a quote-driven context, will translate to the submission of an aggressive limit order. This will narrow the existing bid-ask spread and entice a trader on the opposite side to submit a market order in preference to a limit order. For this reason an upward price revision will trigger a sell, thus producing a negative relationship between M_t and Q_t .

These new fundamental relationships produce the following price equation:

$$\begin{aligned} P_t &= M_t + \frac{S}{2} Q_t + \eta_t \\ &= V_t^* - \alpha \frac{S}{2} Q_t + \frac{S}{2} Q_t + \eta_t \\ &= V_t + \beta \frac{S}{2} \sum_{i=1}^{t-1} Q_i - \alpha \frac{S}{2} Q_t + \frac{S}{2} Q_t + \eta_t \end{aligned} \quad (10)$$

This results in a price change equation that is identical to the original one in equation (1) in every detail but one:

$$\begin{aligned}\Delta P_t &= \beta \frac{S}{2} Q_{t-1} - \alpha \frac{S}{2} Q_t + \alpha \frac{S}{2} Q_{t-1} + \frac{S}{2} Q_t - \frac{S}{2} Q_{t-1} + e_t \\ &= (1 - \alpha) \frac{S}{2} Q_t + (\alpha + \beta - 1) \frac{S}{2} Q_{t-1} + e_t.\end{aligned}\quad (11)$$

Now, order flow relating to P_{t+1} is a component of Q_t and is revealed by $-\alpha$.

Equation (11) identifies the private information component (α) and the temporary buy-sell imbalance component (β) more parsimoniously than equation (2) because it does not require π to identify α . However, there are still three parameters (α , β and S) to be estimated and only two explanatory variables (Q_t and Q_{t-1}). Quote price data is available in our dataset. So we use the quoted bid-ask spread time series in place of the parameter S in our modified trade indicator model, which we rename S_t because it becomes time-varying.¹ Equation (12) expresses our model with time subscripts on the bid-ask spreads:

$$\Delta P_t = (1 - \alpha) \frac{S_t}{2} Q_t + (\alpha + \beta - 1) \frac{S_{t-1}}{2} Q_{t-1} + e_t.\quad (12)$$

Trade indicator models relate return on the left to order flow (Q) on the right. Quote revision and trade execution (= vote counting) are only two channels through which inventory and information can influence price. In quote driven markets, inventory drives the mid-quote and information is revealed through executed trades. In an order driven market, this is reversed. Information drives the mid-quote, while the inventory type factor impacts price via trade execution. The essential point here is that, even though inventory and information swap channels, equation (12) shows that the underlying relationships that inventory and information have with price are preserved.

It is intuitively appealing that informed trading should affect Q_t . After all, why should order flow linked to P_{t+1} have any different relationship with Q_t than order flow linked to P_t had with Q_{t-1} ? Also, the absence of α from the coefficient of Q_t in the original quote-driven model can be traced back to the Glosten and Milgrom (1985) assumption of regret-free quoted prices. If market makers condition their bid and ask prices on the possibility of a trader being informed, in either direction, there can be no role for α at time t . However, the idea of regret-free prices relies on several critical assumptions. If trade size is variable and price signals are uncertain, as Easley and O'Hara (1987) assume they are, then the regret-free assumption cannot hold. Furthermore, regret-free prices presuppose that the market maker is someone who could experience long-term capital exposure and finds unloading inventory difficult. While this is evidently true of equity market makers, it is not a good description of the electronic inter-dealer spot FX market. This notion of a market maker who can widen his bid-ask spread in the face of a surfacing adverse selection risk also hinges on the assumption of monopoly power. If bid-ask spreads are kept tight by competition, if market makers do not all perceive the same risk at the same time, or if the market is so liquid that unwanted positions

1 The quoted bid-ask spread is derived from the nearest preceding bid and ask prices, if both of these are under one minute old. If the nearest bid or ask is older than that, the bid-ask spread is left blank.

are quick and easy to offload, it is possible to see how the bid-ask spread would not need to be regret-free. If the regret-free assumption is dropped then the modified trade indicator model is more generally appropriate than the original Huang and Stoll (1997) model.

The residual component of the bid-ask spread after the private information and temporary buy-sell imbalance factors, (i.e. $1-\alpha-\beta$), have been accounted for is attributed to order processing costs by Huang and Stoll (1997). This explanatory factor is difficult to justify in the electronic inter-dealer spot FX market, since any trader can submit either a limit order or a market order. We believe that a more appropriate interpretation of the residual factor is price clustering, following research by McGroarty et al. (2006) who found this factor to be important in explaining the observed increase in bid-ask spreads after EMU.

4. DATA AND ESTIMATION METHODOLOGY

In 1998, the Bank of International Settlements estimated that the total volume of spot foreign exchange trading was worth almost US\$1.5 trillion per day. While after EMU, the total value of FX transactions fell, the FX market remains the largest financial market in the world, by many orders of magnitude. BIS (1998) and BIS (2001) both show that spot FX transactions account for a little under half of all trading activity in the FX market. In turn, inter-dealer trading accounts for about two-thirds of total global spot FX volume. Over the past decade, the importance of electronic trading venues in the inter-dealer market has risen sharply. BIS (2001) estimates that between 85% and 95% of inter-bank trading occurred over electronic trading systems in 2000. This compares with 50% in 1998 (BIS, 1998).

Even these large volumes understate the importance of the electronic inter-dealer market. This is by far the most transparent part of the spot FX market and, as such, it sets mid-price exchange rates across the entire market. As McGroarty et al. (2006) explain, transactions between FX banks and their customers are bilateral and are not visible to other banks. So, the other banks cannot use the buy/sell information of this trade to update their prices. However, customer transactions give rise to inventory imbalances. The bid-ask spreads on the inter-dealer market are smaller than those that banks charge their customers. Banks can (and do) take on inventory from their customers and rapidly offload that inventory on the inter-dealer market at near mid-market rates (see Lyons, 2001 for greater detail on FX market structure).

There are two electronic venues in the inter-dealer spot FX market, namely EBS and Reuters 2000-2. EBS is the global leader in foreign exchange broking and is dominant in the large currencies involving the USD, EUR and JPY. Reuters 2000-2 dominates the Commonwealth and Scandinavian currencies. Killeen, Lyons and Moore (2006) provide a detailed description of how the EBS market works. EBS provided us with the data for the present study. This dataset has not previously been available to academic researchers.

It contains spot FX quote and trade price data for eight currency pairs from the EBS electronic inter-dealer market. The quotes data comprises the best bid and ask quote prices per second (Greenwich Mean Time (GMT)). Trade data is also time-stamped to the nearest second (GMT). No information about the size of each transaction is provided. Also, there are no identifiers of the parties to each trade. The data consist of two separate sample periods with five exchange rates in each. The first covers the

period 01/08/98 to 04/09/98 and consists of the currency pairs USD/DEM, USD/JPY, USD/CHF, DEM/JPY and DEM/CHF. The second covers 01/08/99 to 03/09/99 and contains data on EUR/USD, USD/JPY, USD/CHF, EUR/JPY and EUR/CHF. Each sample contains 20 days of observations which are time-stamped to the nearest second. In this study, the EUR is taken to be the linear successor to the DEM on the grounds that, pre-EMU, the DEM was a pan-European vehicle currency (see Hartmann, 1998).

In our data, the side (initiator) of each spot FX trade price is provided by EBS, i.e. whether a trade was an executed bid limit order or an executed ask limit order. The trade indicator variable, Q_t , equals +1 when the trade was buyer initiated and -1 when it is seller initiated. Return is defined as the change in trade price variable, ΔP_t , which equals $P_t - P_{t-1}$, where P_t is the transaction price and where successive prices occur within contiguous trading periods. The latter is defined as the trading day, to avoid problems with overnight periods.

Both Huang and Stoll (1997) and Madhavan et al. (1997) utilise the Hansen (1982) Generalised Method of Moments (GMM). We follow closely the methodology of the former. Both studies choose this method because its very weak distributional assumptions make it good at capturing unspecified errors. The basic trade indicator model (equation (1)) is implemented in the GMM structure by the expression:

$$f(x_t, \omega) = \begin{bmatrix} e_t Q_t \\ e_t Q_{t-1} \end{bmatrix}$$

where $\omega = [S\lambda]'$ is the vector of parameters. The orthogonality conditions are therefore expressed as $E[f(x_t, \omega)] = 0$. The basic Huang and Stoll (1997) model is exactly identified using this method.

For the more advanced Huang and Stoll (1997) model (equations (2) and (3)), the methodology is the same, except that the $f(x_t, \omega)$ vector is now expressed as:

$$f(x_t, \omega) = \begin{bmatrix} e_t Q_t \\ e_t Q_{t-1} \\ e_t Q_{t-2} \\ u_t Q_{t-1} \end{bmatrix}$$

where $\omega = [S\alpha \beta \pi]'$ is the vector of parameters of interest. The more advanced model is also exactly identified, since the number of orthogonality conditions again equals the number of parameters to be estimated.

The modified trade indicator model (equation (12)) reverts to two orthogonality conditions:

$$f(x_t, \omega) = \begin{bmatrix} e_t \left(\frac{S_t}{2} Q_t\right) \\ e_t \left(\frac{S_{t-1}}{2} Q_{t-1}\right) \end{bmatrix}.$$

However, the parameter vector now becomes $\omega = [\alpha \beta]'$, as S_t is supplied as an independent variable and π has not been included in the model.

5. EMPIRICAL RESULTS

(i) Huang and Stoll Model Results

Results for the basic Huang and Stoll (1997) model (equation (1)) are presented in Panel A of Table 1. λ represents the combined adverse selection and inventory management components of the bid-ask spread. Our analysis reveals very high λ values for the electronic inter-dealer spot FX market, leaving only a small role for the residual (order processing / price clustering) component. However, the size of this residual component appears to have risen considerably since European monetary union. Bid-ask spreads in this market also appear to have appreciated greatly over the same period, while trading volume has fallen drastically. The post-euro fall in λ pervades all 5 FX rates studied, while the increased bid-ask spread is evident in 4 of 5 currency pairs. USD/CHF is the only exchange rate bid-ask spread which does not widen. Instead, it shows a fall of over 7%. On the other hand, this is the only 1 of the 5 currency pairs to experience any increase in volume in 1999.

The results of the advanced Huang and Stoll (1997) model (equations (2) and (3)), presented in Panel B of Table 1, are puzzling. In many cases, this model produced negative values for α , while many of the β values were well in excess of 100%. The negative α values of the stage 2 models are very hard to interpret in any meaningful way. They imply the existence of 'anti-informed' traders. These traders are not just uninformed but persistently find themselves wrong-footed about the direction of the next trade. It strains credulity to think that such agents would not eventually figure out the benefits of doing the exact opposite to what their models or instincts were telling them to do. Furthermore, contrary to the required specification of the Huang and Stoll (1997) model, the π values for these trades are below 0.5, on average. This implies that transaction prices exhibit positive serial correlation, implying that prices in this market are inherently divergent rather than mean-reverting. Finally, any remaining confidence that we may have had in the extended form of the original model was removed by the finding that many of the t -statistics were below the 95% critical value level.

On the other hand, our findings closely resemble Huang and Stoll's (1997) initial results from this model. They found negative α s, oversized β s and $\pi < 0.5$, on average, for NYSE stocks. However, they bunched positively correlated trades together to induce negative serial correlation, i.e. they imposed $\pi > 0.5$. They explain this imposition by arguing that deals negotiated in the upstairs market will be broken up and appear close together in time, as sequences of same side trades in the main market. They contend that such artificial sequences would lead trade indicator models to erroneous answers and so must be removed. The authors justify their actions by arguing that market makers need to 'recover inventory holding costs from trade and quote reversals'. Since the latter is not a necessary feature of the electronic inter-dealer spot FX market structure that we study, we can not uphold such an imposition in our model. Furthermore, there is no obvious equivalent to an upstairs market in the electronic inter-dealer spot FX market.

(ii) Modified Model Results

Table 2 presents the results from the modified trade indicator model. The first thing to note is that α and β , shown in Panel B, behave as the theory predicts, for all exchange

Table 1
Huang and Stoll (1997) Model Results for Electronic Inter-Dealer Spot FX Bid-Ask Spreads

Time Period	USD/JPY		USD/CHF		EUR/USD		EUR/JPY		EUR/CHF	
	01/08/98–	01/08/99–	01/08/98–	01/08/99–	01/08/98–	01/08/99–	01/08/98–	01/08/99–	01/08/98–	01/08/99–
	04/09/98	03/09/99	04/09/98	03/09/99	04/09/98	03/09/99	04/09/98	03/09/99	04/09/98	03/09/99
No. of Obs.	399,124	225,825	42,952	72,939	484,005	310,300	128,064	42,743	73,898	29,654
Panel A: Stage 1 Model										
λ	72% (0.0069)	64% (0.0048)	86% (0.0199)	81% (0.0086)	56% (0.0053)	45% (0.0036)	91% (0.0096)	79% (0.0113)	74% (0.0135)	67% (0.0123)
S.E. (λ)	28% (0.006751)	36% (0.009588)	14% (0.000160)	19% (0.000148)	44% (0.000060)	55% (0.000067)	9% (0.000683)	21% (0.000319)	26% (0.000038)	33% (0.000065)
S	(0.00005)	(0.000054)	(0.000003)	(0.000002)	(0)	(0)	(0.000073)	(0.000319)	(0.000001)	(0.000001)
Panel B: Stage 2 Model										
α	68% (0.0587)	-142% (0.0716)	-2% (0.1087)	-41% (0.0647)	100% (0.064)	-215% (0.0744)	5% (0.1498)	8% (0.0455)	-33% (0.1211)	-6% (0.1316)
S.E. (α)	5% (0.060567)	206% (0.069797)	87% (0.100516)	121% (0.062519)	-44% (0.065773)	259% (0.073154)	86% (0.147768)	71% (0.043994)	107% (0.116317)	73% (0.128533)
β	27% (0.006714)	36% (0.009490)	14% (0.000160)	20% (0.000147)	44% (0.000060)	56% (0.000066)	9% (0.000686)	21% (0.000267)	26% (0.000038)	33% (0.000065)
S	(0.00005)	(0.000053)	(0.000003)	(0.000002)	(0)	(0)	(0.000074)	(0.000323)	(0.000001)	(0.000001)
S.E. (S)	0.5573 (0.00003)	0.4655 (0.0005)	0.4028 (0.0011)	0.4259 (0.0008)	0.5404 (0.0003)	0.4736 (0.0004)	0.4659 (0.0006)	0.3745 (0.0012)	0.4416 (0.0008)	0.4524 (0.0012)

Notes:

Panel A presents the results for the basic model (equation (1)). Panel B shows Huang and Stoll's (1997) advanced model (equations (2) and (3)). Note the EUR in 1999 refers to the euro, but in 1998 it refers to the deutschemark. In order to compare the 1998 and 1999 EUR values, a conversion rate must be introduced – the appropriate rate is the fixed EUR/DEM conversion exchange rate of 1.95583.

α = adverse selection component; β = inventory component; $(1 - \alpha - \beta)$ = order processing component; $\lambda = \alpha + \beta$; S = bid-ask spread; π = probability of reversal.

Table 2
The Components of Electronic Inter-Dealer Spot FX Bid-Ask Spreads

	USD/JPY		USD/CHF		EUR/USD		EUR/JPY		EUR/CHF	
	01/08/98–04/09/98	01/08/99–03/09/99	01/08/98–04/09/98	01/08/99–03/09/99	01/08/98–04/09/98	01/08/99–03/09/99	01/08/98–04/09/98	01/08/99–03/09/99	01/08/98–04/09/98	01/08/99–03/09/99
No. of Obs.	399,124	225,825	42,952	72,939	484,005	310,300	128,064	42,743	73,898	29,654
Panel A: Summary Statistics										
Av. Spread	0.009915	0.010257	0.000231	0.000177	0.000082	0.000073	0.010843	0.024639	0.000071	0.0001
Av. Daily Volume	399,124	225,825	42,952	72,939	484,005	310,300	128,064	42,743	73,898	29,654
Av. Volatility (Rtn)	0.0405%	0.0323%	0.0362%	0.0301%	0.0267%	0.0244%	0.0393%	0.0399%	0.0173%	0.0066%
Panel B: % Breakdown of Bid-Ask Spread (with Standard Errors)										
α	29%	7%	29%	17%	25%	9%	36%	18%	45%	33%
S.E. (α)	(0.0046)	(0.0045)	(0.0133)	(0.0084)	(0.0039)	(0.0036)	(0.0069)	(0.012)	(0.0088)	(0.0098)
β	43%	61%	56%	70%	38%	42%	50%	65%	37%	45%
S.E. (β)	(0.0052)	(0.0056)	(0.0149)	(0.01)	(0.0044)	(0.0039)	(0.007)	(0.0117)	(0.008)	(0.0113)
(1 - α - β)	28%	32%	15%	13%	37%	49%	13%	16%	18%	21%
Panel C: The Components of the Average Quoted Spread										
α	0.002900	0.000732	0.000068	0.000031	0.000020	0.000007	0.003950	0.004549	0.000032	0.000032
β	0.004233	0.006277	0.000130	0.000123	0.000031	0.000031	0.005460	0.016035	0.000027	0.000044
(1 - α - β)	0.002782	0.003247	0.000034	0.000023	0.000030	0.000036	0.001433	0.004055	0.000013	0.000020
Panel D: % Change in the Components of the Average Quoted Spread										
α	-75%		-54%		-40%			52%		2%
β	48%		-5%		81%			287%		68%
(1 - α - β)	17%		-32%		118%			273%		65%

Notes:

This table presents the components of the bid-ask spread for the USD/JPY, USD/CHF, EUR/USD, EUR/JPY and EUR/CHF spot exchange rates, computed using the Modified Trade Indicator Model. 'Av. Daily Volume' is measured as the average number of trades per day. The currency code EUR refers to the euro and to its predecessor, the deutschemark. The EUR rates comparison in Panel D has been adjusted by the fixed EUR/DEM conversion rate of 1.95583.

α = private information component; β = temporary buy-sell imbalance component; (1 - α - β) = price clustering component.

rates, in both sample periods. In contrast to the results for the original model, α is positive in every case, and α and β always sum to less than 1. π is not a necessary feature of the Modified Trade Indicator Model. Also, all t -statistics are well above the 95% critical value.

Panel B of Table 2 reveals the percentage components of the bid-ask spread for electronic inter-dealer spot FX rates. Panel C of Table 2 shows the component percentages from Panel B multiplied by the average bid-ask spreads from Panel A, which reveal the actual bid-ask spread components in amounts. In Panel D, the pre-EMU to post-EMU change in the bid-ask spreads from Panel C is shown. In particular, note that Panel D shows that by far the largest change in the components of the EUR(DEM)/USD following EMU was a 118% increase in the price clustering component.²

Compared with the original model results, where β often accounted for more than 100% of the bid-ask spread, the modified model's β component accounts for an average of around 45% of the bid-ask spread in 1998 and 57% in 1999. In every case, the 1999 β value is larger than that in 1998. Furthermore, in all but one case, the inventory component is bigger than either the information component or the price clustering component. This fits in with the conclusions of McGroarty, ap Gwilym and Thomas (2005) who found that private information could not account for observed excess volatility in the spot foreign exchange market.

For all currency pairs, in both time periods, it is evident from Panel B that the private information component comprises less than 50% of the bid-ask spread. In 9 out of 10 cases, the informationless temporary buy-sell imbalance component is a more important factor than the private information factor. In 3 out of 10 instances, price clustering proves to be a more significant factor than private information, while in another 3 instances, their magnitudes are broadly similar. In all cases studied here, the private information component is smaller in the post-EMU sample than it was before. Average α declined from 33% in 1998 to 17% in 1999. This is counterbalanced by a larger post-EMU temporary buy-sell imbalance component in every instance. Panel D corroborates the finding that the latter factor grew greatly in importance after EMU, that price clustering also grew in importance and that the relative role of private information was greatly diminished.

The finding that private information accounts for so little of bid-ask spread composition relative to temporary buy-sell imbalance and price clustering seems very much at odds with Bjonnes and Rime's (2005) finding that private information accounts for as much as 80% of (DEM/USD) bid-ask spreads. However, the two studies attempt to explain very different phenomena. Our objective is to identify the components of global market electronic inter-dealer bid-ask spreads for major exchange rates. By contrast, Bjonnes and Rime (2005) sample is quite small, covering only 4 dealers at a single Scandinavian bank, who trade with customers and directly with other banks, as well as in the brokered inter-dealer market. Bjonnes and Rime (2005) find that inventory turns over quickly and does not require price shading by market makers to entice buyers as is commonly proposed in the literature. Assuming that their findings are representative of the wider global market, our finding that the inventory type factor makes up much of the bid-ask spread does not contradict their conclusion that inventory is a small component.

2 The EUR/DEM official conversion exchange rate of 1.95583 is applied to all cases where EUR denominated amounts are compared to DEM denominated amounts.

Where does the inventory identified by Bjonnes and Rime (2005) go? Our model provides a possible solution. What we interpret as temporary buy-sell imbalances could well be their dealer inventory passing easily into the low cost (relative to customer market) and very liquid inter-dealer market, where it ultimately impacts on prices. This would make inventory an important factor for us but a small factor for Bjonnes and Rime (2005), as is observed. Individual dealers may be able to extract private information from bilateral trades with customers. However, they may not parlay this advantage undiminished across the electronic inter-dealer market. Dealers exploiting private information by strategically mixing limit orders with market orders would cause our inter-dealer private information component to be smaller than Bjonnes and Rime's (2005) individual dealer one, as is observed. Finally, we do not need to reconcile our residual components of the bid-ask spreads. Order processing is a plausible concept for Bjonnes and Rime's (2005) dealer-customer-dominated bid-ask spreads, whereas price clustering makes much more sense as the residual of the narrow bid-ask spreads in inter-dealer trades between equals.

6. CONCLUSIONS

Our modified trade indicator model proved more appropriate for the electronic inter-dealer spot FX market than the original model. The latter produced implausible results. The principal reason for those extreme results proved to be a key assumption in quote-driven market microstructure models, namely, that negative serial correlation, induced by market maker inventory management behaviour, should cause prices to revert to the mean. However, order-driven markets like the electronic inter-dealer FX market work differently, since market makers are not a necessary feature of these kinds of markets. New theory from Bloomfield et al. (2005), which takes account of these differences in market structure and trader behaviour, enabled us to develop our modified trade indicator model. This model produced reasonable results for all FX rates and time periods.

We revised two of the three bid-ask spread component definitions. We used the terms 'temporary buy-sell imbalance' rather than 'inventory' and 'price clustering' rather than 'order processing'. For our third component we retain the term 'private information' which had been used in earlier bid-ask spread models, but we reject the synonymously used term 'adverse selection'. Our definitions make more sense in the context of known features of the electronic inter-dealer spot FX market. Our three factors provide a very plausible explanation of how prices are formed in this important global market. Firstly, inventory passed on by dealers finally impacts on price in the inter-dealer market. Secondly, private information from customers is obscured and exploited by dealers. Thirdly, price clustering is a more credible residual factor than order processing in an egalitarian electronic inter-dealer market setting.

The sharp decline in the size of the post-EMU private information bid-ask spread component suggests that 'informed' FX limit-order traders were less able to predict and profit from future price moves in the period following currency convergence than they were before. Factors relating to the transition of one market regime to another could account for this. For currency pairs involving the EUR, the market may have had early difficulty in interpreting and predicting the actions of the new European Central Bank (ECB). For all exchange rates, the changing market structure and different set of international investment opportunities may have diminished traders' ability to interpret

and forecast order flow. The market configuration would have changed when former cross-rate traders were redeployed or left the industry. In addition, the actions and behaviour patterns of international investors and risk managers probably changed as they navigated a new and different post-EMU economic landscape.³

The dominance of price continuations over price reversals remains a curious finding. In conjunction with the post-EMU dominance of informationless temporary buy-sell imbalances, it suggests that accumulated order flow imbalances, which are not linked to changes in economic fundamentals, may have a lasting impact on price. This would contradict the conventional notion that lasting price perturbations can only arise from fundamental information. It suggests that the market requires price concessions in order to absorb accumulated excesses of demand or supply and prices do not immediately recover from the new concessionary levels, as is usually supposed.

REFERENCES

- Angel, J.J. (1994), 'Limit versus Market Orders' (Mimeo, School of Business Administration, Georgetown University).
- BIS (Bank of International Settlements) (1998), Central bank survey of foreign exchange and derivative market activity in April 1998.
- (2001), Central bank survey of foreign exchange and derivative market activity in April 2001.
- Bjornnes, G.H. and D. Rime (2005), 'Dealer Behavior and Trading Systems in the Foreign Exchange Market', *Journal of Financial Economics*, Vol. 75, pp. 571–605.
- Bloomfield, R., M. O'Hara and G. Saar (2005), 'The 'Make or Take' Decision in an Electronic Market: Evidence on the Evolution of Liquidity', *Journal of Financial Economics*, Vol. 75, pp. 165–200.
- Cai, C.X., R. Hudson and K. Keasey (2004), 'Intra Day Bid-Ask Spreads, Trading Volume and Volatility: Recent Empirical Evidence from the London Stock Exchange', *Journal of Business Finance & Accounting*, Vol. 31, pp. 647–76.
- Choi, J.Y., D. Salandro and K. Shastri (1988), 'On the Estimation of Bid-Ask Spreads: Theory and Evidence', *Journal of Financial and Quantitative Analysis*, Vol. 23, pp. 219–30.
- Cohen, K.J., S.F. Maier, R.A. Schwartz and D.K. Whitcomb (1981), 'Transaction Costs, Order Placement Strategy, and Existence of the Bid-Ask Spread', *Journal of Political Economy*, Vol. 89, pp. 287–305.
- Easley, D. and M. O'Hara (1987), 'Price, Trade Size and Information in Securities Markets', *Journal of Financial Economics*, Vol. 19, pp. 69–90.
- Foucault, T., O. Kadan and E. Kandel (2001), 'Limit Order Book as a Market for Liquidity' (Mimeo, HEC School of Management).
- George, T.J., G. Kaul and M. Nimalendran (1991), 'Estimation of the Bid-Ask Spread and its Components: A New Approach', *Review of Financial Studies*, Vol. 4, pp. 623–56.
- Glosten, L. (1994), 'Is the Electronic Open Limit Order Book Inevitable?' *Journal of Finance*, Vol. 49, pp. 1127–61.
- and L.E. Harris (1988), 'Estimating the Components of the Bid-Ask Spread', *Journal of Financial Economics*, Vol. 21, pp. 123–42.
- Glosten, L.R. and P.R. Milgrom (1985), 'Bid, Ask and Transaction Prices in a Specialist Market with Heterogeneously Informed Traders', *Journal of Financial Economics*, Vol. 14, pp. 71–100.
- Goettler, R., C. Parlour and U. Rajan (2005), 'Information Acquisition in a Limit Order Market', presented at the Norges Bank/BI Conference on The Microstructure of Equity and Currency Markets (Oslo).

3 Yang, Ming and Li (2003) found that European stock markets became integrated after EMU but more detached from non-EMU members like the United Kingdom.

- Gregoriou, D., C. Ioannidis and L. Skerratt (2005), 'Information Asymmetry and the Bid-Ask Spread: Evidence from the UK', *Journal of Business Finance & Accounting*, Vol. 32, pp. 1801–26.
- Hansen, L. (1982), 'Large Sample Properties of Generalised Method of Moment Estimators', *Econometrica*, Vol. 50, pp. 1029–84.
- Harris, L. (1998), 'Optimal Dynamic Order Submission Strategies in Some Stylised Trading Problems', *Financial Markets, Institutions and Instruments*, Vol. 7, pp. 1–75.
- Hartmann, P. (1998), *Currency Competition and Foreign Exchange Markets* (Cambridge University Press).
- Hau, H., W. Killeen and M. Moore (2002), 'How has the Euro Changed the Foreign Exchange Market?', *Economic Policy*, Vol. 17, pp. 149–91.
- Ho, T. and H.R. Stoll (1981), 'Optimal Dealer Pricing Under Transactions and Return Uncertainty', *Journal of Financial Economics*, Vol. 9, pp. 47–73.
- Huang, R. and H.R. Stoll (1997), 'The Components of the Bid-Ask Spread: A General Approach', *Review of Financial Studies*, Vol. 10, pp. 995–1034.
- Killeen, W., R. Lyons and M. Moore (2006), 'Fixed Versus Flexible: Lessons from EMS Order Flow', *Journal of International Money and Finance*, Vol. 25, pp. 551–79.
- Lyons, R.K. (2001), *The Microstructure Approach to Exchange Rates* (MIT Press).
- Madhavan, A., M. Richardson and M. Roomans (1997), 'Why Do Security Prices Change? A Transaction-Level Analysis of NYSE Stocks', *Review of Financial Studies*, Vol. 10, pp. 1035–64.
- McGroarty, F., O. ap Gwilym and S.H. Thomas (2005), 'Private Information, Excessive Volatility and Intraday Empirical Regularities in the Spot Foreign Exchange Market', Discussion Papers in Centre for Risk Research, CRR-05–01 (Southampton: University of Southampton).
- _____ (2006), 'Microstructure Effects, Bid-Ask Spreads and Volatility in the Spot Foreign Exchange Market Pre and Post-EMU', *Global Finance Journal*, Vol. 17, pp. 23–49.
- Parlour, C. (1998), 'Price Dynamics in Limit Order Markets', *Review of Financial Studies*, Vol. 11, pp. 789–816.
- Rock, K. (1990), 'The Specialist's Order Book and Price Anomalies' (Mimeo, Graduate School of Business, Harvard University).
- Roll, R. (1984), 'A Simple Implicit Measure of the Effective Bid-Ask Spread in an Efficient Market', *Journal of Finance*, Vol. 39, pp. 1127–39.
- Seppi, D.J. (1997), 'Liquidity Provision with Limit Orders and a Strategic Specialist', *Review of Financial Studies*, Vol. 10, pp. 103–50.
- Van Ness, B.F., R.A. Van Ness and R.S. Warr (2002), 'Is the Adverse Selection Component Really Higher on the NYSE/Amex than on the Nasdaq?', *Journal of Business Finance & Accounting*, Vol. 29, pp. 807–24.
- Yang, J., I. Min and Q. Li (2003), 'European Stock Market Integration: Does EMU Matter?', *Journal of Business Finance & Accounting*, Vol. 30, pp. 1253–76.