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ONE DAY IN JUNE, 1993: A STUDY OF THE WORKING OF REUTERS 2000-2 ELECTRONIC FOREIGN EXCHANGE TRADING SYSTEM

Charles Goodhart
Takatoshi Ito
Richard Payne

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This lengthy empirical exercise was done in a number of stages. After one of the authors, C. Goodhart, had obtained the original video-tapes from Reuters, to whom we are most grateful, the data on the tapes was transcribed onto paper by two of the authors' wives, Mrs. Goodhart and Mrs. Ito, assisted by Yoko Miyao, a painstaking task beyond and above the normal requirements of matrimony. The data were then sorted and organised by T. Ito and R. Payne, separately in the U.S.A. and U.K. The graphical appendix is entirely Ito's work. The descriptive material in Sections I and II was mostly written by Goodhart. The comparison of D2000-2 and FXFX in Section III had inputs from all authors, but mostly Goodhart and Payne. The comparable FXFX data were obtained from Olsen and Associates, to whom we are most grateful. Only the first three sections were ready in time for the July Perugia Conference, so this is all that our discussants, to whom we are most grateful, then had before them. Section IV, completed thereafter, was entirely the work of Goodhart and Payne, with Payne responsible for the econometrics, apart from Table 15 by Ito. Charles Goodhart and Richard Payne wish to thank the ESRC for financial support. Takatoshi Ito thanks Charles Kramer for technical assistance in producing the graphical appendix. This paper is part of NBER's research programs in Asset Pricing and International Finance and Macroeconomics. Any opinions expressed are those of the authors and not those of the National Bureau of Economic Research.

I Introduction

This is a study of foreign exchange dealers' behaviour as revealed in the working of Reuters 2000-2, a recently developed electronic foreign exchange trading system. It was launched in 1992 with 23 subscriber sites in two countries, and by September 1993 had more than 230 dealing sites in 28 cities in 17 countries.[1] The working of the System is described in more detail in Section 2. This dealing System 2000-2, henceforward termed D2000-2 is, however, still at the developing rather than a mature stage and the snapshot that we have of its operations on one day in June, 1993, June 16th, may have become out-dated and obsolete by the time that this is published.[2]

Reuters has become subject to competition in this market place, from Minex, and from the Electronic Broking Service, (EBS). The former was established in April, 1993, by Japanese institutions and, according to Blitz (Financial Times, Sept 13, 1993) "much used in Asia", although it did not, as of September 1993, reveal the number of trades crossed or terminals used. EBS was founded on Wednesday, September 21st, 1993. It cost, again according to Blitz, around £40 million to launch, and has been backed by a dozen leading banks in foreign exchange -such as Citibank and Chase Manhatten - who formed a consortium with Quotron, an electronic information screen competitor with Reuters.

In September 1993, Mr Bob Etherington, Reuters' international marketing manager would not reveal his dealing system's current volume levels, though Blitz did report that the "System has reached [its] initial target of 1,000 trades a day, each for a minimum 1 million units of currency dealt".[3] As noted, Minex was not then disclosing the number of trades, and EBS had not started, but was going to invite dealers "to trade in standard amounts of $5 million in Dm/$ and £5 million in £/Dm".

Such electronic dealing systems, (as contrasted with informational pages supplying indicative bid/ask quotes, such as Reuters FXFX page), are still in their early stages, and are highly competitive. Moreover, they may have an important future. "Roughly 60 per cent of deals in the currency market are now done by traders in two banks - or counterparties - who call one another up directly. The remainder of deals are done through brokers, who bring together diverse buyers and sellers. ... But they [the banks] complain that the commissions charged for broking a deal are very high. Automated brokerage terminals do the same job as humans at a reduced cost. ... The banks are attracted by the reduced cost of commission. But they fear that 2000-2 will help monopolize the market in electronic dealing systems. Mr Bartko, [chairman of the EBS partnership], admits that this is one of the principal motives for this week's launch of EBS."[4]

Electronic trading systems have been in use for rather longer in other financial markets, notably in standardised futures and options markets. Instinet and Globex are two such which Reuters has again been developing. A useful taxonomy of the modus operandi of such electronic trading systems has been provided by Domowitz (JIMF, 1993, and JFI, 1990).

Under these circumstances details of the workings of such systems remain commercially sensitive. The data base which we have studied, a video-tape of all the entries over D2000-2 for almost exactly seven hours for the Dm/$, and some sixteen minutes less for five other bilateral exchange rates, shown on D2000-2 screen during European business hours on June 16th, (from 08-31-50 to 15-30-00 BST, i.e. GMT +1), remains the copyright of Reuters.[5] Anyone wishing to use these data should refer to them, not to us. We should like to emphasize that this video-tape did not include, and we have not been given any access to, any information regarding the identity of any of the parties involved in trading; all the trades observed by us remain anonymous. Indeed it is not possible for any observer, even in Reuters itself, to identify which are the individual banks using the system.

Readers should keep in mind the shortcomings of these data. They represent a short snap-shot of conditions in a rapidly changing market over a year ago. Trading undertaken over such electronic trading systems may well be, as discussed further below, not representative of the market as a whole; trading activity on D2000-2 on June 16th 1993 may have differed in some respects significantly from that in surrounding days and weeks; the volume and characteristics of electronic trading (over Reuters) in June, 1993, may well be quite different from that now, since over a year has passed.

Given these disclaimers, why should anyone bother to read on? Despite these shortcomings there are, however, several reasons why this study provides new insights in the literature of high frequency exchange rate behaviour. First, there have up till now been virtually no continuous time-series data available at all on actual trades, prices and volumes, in the foreign exchange market.[6] The 60%, or so, of deals done directly by two bank counterparties over the telephone remain, naturally, private information. There has been little use made of data on forex transactions intermediated by specialist inter-bank brokers, no doubt partly because of commercial and confidentiality sensitivities. The only studies currently known to us making use of such data are by Professor R Lyons (1993a, 1994.) Data of any kind on the characteristics and continuous time series behaviour of actual trading transactions on the forex market are, therefore, still rare.[7] Second, there have been so few data on transactions in the foreign exchange market, that almost all the studies on this market have used data on bilateral currency exchange rates which emanate from the indicative bid/ask prices shown on electronic screens by the specialist information providers, e.g. Reuters, Telerate, Knight Ridder, Quotron. There has, naturally, been some concern whether the high-frequency characteristics of such indicative quotes, e.g. the negative auto-correlation and the fact that the size of the spread clusters at certain conventional values, are representative of the characteristics of firm (committed) bid/ask quotes at the touch. The touch, a term more commonly used in the UK than in the USA, is defined as the difference between the best (highest) bid and lowest ask on offer, where these are (usually) input by different banks. Lyons (1993a), for example, expressed such concerns when he wrote "Some of the shortcomings of the indicative quotes include the following. First, they are not transactable prices. Second, while it is true that the indicated spreads usually bracket actual quoted spreads, they are typically about twice as wide as quoted spreads in the interbank market. Third, the indications are less likely to bracket true spreads when the intensity of trading is highest: marketmakers can get too busy dealing to update their indications. And finally, my experience sitting next to marketmakers at major banks indicates that they pay no attention to the current indication; rather, marketmakers garner most of their high frequency market information from signals transmitted via intercoms connected to brokers and the IMM futures market [see Lyons (1993b)]. In reality, the main purpose of the indications is to provide non-marketmaker participants with a gauge of where the market is trading."[8]

Do, for example, the frequency and volatility of the indicative quotes provide a reasonable proxy for the same characteristics both in the committed bid/ask quotes and the associated transactions in the electronic trading systems? We provide an initial answer to such questions in Section 3, where we seek to compare characteristics of the FXFX time series[9] with those of the D2000-2 data for the overlapping seven hours. As described in more detail in Section 3, the D2000-2 series was not time-stamped and our study of this relationship is conditional on the assumptions and techniques used to match these two series temporally.

Subject to that condition, and to anticipate some of our main findings in Section 3, the averages of the bid/ask in both series (FXFX and D2000-2) are almost identical. A graph of the time path for the Dm/$ from the two sources looks like one line; see Chart I. Thus the time path of the indicative quotes can, on this evidence, be taken as a very good and close proxy for that in the underlying firm series. Nevertheless some of the characteristics of the bid/ask series, e.g. the pattern of auto-correlation, are somewhat different. Even so, both series indicate a somewhat similar GARCH pattern. As would be expected, the two series are cointegrated, with the indicative series responding more to deviations from the equilibrium (i.e. a larger and more significant negative coefficient on the error correction mechanism). By contrast the characteristics of the spreads in the FXFX as compared with the touch in D2000-2 are markedly different. The spreads in the FXFX series show clustering among a small number of standard values (eg 5, 7 and 10 pips for the Dm/$), whereas the spreads at the touch show no such signs of clustering.

After examining the relationships between the quote series and associated spreads of FXFX and D2000-2 in Section 3, we turn in Section 4 to a more detailed study of the characteristics of D2000-2, and in particular the interaction between quotes and transactions in that data set. This long section has five sub-sections. First, in Section IVA, we examine the statistical characteristics of the transaction price series in D2000-2. Whereas the quote series, for both D2000-2 and FXFX, incorporate a first order negative moving average, the transaction price data appear to follow a random walk. Our most interesting finding is that the series of runs of deals, sequences of trades at the bid and the ask, is not normally distributed, but contains some very long consecutive sequences, another fat-tailed distribution.

Second, in Section IVB, we examine the inter-relationships between the available data series, using nine main series from D2000-2, all of which, apart from the spread, can be separately obtained for the bid and the ask. These are the frequency of transactions (deals), their size, and whether such transactions exhausted the quantity currently quoted; then the frequency of quote revision, the change in the quoted prices, and the quantity quoted; two measures of volatility, the absolute change in the quote and the standard deviation of the quotes. Our main finding is that there is a two-way inter-relationship between the frequency of quote revisions and the frequency of deals,and that when a deal exhausts the quantity on offer this then affects (with one-way causality) a nexus of relationships between volatility, spreads and quote revisions. We also do similar companion studies on the (temporally associated) FXFX data using a smaller sub-set of data series, (since we have no data on transaction characteristics or on posted quantities from FXFX,) but these have less interesting results.

Our finding that there is a strong two-way relationship between the frequency of quote revisions and of transactions within a period is, we believe, new, though the underlying cause, that both derive from the arrival of 'news' is theoretically straightforward. Most studies of transactions in other asset markets, e.g. the NYSE, have used data series calibrated in transaction (tick) time, so that one cannot then infer calendar time frequency. Otherwise, with relatively low frequency transactions on the NYSE, so many of the observations would exhibit zero change. With much higher frequency transactions on forex markets, it seemed worthwhile to us to explore the form of these relationships both in clock time and transaction time, though we feel that much remains to be done in clarifying the appropriate econometric usage in this field.

Next, in Section IVC, we examine the ARCH (autoregressive conditional heteroscedasticity) characteristics of the quote series, in particular to discover whether their GARCH characteristics would be affected by the addition of transactions data. In this case, unlike most of the other main results in Section IVB, the results did appear sensitive to whether the exercise was run in clock time or tick time.

Largely because much more data have been made available for the equity market, especially the NYSE, and its associated derivative markets, there has been much more empirical work on those markets than for the forex market. Moreover the two markets are quite dissimilar in format and micro-structure, as nicely described in Bessembinder (1994). Nevertheless, despite the comparatively very small size of our data set, its coverage of transactions, as well as quotes, brings it somewhat nearer to the richer data sets available on equity markets. In particular our study here, examining the interaction between trades at the bid and ask and price quote revisions, has some features in common with that of Hasbrouck's (1991) study of such effects in the New York Stock Exchange, 'Measuring the Information Content of Stock Trades'. So we then replicate his study as closely as we could, using our own data set, and adding some variations of our own.

We draw the conclusions of these exercises undertaken earlier in Section IV together in the final part, Section IVE. Throughout this work the caveat that our data set only lasts for seven hours, a possibly atypical period, must always be kept in mind, despite the comparatively large number of data points. It is in this sense a very small sample. All our findings, both positive and negative, must be treated with caution.

II The Characteristics of D2000-2

Automated brokerage terminals do the same job as humans but at a reduced cost. A bank dealer, who is a member of one of these electronic systems, can enter her buy and/or sell price into them. Reuters D2000-2 and EBS only show the touch, the highest bid and lowest ask; these will normally, but not necessarily, be entered by different banks. This is different from the indicative forex pages, e.g. FXFX, which show the latest update of the bid and ask entered by a single identified bank. On all the electronic trading systems the identity of the inputting bank is not shown. The quantity which the inputting bank is prepared to trade is also shown on D2000-2. This was then shown as integers of 1 million dollars, and in some bilateral cases 1 million Dm, from 1-5; entered as M (Medium) for a sum between \$6 and \$10 million; and L

(Large) above $10 million[10]. More than one bank may input the same best bid (ask) price, in which case the quantity shown is the sum of that offered by these banks. The limit orders, i.e. those below the (best) bid and above the (best) ask, and their associated firm quantities are entered and stored in these systems, but are not revealed over D2000-2 and EBS. Such reserve limit orders are shown on Minex.

Another bank dealer, and member of the trading system, can then 'hit' either the bid, or the ask, by typing instructions on his own machine. The first check is prudential. Banks in such systems may want to restrict the amount of dealing with certain other counterparties, (in some cases refusing to deal at all with some counterparties). The computer first checks whether the deal is prudentially acceptable to both parties (who remain at this stage anonymous). If not, the deal is refused and the 'hitter' so informed. We have no information how often this might happen, but we surmise that it might be fairly rare. Assuming that the 'hit' is accepted, and that several banks are offering the same best price, their offers are met on the basis of the time of entry, first in first out. When a new deal is made, the new transaction price enters on the right hand column of the screen[11], and there must be an associated change in the quantity of the bid (ask), depending on which is hit[12], and also in the price offered if the size of the deal exhausts the quantity offered at the previous price. In such cases, the bid price must move downwards if there was an exhaustive deal at the bid, and the ask price upwards following an exhaustive deal at the ask, or indicate that there are no remaining limit bids (asks) in the systems, i.e. no quote shown[13]. Note that in an automatic system like this, a deal must be made at either the posted bid or ask, and cannot be made at an interior price between them, as can happen with non-automated human dealers, which can cause problems in empirical studies. This has been a particular problem for empirical studies of the NYSE, see for example Petersen and Fialkowski (1994) and Lee and Ready (1991).

D2000-2 allowed traders to deal in some 15 major bilateral exchange rates at the time of our exercise. The number and range of currencies covered has been changing over time, as is no doubt the case for EBS and Minex as well. The size of the screen for D2000-2 is not big enough to show all 15 at once, and in any case such a large number of separate rates might be distracting. So, the dealer on D2000-2 can call up to six bilateral exchange rates onto the screen at any one time.

All this may be made somewhat easier to follow by seeing an example of what a dealer would see when looking at her screen. This is shown in Table 1, in the collected Tables at the end of the paper. Note, in particular, that not all the cells have entries. There are periods, especially in the less actively traded bilateral exchange rates, when no bank is making a firm offer. A bilateral currency can have a firm bid (ask) exhibited without there being any corresponding ask (bid) on the screen, as in this example for the DEM/FRF exchange rate; so there is no observed spread at such times. Any bid/ask price must be associated with an accompanying quantity offered, (and vice versa). As electronic trading becomes more popular, so such gaps in prices may be expected to become fewer. Also note that the representation of the bilateral exchange rate in the left hand column is the reverse of what would be normally expected, i.e. row one would in normal usage be described as the number of Yen per $. (We thank a discussant for noticing this.) The reason, we understand, for this ordering is that all the volumes are denominated in units of 1,000,000 of the first currency shown. Henceforth however, we will revert to the standard representation of the bilateral rates.

D2000-2 runs throughout the whole day during the week, apart from a short break from 2300 to 0100 GMT. On June 16th, a Reuters employee started to video-tape the bilateral Dm/$ exchange rate at approximately 08.30 hours BST. This is the dominant and most active of all exchange rates. (See, for example, Goodhart and Demos, 1990 and 1991 a and b.) About 16 minutes 30 seconds later he also put the additional five bilateral exchange rates up onto the screen that were shown in Table 1[14].

It is this videotape, initially filmed for their own purposes, which Reuters were kind enough to let us observe, subject to confidentiality commitments. There are four Betacam tapes, which ran virtually continuously, subject to a future minor qualification, from 08.32 BST to 15.30 BST (on June 16th). The screen does not show the clock time, and the entries are not time stamped, but a time elapse (time passed since the start of videotaping) was entered onto the tape[15].

As might be expected, when the commitments made on screen are firm, and deals are made at those prices, the original data are, as far as we can judge, remarkably accurate. We ended with only a couple of data points which we felt must be an error. This compares with errors that occur about once in every 400 entries over FXFX (see Pictet et al. 1994, table 5). By contrast, we are conscious that there will be a number of transcribing errors. In particular, whether because of the need to copy the tapes, or for some other reason, the final digit of the five (in one case four) digit number was often hard to decipher. In particular it was difficult to distinguish zero from eight, when these were faint on the videotape[16].

In one respect, fortunately, the data are self-checking. When a deal occurs, the transaction price on the right hand column <u>has</u> to be the same as the <u>prior</u> (that is, within seconds earlier) bid, or ask, that was hit, and must change the quantity offered at that prior price, and also the price itself, should the quantity be fully taken up. The two series (i.e. of transactions prices on the one hand, and bid/ask prices and their associated quantities on the other) were transcribed at separate times. By marrying these up[17], and reviewing in cases of errors, we can crosscheck both the accuracy of our transaction data and get some idea of the remaining errors in variables for the entries (bid/ask and associated quantities offered) where no such cross-check was possible.[18]

Turning now to the data themselves, the data base divides into two separate parts. First there is the Dm/$ market. This is the dominant exchange rate in the forex market overall, and its dominance of the electronic market in our snapshot is even more marked. There were 799 bid entries and 823 ask entries, (nb these entries would usually come from separate banks). Quantities offered at the bid were entered on 802 occasions and at the ask on 841 occasions. (Note that the quantity offered can, and does, change quite frequently without an associated bid/ask price change. Similarly the price can change without the associated quantity being altered; this happened on more occasions than we would have expected, perhaps because a bank changed the price for a given amount that it wanted to trade.) Although we cannot possibly deduce the total number of independently made entries, these might conservatively be put at around 1,500 in seven hours, or 200 or so per hour. This compares with some 3500 entries over FXFX for the Dm/$ bilateral exchange rate in the same hours, about 500 per hour. Considering that FXFX represents almost costless advertising, and is the most commonly used indicative forex price screen, this shows just how busy the Dm/$ market on D2000-2 was during this snapshot.

The number of deals in the Dm/$ market was also quite large, relative to the commercial target, reported in Section 1, of 1,000 per day for deals in all 15 exchange rates. During this snapshot, there were 186 deals done at the bid and 251 at the ask. Whether this ratio of deals to bid/ask entries is high, low or normal, we cannot tell. We examine whether this ratio varied significantly from half-hour to half-hour over our data period in Section 3.

The depth of the Dm/$ market on D2000-2 was fairly good, though it can, and no doubt will, improve further. Following a deal that exhausted the quantity offered, or the removal of a bid/ask price, most of the time there was another limit order on the computer at a closely related price. Histograms of quantities offered at the bid measured both over frequency of entry and duration of entry are shown below in Figures 2 and 3. The histograms for the Ask are nearly identical and have been omitted to save space. From these it can be seen that the frequency and length of time during which no bid or ask price is on the screen for the Dm/$ is both few and brief.

Note that the majority of the quantities offered, both at the bid and the ask, are usually at or below 5. Consequently the average size of deal here is also low. We cannot estimate it exactly because we cannot see the actual data lying behind M and L. If, however, we take M to be 8 on average, and L to be 15, then the average size of deal at the bid was $2.51 mn and $2.49 mn at the ask, i.e. of similar size. A recent paper by Garrett Glass, (forthcoming,) examining all forex deals over the Multinet system puts the average size of deals at about $9 million.[19] Be that as it may, it is the case that deals in the Dm/$ D2000-2 market were, by this standard, unrepresentatively small on average. Why this should have been so, we do not know, but in an accompanying paper in this Volume, Prof. R. Lyons reports that the average size of deals done through brokers is lower than that of customer deals, and his figure for the size of average broker deals is not that much larger than that shown here.

One factor reducing the number/duration of occasions on which there might have been no entry in the Dm/$ ask series was that a participant, presumably a single bank, kept an off-market ask entry in the computer at 1.6475, when the market was actually running at about 1.6440. When no other entry was better, this was triggered, see Figure 4. As the graph shows, the US$ appreciated sharply thereafter and the bank involved presumably disposed of its unwanted dollars. In the meantime, however, it represented a nuisance entry for us, distorting the true underlying pattern of the market. No deal was, naturally enough, done at such an off-market price, prior to the occasion of the $ appreciation. We decided to remove these off-market asks, [between observations 250 and 450 on the ask side]. We did not remove the few asks at the same price earlier, (around the 50th observation), since these were not seriously off-market, [nor did we remove two solitary occasions of off-market bids at 1.6405]. The resulting, adjusted ask series looks as follows, as shown for comparison in Figure 5.

As these charts clearly show, the major events in the forex market on June 16th were two brief periods of sharp appreciation in the US$, the first lasting from about 1339 BST to about 1345 BST and the second from about 1443 to 1445 BST as indicated by the time stamp on the FXFX data series. The average price of FXFX quote entries in each minute during the course of these two jumps is shown in Table 2.

The underlying cause, from 'news' arrival, of these $ appreciations against the Dm are clear enough, but their exact timing is difficult to relate to the news items coming over AAMM (the Reuters news page) on that day. The news on that day was 'bearish' for Germany and 'bullish' for the US. See Table 3. Possibly the 1338-1345 BST jump in FXFX could have been triggered by the US housing figures, (certainly the dollar opened firm in the USA), and the 1442-1445 jump to a delayed reaction to the German government report, but such links cannot be firmly established. The finding here is consistent with other findings in the literature which tend to find difficulties in matching news events to jumps in the asset price and vice versa. Nevertheless one can hardly query the time stamp on the FXFX data, and the extent, and timing, of these jumps are very closely matched by the data on D2000-2, as will be discussed further below. One interesting feature of these jumps in the value of the dollar is that they were associated with great activity on the ask side of the market, and very little action, even in the guise of price revisions, on the bid. From 1337 BST to 1345 BST, there were 17 deals at the ask in D2000-2; none at the bid. Over the same period there were some 39 price revisions at the ask; and 13 at the bid, two of these remaining established and unchanged for almost two minutes each. From 1442 BST to 1446 BST there were 13 deals at the ask; none at the bid. There were some 26 price revisions at the ask. A few seconds after the start of the $ appreciation, the existing bid price was removed from the screen, and for the remaining 3½ minutes of the appreciation no bid price at all was posted; this was the longest gap in having a firm price set for either the bid, or ask, in our data set for the Dm/$. Otherwise price setting in the Dm/$ over D2000-2 was nearly continuous.

A graphical representation of the bid/ask prices quoted, the occasion and price of deals, and the quantities offered for the Dm/$, for the first and sixth hour is shown in Graphs 1-6 in the graphical Appendix.

Such continuous price setting was not the case for the other five bilateral exchange rates exhibited on the screen during our 7 hour snapshot. Simple observation revealed that market activity in these rates on D2000-2 over our data period was far more patchy. Initially the rates were not put onto the screen for some 16 minutes after the Dm/$ was shown. Thereafter during the following 6¾ hours, there were in some cases quite long gaps in setting bid/ask prices. The average quantities dealt ranged from just over $1 mn (CHF/$ Bid) to nearly $3 mn (FrFr/Dm Ask); the data are shown in Table 4; the figures in brackets in Table 4 report the original average Dm size when the deals were done in units of 1 mn Dm. Deals were, however, much fewer in number, than for Dm/$. When there are large price movements, the majority of the deals seem to be purchases of the appreciating currency and the majority of quotes are on the strong side of the market (see Table 5.) We pursue this effect somewhat further in Section 4 below. A graphical representation of activity in the Yen/$ exchange rate, over these hours, is shown in Chart 2 in the graphical Appendix. Data on these deals and the number of bid/ask price entries are given in Table 4, and histograms of the bid quantities offered are shown in Charts 6-10; again the similar Ask histograms are omitted to save space.

These histograms show differing patterns. The quantities offered on the $ based bilaterals, i.e. Dm/$, Yen/$, Chf/$, are predominantly for 1 or 2 units, with increasingly few offers made as size increases. The quantities offered on the Dm-based bilaterals, i.e. Yen/Dm, Chf/Dm and FrFr/Dm, show many more (proportionately) larger offers, quite remarkably so for the FrFr/Dm (Chart 9). One possible explanation is as follows. Suppose that the European cross rates tend to move less than the dollar-based bilaterals, then the risk involved in building up inventories for a dealer is less. Hence, a larger unit bid is offered. Now; the Chf/Dm and FrFr/Dm rates should move less than the correspondant currencies vis-a-vis the dollar, because the Dm and FrFr are in the ERM and the Chf closely follows the Dm historically. Even the Yen/Dm volatility tends to be less than in the Yen/$ or Dm/$ rates.

We should again stress that we have no means of knowing whether these, somewhat patchy, results were representative of activity in these exchange rates at other times of the day, (n.b. activity in the Yen/$ exchange rate might be expected to be somewhat muted in European market space), or on other days, nor whether they would have been representative of the nine other unshown bilateral exchange rates. Moreover, the use of electronic market systems is developing rapidly over time. Be that as it may, the somewhat occasional nature of the market then in these other five exchange rates means that we will concentrate most of our econometric studies on the Dm/$.

III Comparison of FXFX and D2000-2

As described in the Introduction, indicative screen prices, as provided over FXFX, provide the basis for almost all current time series studies on the forex market. While there is no doubt that these are close enough approximations to the underlying firm quotes for low frequency studies, e.g. frequencies of one hour or longer, concern has been expressed whether they do necessarily provide sufficiently close approximations to the underlying firm data for very high frequency studies. For example, Baillie and Bollerslev (1991) have conjectured that the negative MA characteristics found in FXFX ultra high frequency data may be a facet of their indicative nature, and that the underlying price(s) would not exhibit this characteristic. Also see Zhou (1992), Bollerslev and Domowitz (1993) and Bollerslev and Melvin (1994).

Now that we have a 7 hour snapshot of firm prices in D2000-2, we can, in principle, make a comparison of them with the bid/ask series from FXFX over the overlapping period, for the three data sets, Dm/$, Yen/$ and CHF/$. A problem, however, is that the D2000-2 data series is not time stamped, though it does have a time elapse shown on the videotape. In practice, of course, the two series can be matched pretty closely by eye alone by matching the two occasions of short-term appreciation in the Dm/$.

To try to match the series even more closely, we constructed artificial series for both the D2000-2 and FXFX Dm/$, bid and ask, with observations evenly spaced every five seconds, (Note that the original series in both cases is irregularly timed, and hence cannot be directly correlated). We assumed, for the purpose of matching (D2000-2 and FXFX) only, that the existing price held until revised, for the purpose of interpolation, where necessary. When no price was exhibited on D2000-2, we treated the prior price as still holding, except for the gap in the bid price in the second jump, discussed in the preceding Section, where we applied a linear interpolation (between 1.6565 and 1.6590)[20]. Alternative rules of thumb for interpolation could have been tried, but we are confident that doing so would have made no difference for this timing exercise.

Our crucial assumption is that price adjustments on FXFX and D2000-2 would be synchronous. We believe that to be justified. Studies made by one of us (Goodhart 1989) on the reaction of FXFX bid and ask prices to precisely timed news announcements (eg US 'news' released at 0830 EST) shows that these are virtually instantaneous (a few seconds at most), and we should surely expect no slower reaction where prices represent firm commitments [see for example Ederington and Lee, 1993]. Accordingly, our strategy was to assume that prices in both series would move synchronously. Given this assumption, our approach was to compare the correlation of the two series for the Dm/$ as we varied their temporal overlap, and see which temporal overlap gave the best fit.

In practice, all the exchange rate action came in the second half of our data period (last two tapes), and the market was so flat in the opening hours (tapes) that we could not find any clear peak in the fit when starting from the front. We, therefore, worked from the back, fitting the final tape to the FXFX data, to the front. In the event, and slightly disturbingly, we found a 20 second discrepancy between our best-fit timing for the comparison of the bid and the ask series. See Table 6. However, given our exact knowledge of how the bid and ask series are timed relative to each other on D2000-2, we overrode this apparent discrepancy from the time-series fitting exercise and split the difference between the two, so that the observations on D2000-2 are all properly aligned with each other.

This then gave us the basis for comparison of the D2000-2 bid/ask series with the FXFX series over a closely matched data period, (with the exact match uncertain by some fraction of a minute). We have to be careful, however, in using the interpolated five second series themselves in econometric comparisons, since the interpolations distort some of the characteristics of the raw data. There were some 800 observations in the basic D2000-2 series, and about 5000 in the interpolated series for D2000-2. By construction, the extra 4200 observations will exhibit no change, which must tend to drive any estimated auto-correlation towards zero, and may also bias the ARCH characteristics. We discuss some of the issues raised by the question of whether to scale the series by time, or by tick activity, at greater length in Section 1V below.

Subject to that condition, the means of the bid/ask in both series (FXFX and D2000-2) are almost identical. A graph of the time path for the Dm/$ from the two sources looks like one line; see Chart I. Thus the time path of the indicative quotes <u>can</u>, on this evidence, be taken as a very good and close proxy for that in the underlying firm series. Nevertheless some of the characteristics of the bid/ask series, e.g. the pattern of auto-correlation, are somewhat different. Even so, both series indicate a somewhat similar GARCH pattern. As would be expected, the two series are cointegrated, with the indicative series responding more to deviations from the equilibrium (i.e. a larger and more significant negative coefficient on the error correction mechanism). By contrast the characteristics of the spreads in the FXFX as compared with the touch in D2000-2 are markedly different. The spreads in the FXFX series show clustering among a small number of standard values (eg 5, 7 and 10 pips for the Dm/$), whereas the spreads at the touch show no such signs of clustering. The basic characteristics of the, temporally matched, filtered (but not interpolated) series are shown in Table 7. The main pattern of results shows that the D2000-2 and the FXFX raw series are, in general, remarkably similar for the Dm/$.[21]

The differences between the first four moments of the various price series (bid, ask, and average of the bid and ask) in either levels or first differences are minor. The FXFX series in levels have a somewhat lower average value, [probably owing to a larger proportion of their observations coming in the earlier part of the period, see Table 9], an insignificantly lower volatility (standard deviation), and marginally higher skewness and kurtosis. The FXFX series in first differences have lower means, by a factor of 1½ in the mean, and about 2 or 3 in the bid and ask, [perhaps again because of more observations when little was happening in the early part of the period]. These FXFX differenced series have a lower skewness, and a slightly lower kurtosis.

There is, however, a more marked difference in the autocorrelation data. The FXFX series exhibit stronger negative autocorrelation in all cases and at all lags, particularly after the first lag. This is least marked at the first lag of the bid and ask series, where the D2000-2 coefficient is about -0.61 compared with values of -0.62 (bid) and -0.67 (ask) for the FXFX series. In the average series the first lag value for D2000-2 drops to -0.37, compared with -0.61 for FXFX. After the first lag the absolute size of the negative coefficients, and of the t values, drops much more rapidly for D2000-2 than for FXFX. The first four lags in FXFX in each case have significant negative coefficients. This is so only for the averaged series of D2000-2, and the sum of the negative coefficients is always considerably greater in absolute size than -1 for FXFX, whereas it is between -0.75 and -0.90 for D2000-2.

We find relatively little difference in the GARCH data, which approximate to IGARCH values, except that the FXFX series for the changes in the average and the level of the spread show less persistence of volatility (a lower B_1 coefficient) than the D2000-2 series.

One of the main findings about the characteristics of the continuous time foreign exchange indicative quote series was that they appeared to have a negative moving average component. One supposition was that this could be due to the fact that they were indicative, not firm quotes. Now that we can observe the firm quotes, the negative moving average does appear somewhat attenuated, especially for the average of the bid and ask, but it remains a highly significant feature of the time series.

The main difference between the two series occurs in the case of spreads. The most distinctive difference relates to the numerical pattern of the spread, with the FXFX data showing the spread clustering around certain conventional values[22], while the D2000-2 spreads, being at the touch with the bid and ask prices being input usually by different banks, show no such clustering. Histograms of the frequency of spreads at various sizes for D2000-2 and FXFX are shown for Dm/$ in Charts 11 and 12. The Yen/$ and CHF/$ Charts which show almost identical patterns are available from the authors.

One feature of the Dm/$ spreads in D2000-2 (Chart 11) is that there are a number of occasions of zero spread, i.e. the best bid and best ask are equal. In FXFX, when the quotes are input by the same bank, a zero spread would signal an input error.[23]

These comparative tables possibly understate the extent to which the two quote series actually do move together. As shown in the earlier diagram, Chart 1, when the two interpolated series are drawn on the same graph, there appears to be only one line. If we regress the two interpolated series for the Dm/$ together, after temporal matching, we get the results in Table 8. As can be seen, the respective series, for the average of the bid/ask, and the bids and asks separately, are all strongly cointegrated, (as should be expected). Only in one case, however, when the average of the interpolated FX series is regressed on the average of the 2000-2 series do the coefficients take on their ex ante expected values with a constant insignificantly different from zero and the coefficient on the right hand side variable insignificantly different from unity. Otherwise the constants are all significantly different from zero, with the D2000-2 bid on average just above and its ask just below that on the FXFX series. As might be expected, the D2000-2 bid is slightly less variable than its FXFX equivalent, while the D2000-2 ask is a tiny bit more variable, (perhaps a reflection of our treatment of outliers in the data?)

Such a finding of strong cointegration enables us, always subject to our prior assumption that the two series are synchronous, and our temporal matching procedure valid, to examine short-term dynamics, and whether a deviation between the two series is corrected primarily by a shift in the FXFX series or in the D2000-2 series. Our hypothesis is that, since the D2000-2 series is the underlying firm series, the indicative FXFX series should adjust to it, rather than vice versa. When, therefore, examining the error correction mechanism, we expect a large, significant negative coefficient on the ECM, when the change in FXFX prices is the left hand side variable, and a much smaller, possibly insignificant coefficient when the change in D2000-2 prices is the left hand side variable. The ECM is taken, as appropriate, from the residuals of the equations in Table 8.

Taking the average of the bid/asks as our example, (the results will not change much for the bid or ask series individually), we ran regressions, as follows:-

$$\Delta \text{ Average Series } 1_t = f(\text{Lags } \Delta \text{ Average Series } 1, \text{ Lags } \Delta \text{ Average Series } 2, \text{ ECM})$$

The results can be seen in Table 9. As expected, both the ECM and the effect of prior changes in the underlying D2000-2 series on the FXFX series are more strongly pronounced than the effect of the FXFX series, or the ECM, on the D2000-2 series, though the latter is still clearly significant, despite being much smaller[24].

Since time series on transactions, i.e. the number and value of deals, have not been available for the foreign exchange market, variations in either the frequency of entry, or the volatility, of indicative prices, or some combination of both, have often been taken as a proxy for the volume of unobservable transactions. Here we examine whether this may have been a good proxy.[25] Since we cannot, however, compare the profile of D2000-2 and total market transactions, we will proceed on the presumption that the former may be a good proxy for the latter.

For this exercise we divide our data period into half-hours for the Dm/$ series. We take these periods from the start, so the final period is not quite a complete period. Then we compare both the frequency and size of deals in each half-hour period, (as a % of the total) as compared with the frequency of quote entry (as % of the overall number) and relative volatility (Standard deviation of the average of the bid/ask in sub-period divided by overall SD). We also examine how the average size of spread related to these variables. The basic results for the D2000-2 and FXFX variables are in Table 10. Then simple regressions between these variables were run, as shown in Table 11.

The results are disappointing for those who would use the indicative FXFX data as a proxy to infer the underlying transactions series. The FXFX volatility series is an excellent predictor of the volatility in the firm quotes of D2000-2 (equation 4); the spread series of FXFX is a mediocre predictor of the spreads on 2000-2, with the latter in this case being on average lower, but much more variable, by a factor of nearly 5; compare lines SS and FS in Table 10 and see equation 8 in Table 11. This must raise some doubts about certain aspects of the results of recent empirical studies based on FXFX data e.g. Bollerslev and Melvin (1994) and Bessembinder (1994). This is discussed further in Section IV.B. The frequency of quotes series on FXFX was a relatively poor predictor of the quote frequency on D2000-2. Unfortunately the importance of these series as a predictor of deals is largely in reverse order in this data set. As can be seen, (equations 3, 6 and 11), the frequency of quote entries over D2000-2 is the dominant predictor of the number of deal entries, with neither volatility (whose coefficient was even wrong signed) nor spreads being significant. But FXFX entry frequency is a poor predictor of D2000-2 quote entry frequency. Thus using FXFX data to predict the number of D2000-2 deals was not very successful. The frequency of entry (FXFX) was the most significant variable for predicting D2000-2 deals of the data series available over FXFX (equations 2, 7 and 12), but both FXFX volatility and spreads made some positive contribution. We are fully aware of the small size of this sample among many dimensions, length of time, number of observations, etc. While more work is undoubtedly needed, we must warn that this preliminary exercise suggests that it would be dubious to try to infer transaction frequency from the more widely available FXFX indicative quote data.[26]

To sum up, in this Section we have sought to compare the characteristics of the D2000-2 and FXFX series over a temporally matched period. The main result is that the time paths for the prices quoted over the two series are extremely close, and most of the time series characteristics of the two quote series are closely similar. The negative auto-correlation is somewhat attenuated, but still highly significant, in the firm D2000-2 series. As expected, the distribution of spreads is markedly different between the indicative series, which clusters at certain round numbers, and the touch with a much more even distribution.

The size of spreads and the frequency of quote entry showed much more variation between sub-periods in the D2000-2 series than in FXFX, and the latter were not good predictors of their D2000-2 counterparts, unlike FXFX volatility, which like its mean value, matched D2000-2 almost exactly. This meant that the FXFX data proved poor predictors of the frequency of deals over Dm2000-2 for the Dm/$, since this was most closely associated with the frequency of quote entries in that same data set.

IV The Interaction of Transactions and Bid/Ask Quotes on the Forex Market

A. Characteristics of Transactions Data

In the preceding Section we asked how accurate a proxy the commonly available FXFX data were to the underlying firm D2000-2 quotes, [excellent as a guide to price movements], and to the spreads and number of underlying transactions over the same data set, [which suggested that a lot of caution would be needed]. In this Section we test certain hypotheses about the determinants of the occurrence and size of such transactions, and their effect in turn on quote revision. We concentrate solely on the Dm/$ series here, because only in this series are there sufficient data points.

Our first hypothesis is that the time series for transactions prices (returns) will be random walk. This is the standard efficient markets hypothesis. Most of the evidence of autocorrelation in returns in stock markets has related to discrete break points in markets, i.e. market openings and closings, week-end effects, end-tax-year effects; see for example Dimson (1988), McInish and Wood (1991), Wood, McInish and Ord (1985), Griffiths and White (1993). The forex market exhibits fewer discrete break points; in any case our sample is far too small, covering no such break points, to hope to test for any such anomalies.

We exhibit the characteristics of the transactions data, separately for transactions at the bid and the ask, and also for the two series taken together (to see what the effect on the characteristics would be if, counterfactually we could not distinguish between deals at the bid and the ask). See Table 12. During our short snap-shot the Dm/$ traded upwards (i.e. the dollar appreciated). So the mean change on all three series was positive, but less so for the composite series because of bouncing between deals done at the bid and the ask.

Because of that same bounce, the absolute size of the negative auto-correlation on the first lag becomes larger (almost doubles) and becomes significant. Thus we claim to be able to document here the statistical effect of the bounce. It would be possible to use these data to check the accuracy of the Roll (1984) model whereby the size of the bid-ask spread is estimated using only transaction prices. We leave that for later work, though we doubt whether that model would perform well, e.g. because the direction of deals is autocorrelated and information asymmetry (volatility) is time varying. The positive coefficients at higher lags on the other two series may be owing to the large jumps in the $ during our short data period. Bollerslev and Domowitz (1993; also see their 1991 paper) generate artificial transactions series from automated trade execution algorithms which exhibit positive first-order serial correlation, pp 1430-2; we find no sign of that outcome in our data set of actual transactions prices.

Hasbrouck and Ho (1987) find for the NYSE that, "the pattern consists of a large negative auto-correlation at the first lag, followed by positive auto-correlations of decreasing magnitude that are statistically significant... through the fifth lag. The negative first order auto-correlation in transactions data is consistent with the findings of other studies. The positive auto-correlations, however, are (in transactions data) new." While the size and significance of our coefficients is considerably less, the general pattern in our data is exactly the same. With the significant negative first-order auto-correlation being caused by the bounce, and none of the later positive auto-correlations being either large, or significant, our results are, not surprisingly, consistent with efficiency.

The Dickey-Fuller test indicates stationarity. This does not disturb us. The random walk characteristic of asset prices results from their subjection to a sequence of 'news' shocks. At any one point of time the market price of an asset should have an equilibrium value, dependent on assessments of past 'news' shocks. If the time period is short enough, here only seven hours, the amount of additional 'news' is limited, so one might expect, over very short time-periods, to observe stationarity.

What we do feel remains to be clarified and modelled is the nature of the interaction between a quotes series which shows clear evidence of a negative moving average component, and a transactions series which exhibits no such significant autocorrelations. This is the subject of our ongoing research.

According to the simplified models wherein a single dealer undertakes one transaction of a standardised size per period, the dealer should adjust prices until the expectation of a transaction at the bid next period is equal to one at the ask. So the sequence of deals between bids and asks should be random, see among many authors Admati and Pfleiderer (1988 and 1989) and Hasbrouck and Ho (1987). If inventory effects are present, the sequence might be expected to show some negative autocorrelation. With many dealers posting limit orders and multiple orders possible in any finite period, we would, however, not expect that. Instead we would expect runs of deals of each kind. We test that hypothesis, both by a histogram showing the lengths of sequences of deals of both kinds, and also by a formal runs test.

The histogram, figure 13, shows that there are a number of runs of deals, both at the bid and the ask, that are much longer than one might normally expect to see. These are shown in Table 13, together with their individual expected probability of occurrence. The probability of finding all such runs together is infinitesimal. Thus, rather like the kurtotic characteristic of the price change series, the run series for deals appears to have a fat tail. There are, as noted earlier, indications that runs of similarly signed deals occur when the price series is trending in one direction, e.g. dollar buying at the ask where the dollar is appreciating. We show the associated change in the relevant quoted price during each run over the same period in Table 13.

The formal runs test that we use is the Geary test. This concentrates attention on whether the number of runs observed in the sample is large or small relative to the number one would expect to occur in a strictly random sample. According to this test, we are led to reject strongly the null that successive observations are independent, since the test statistic is -7.11 compared to the standard normal critical value of -2.58 under the null.

Some earlier empirical work has also found evidence that deals tend to run in sequences, (bid deals followed by bid deals and ask deals followed by ask deals,) e.g. Hasbrouck and Ho (1987) and Lease, Masulis and Page (1991) for the NYSE. Some of the reasons for this are straightforward e.g. a trader with a large order working up the limit order book. We would, however, conjecture, but have yet to do the work required to demonstrate, that the extent of autocorrelation revealed here is considerably beyond that explicable on the basis of such simple micro-structural factors.

The only theoretical explanation yet given for such positive autocorrelation is by Admati and Pfleiderer (1989). They suggest that market dealers may shade the costs of dealing, on one side of the market, to encourage liquidity traders to bunch together on that side, isolating and identifying informed traders on the other. "The intuition behind our results suggests that there will be periods in which prices rise at a slow rate when shares are purchased but fall at a more rapid rate when shares are sold. These periods will be periods of concentrated buying - periods in which it is expected that discretionary buyers will be trading." Our results are very different. In our data buys concentrate together when prices are rising rapidly, and spreads rising, but not enough to choke off the stream of purchases. At such moments seller-initiated trades dry up altogether. Further research to check whether our results are typical of the forex market, and, if so, what the reasons for this might be, would be desirable.

B. The Inter-relationships between the Data Series

Given the existence of such long runs of deals at the bid and ask, one variable that may help to predict the occurrence of a deal at the bid (ask) is whether there has been a prior deal at the bid (ask). Hence we now turn to regression analysis to explore the inter-relationships between our series, separately for both D2000-2 and FXFX. For this purpose we used our constructed 5 second data set, where for D2000-2 a non-entry at either the bid or the ask is replaced by the prior entry, if no deal had occurred, or the subsequent entry following a deal. There was never more than one deal in any five second period, but, of course, over longer periods, e.g. one minute, there were often several deals.

For D2000-2 we had the following data series, (shown overleaf,) for both the Bid and the Ask; Bid series are given the notation B and A for Ask,

	Bid	Ask
	--------	--------
Number of deals in period	BD	AD
Quantity traded in deal	BDQ	ADQ
Dummy if deal exhausted quantity	BDE	ADE
Change in quote	DB	DA
Quantity quoted	QB	QA
Frequency of quote revision over period	BF	AF
Absolute value of change in quote	ADB	ADA
Standard deviation of changes in quotes	BV	AV
Spread	S	

There were thus 17 basic series for D2000-2, 8 bid, 8 ask and the spread. Initially we used our 5 second data base, with lags covering the previous two 30 second intervals, and the two minutes before then,

$$\text{eg } Bd_{-1\,-\,-6},\ BD_{-7\,-\,-12},\ BD_{-13\,-\,24},\ BD_{-25\,-\,36},$$

noted as BD_6, BD_{12}, BD_{24}, BD_{36}. In some cases, e.g. for spreads and quote revisions, we also used shorter unit (5 second) lags, noted as Lag 1 S, Lag 2 S, Lag 3 S, etc.

For FXFX, we did not have the first three series (BD, BDQ, BDE), or QB, so there were 4 basic series in this case, with similar notation, (DB, BF, ADB and BV) for bid quotes four for asks and the spread.

This meant that we had over 85 basic series (including lags), for D2000-2, and a data se of 5000 observations.[27] Our basic approach was to regress each variable of interest on lagged values of all the variables (including the lagged dependent) separately, and then include significant values from these first stage equations in a larger equation to search for the best fitting equation.

There is a general problem in such exercises of how to scale the data. The two main alternatives are to use standard clock time or transactions (tick) time, whereby each activity observation is ordered consecutively, irrespective of the varying time gap between them. With very high frequency series, e.g. five second intervals as here, a problem with the use of clock time is that most observations of price changes, deals etc. are zero. Hence the distribution of these variables is non-normal, with a spike at zero. On the other hand there are certain questions relating to the temporal relationships between series, especially in multi-variate analysis, that can only be answered using a clock time scale. Several analysts have wrestled with this problem, notably McInish and Wood (1990, esp. Section 4.4) with respect to the NYSE, and the various studies undertaken by analysts at Olsen and Associates, e.g. Müller et al. (1990) and Dacorogna et al. (1993), on the FX market! Most empirical work has been done, in both markets, on activity, transactions scale. The studies, e.g. on price scaling laws, notably those carried out by Olsen and Associates, do suggest that this is probably preferable, where feasible for the question under consideration. In our case, however, we are interested in multi-variate inter-temporal relationships, so we have primarily used a clock time scale, but have, in certain cases, checked the result from these exercises against similar exercises on an activity scale.

The following exercises are quite detailed. The relevant tables are 14-31. Readers may prefer to skip first to the Charts showing, qualitatively, the main directions of relationships (Charts 14-16), and also to the summary of main findings in Section IVE, before deciding how much detail in the next few pages they want to absorb.

There were only some 186 bid deals in the DM/$ during the 5000+ five second intervals. So to examine the likelihood of a bid deal occurring we used probit analysis. Our 'best' equations for the probability of bid and ask deals occurring are shown in Table 14.

The main finding from this, which was foreshadowed in the results in the earlier Table 11, is that the most important set of variables to determine bid (ask) deals is the frequency of bid (ask) quote revisions in the previous few minutes. This frequency, we believe, is probably a proxy for the extent of prior information. When lagged values of BF (AF), the frequency variable, are entered, lags of the dependent variable BD (AD) lose most of the significance they had when entered alone. Besides this frequency variable, in both cases, if there was a deal of the opposite sign, e.g. AD6 in the BD equation, in the previous 30 seconds, there is less likelihood of seeing a deal now. Bid deals in the Dm/$ are considerably more likely to occur where current spreads are low, i.e. prices are good, and when prices have recently been improving (DB6 is positive). This suggests that traders are doing their job effectively, i.e. hitting comparatively good prices. A comparison of average spreads when there is no deal, and when there is a deal, for the Dm/$ and the Yen/$ is shown in Table 15[28].

The AD (ask deal) results are more problematical with some non-intuitive variables entering significantly, i.e. a positive lagged spread (thirty seconds previous), positive changes in bid quotes and a deal quantity variable, ADQ. We surmised that these results might have been due to many of the ask deals occurring in the latter part of the period, when spreads and volatility were high, and both bid and ask quotes prices rising markedly. In order to test this we divided our sample into two parts, the flat first half (Obs 1-3560) and the upward trended second half (Obs 3561-5000), and redid the probit analyses for both the bids and the asks. The results for bid-deals remained much the same. For Ask deals, the spread becomes negative (as expected) in the first half, and insignificant in the second part; and the change in the ask price

(DA36) also enters negatively, as expected, in the first half of the period. Apart from the insignificant spread, the results for the first part Ask are similar to those of the contemporaneous Bid. The table giving these two half-period results is available on request from the authors.

Overall, however, the fit was rather poor. Perhaps it was expecting too much of the data to be able to predict the probability of a deal within a period as short as five seconds. So we lowered the frequency of analyzed periodicity to a minute. Within a minute, however, there were often several deals. So we used ordered probit analysis to estimate the inter-relationships. Somewhat to our surprise, the change of periodicities to the lower frequency of one minute intervals made relatively little difference to the major apparent patterns of relationships. See Table 16.

Given the probability of a deal, the next question is what will be the volume, the size of the deal. In 145 out of 186 deals at the Bid, and 179 out of 251 deals at the Ask, the deal, however, exhausted the outstanding quantity offered. So the size of the deal was usually limited by the amount on offer. That means that it is more sensible to try to model the amounts offered by the dealers (BQ and AQ), rather than the amounts sought by the hitters, (i.e. the supply function is better identified than the demand function).

Similarly, of course, the price of the deal has to be at the price posted, either the Bid or the Ask, in the firm quotes. So we turn next to an analysis of the determinants of the changes in such prices, DA and DB. As noted earlier, when a quote is hit and exhausted, the price must change to the next limit order, if such exists. There is also known to be negative auto-correlation in the quote series. Our first basic exercise was, therefore, to regress DA and DB against their first six, t-1 to t-6, own lags and the dummy exhaust variable, BDE and ADE, taking the value 1 when the quote was exhausted by a deal. The results are as shown in Table 17. The value of the dummy exhaust variables (BDE and ADE) was in each case about + or -

.000375, showing that this is the average price revision, (down following a bid exhaust, up after an ask exhaust), or alternatively the gap between limit orders, following a deal. The negative values for the lagged own values are consonant with the, now-well-established, high frequency negative auto-correlation.

The lower value of the coefficient on the first lag, than in the earlier Table 7, is due to the fact that the series here are on clock time, five second intervals, and not taken, as in Table 7, by consecutive quotes. Consequently most of the observations on price changes show zero. When we re-ran the exercise on exactly the same basis, but omitting those observations when price changes were zero, we got the results shown in Table 18. The absolute size of the coefficients of the lagged dependent variables increase by a factor of about 5 times, (as the 80% of zero observations in the complete, clock time, sample are removed), but the standard errors increase by as much, or slightly more, so the t values actually decline, just, on balance. Since there virtually has to be a change in price after a deal exhausts the previous quote entry, coefficients of the deal exhaust dummies, BDE and ADE, only rise slightly, and with a commensurately higher standard error, their t values fall from around 20 to about 9. The resultant series without the zeros, i.e. in transaction time, is much more variable, so, although the fit of the series is much improved (the adjusted R square doubles from around .12 to about .25), the Root MSE also doubles.

We then explored to find other variables that might contribute significantly to the determination of quote revision, though the own lags out to t-6 and the exhaust dummy remained the key variables. The main additional variables that entered in Table 19 were the spread with a one period lag, negatively for the ask and positively for the bid, (i.e. where the spread was unusually large, someone would come forward with a more competitive quote); longer own lags, (though this was more apparent in equations run without the spread, as shown in Table 20); and some volatility variables[29].

When the spread variable is not included, changes in the ask price have a strong positive effect on changes in the bid price, whereas changes in the bid price had a weaker effect on changes in the ask prices, see the coefficients underlined in Table 20. But the sum of the coefficients is well below unity. What this means is that, in this market, a change in the best bid (ask) only has a slight effect on the contemporaneous ask (bid). Most of the immediate effect becomes translated into a changed spread, which is highly positively auto-correlated. The spread returns towards normal only slowly. So in this market, with best bids and asks being entered by different banks, the hypothesis that these two quotes will be revised closely and quickly in step with each other is convincingly refuted; instead bids and asks vary somewhat independently, rather like two variables which are cointegrated in the longer run, with the spread acting as the Error Correction Mechanism between them.

We have no convincing explanation for the asymmetry whereby the change in the Ask quote price had a stronger effect on the Bid quote price, than vice versa. We initially thought that this might be due to the surge in the value of the $ in the second half of the period, impacting first on Ask deals and quotes, and thereafter on Bid quotes, but when we divided the period into two, and reran, this hypothesis was refuted, since the effect of DA on DB, though slightly weaker than in the full sample, was clearly stronger in the first, untrended, part of the period, than in the second part, when the $ strengthened.

We also looked for any signs that either the event, or the size, of deals influenced quotes, apart from the exhaust dummies, which, as already noted, were highly significant. We found generally rather weak effects, as in Table 19, of these variables on quote revisions, but where significant usually of the expected sign. Thus in some of the equations for bid quote revisions, DB, the event (BD) or the quantity (BDQ) of a deal in prior periods would enter with a significant negative sign (and, even more occasionally, AD or ADQ lagged would enter with a positive sign), suggesting that stronger deal activity at the bid (ask) caused bid quotes to be lowered (raised). The same feature also occurs weakly for DA, with AD entering positively in equation 19B.

Again we examined how the results would change if we ran the regressions omitting all zero price change entries (80% of the sample). The results are shown in Table 21. Our process of trying to eliminate insignificant variables resulted in almost identical 'best' equations, with and without zero price changes, but the relative importance of the coefficients as measured by their t values changed[30]. The fit, as before, improves sharply, once zero price changes are omitted, with the adjusted R squared improving threefold in the bid price equation (to 0.43) and more than doubling (to 0.33) in the ask price equation. But, with a more variable series, the Root MSE also again doubles.

We next compared our results for the determination of quote revision over D2000-2, with a similar exercise for FXFX, see Table 22. The results for DFXB and DFXA showed similar features for the lagged dependent variable with strong negative auto-correlation, (a first-order negative moving average pattern), and a significant role for the spread, (positive in the bid equation, negative in the ask). Again as in the D2000-2 equations, volatility variables appear to enter, but in rather a complicated way. Thus the absolute change in the ask price enters the determination of the change in both the ask and the bid price at two separate lags with reversed signs. Tests over a longer run of data are needed to resolve whether, and how, prior volatility affects price quote revision, either over D2000-2 or over FXFX. The other variables tested, (i.e. the prior frequency of quote revision, the absolute change in lagged bid prices, etc.,) were not significant.

In D2000-2, unlike FXFX, changes in the bid (ask) price initially become incorporated into the spread, which is highly positively correlated. Indeed, the first order autocorrelation with the spread in the previous five second period has a coefficient of about 0.88 and a t value in excess of 50, as will be shown below. In order to lessen the power of this relationship, and show the effects of other variables, we mostly worked with a lagged dependent variable with a 30 second lag, lag 6s. Once again, a deal that exhausts a quote will force a price revision, and an increase in the spread, as the price shifts to the next limit order, so BDE_{t-1} and ADE_{t-1} were always entered. Thus the basic equation was:-

$$S = .000220 + 0.620\, S_{-6} + .000179 BDE_{-1} + .000313\, ADE_{t-1} \qquad R^2 = 0.398$$
$$(.000015) \quad (0.011) \quad (0.000047) \qquad (0.000042)$$

As earlier noted, an increase in the bid price will reduce the spread, and an increase in the ask price will increase it. These results came through strongly in the equations. The standard finding is that volatility will increase spreads, and this was also strongly supported, as shown by the significant t values on AV and BV. Our basic equation, using S_{t-6} as the lagged dependent variable is shown in Table 22. When S_{t-1} is introduced instead, the fit improves, but the significance of all the other variables weakens dramatically, and even the sign of the other independent variables often goes wrong, since almost all their influence is incorporated into S_{t-1}, as shown in Panel B of Table 23. Besides the exhaust dummies, price revision and volatility variables, we also looked to see if either the event, or size,of deals, or the frequency of quote revisions affected the spread. The answer is generally no, once the significant variables above are also entered. As can be seen from Table 23, the number of bid deals in the thirty seconds from t-30 to t-60, i.e. BD12, enters with a negative significant coefficient.

There is some uncertainty in the literature about what relationship to expect between the volume (number) of transactions and the spread. On theoretical grounds, Admati and Pfleiderer (1988) and Foster and Viswanathan (1990) expect liquidity trading to cluster together so that low adverse selection trading costs should occur at times of high volume; yet there is evidence in both the NYSE, (Foster and Viswanathan (1993),) and the foreign exchange market (Glassman (1987),) that the intraday pattern is for spreads to be positively correlated with volume. Bessembinder (1994) seeks to resolve this conflict by distinguishing between expected and unexpected volumes , with the expected signs on these being found to be, as hypothesised, negative and positive. We do not however, feel that our relatively weak finding of a negative coefficient on a volume variable helps to resolve this problem; we are inclined to dismiss this finding as possibly occurring by chance; its significance, along with those of many other variables, was cut back sharply when S_{t-1} was entered as the lagged dependant variable.

By contrast there is no uncertainty in the literature that information asymmetries and high volatility will be associated with high spreads[31]. This has been found in two recent articles using FXFX data, Bollerslev and Melvin (1994) and Bessembinder (1994). We have, however, shown earlier, Tables 10 and 11, that the form of the (numerical) relationships (the coefficients) between volatility and spreads differ depending on whether D2000-2 or FXFX data are used.

So next, for comparison, we examined the determination of spreads on FXFX for the same DM/$ exchange rate over the same period. The results of this (see Table 24) show that, besides positive auto-correlation, (though much weaker than in D2000-2, the coefficient on the first lag drops from 0.88 to 0.38), the spread is again positively related to volatility (ADFXB24). There is also a weak relationship with the frequency of quote entry, but the coefficients are of equal and opposite sign, so the net effect is negligible. Most of the variation in spreads in FXFX is just noise, with an adjusted R-square of 0.15, as compared with over 0.75 for D2000-2.

We then looked at the factors affecting the absolute change in prices, (a measure of the volatility), of Bid (ADB) and Ask quotes (ADA) both in D2000-2 and FXFX. The results of this part of the exercise were not particularly exciting, and for brevity are described in footnote 32 below[32], as well as in Tables 25 and 26.

As described earlier, the frequency of quote revision (BF and AF) Granger causes the event of deals. The reverse causal relationship also holds, with the number of recent deals influencing the frequency of quote revision. This is consistent with the hypothesis that trading activity itself generates revisions of prior information and hence further trading, e.g. French and Roll (1986). Thus BD6 is the dominant influence on BF, and AD6 on AF. Besides this, there is a weak positive effect from the lagged dependent variable; and from the lagged frequency of the other quote (AF in the equation for BF, and vice versa); some positive effect of higher price volatility on the frequency of quote revision; and finally a weak, and rather uncertain (the lagged variables usually had an offsetting effect) impact from the quote size variables (BQ and AQ). We show two of our better representative equations in Table 27.[33]

Once again, largely for the record, we ran associated regressions to examine the determinants of the frequency of quote entry over FXFX. This showed that, apart from own lagged values, the only variable, from the set of FXFX data available examined here, which influenced the frequency of quote entry over FXFX was a lagged volatility variable.[34] In order to save space, the table is not shown, but is available from the authors on request.

Finally in this set of studies of activity on D2000-2 (and FXFX), we explored the determinants of the quantities posted, BQ and AQ. (Recall that we chose <u>not</u> to seek to examine the determinants of the size of deal, BDQ and ADQ, since these most often just exhausted the quantity already on offer). A noteworthy feature of our results is that the quantities posted, BQ and AQ, did not significantly affect most of the preceding variables (e.g. probability of deal, quote revision, spread), and only weakly affected, if at all, volatility and the frequency of quote entry. Anyhow, the main factors affecting the quantities offered, BQ and AQ, as shown in Table 28, are the respective lagged dependent variables, with strongly significant first-order positive auto-correlation, (but in the case of BQ thereafter a somewhat complex dynamic process), and the number of prior deals (BD in the BQ equation, AD in the AQ equation) which reduces quote size. Other activity variables, such as BF, AF and BDQ, enter weakly and often with offsetting signs, so their net effect is negligible. A volatility variable (BV12) enters the BQ equation positively. The only factors, however, about which we have some confidence are for the lagged dependent variable, and the negative effect of deal activity on quote size.

This extended series of results and tables must seem quite complicated, and so in a manner it is. We try to simplify by showing Charts, Figures 14-16, illustrating the main inter-relationships (excluding the inter-actions whereby Bid variables affect Ask variables, and vice-versa), with the direction of causality given by the arrow, and the strength of the inter-relationship by a double (strong), single (weak), or dashed (questionable) line. A key point is that deals mainly affect quote (price) revisions, spreads and volatility if they have exhausted the amount then on offer, but with a much weaker effect otherwise. This deal exhaustion effect is the main link <u>from</u> the deal occurrence/frequency of quote revision nexus (one way) <u>to</u> volatility and to the quote revision/spread nexus.

The exercises, whose results were reported in these Charts, were mostly, except for Tables 18 and 21, done on a clock time scale. We were both encouraged and slightly surprised to find that when we changed the periodicity (Table 16 compared with Table 14), or the scale (Table 17 compared with 18, and 19 and 21), the patterns of the basic relationships, as measured by the t values on the key variables, remained quite robust.

C. Conditional Heteroscedasticity in D2000-2

Most asset price series exhibit ARCH, auto-regressive conditional heteroscedasticity. We next turned to examine whether our price series, DB and DA, also had such characteristics, either in clock (5 second) time or on a tick by tick (activity) scale. We could also explore whether the addition of transaction data, (e.g. BD, BDE), would influence the GARCH coefficients. Having already examined the relationship between the GARCH coefficients of the interpolated D2000-2 and FXFX series in Section III, we now focus solely on the former to investigate whether, in clock time or using a dataset constructed solely using quote and transaction activity, the series exhibit signs of conditional heteroscedasticity. The basic specification which we used is shown below. Quote revisions are assumed to depend on their own first lag and a dummy indicating a deal which exhausted the quantity on offer at the prevailing price in the previous period. The volatility expression is based on a simple GARCH(1,1), extended subsequently to examine the impact of deals on volatility.

$$\Delta b_t = \alpha_0 + \alpha_1 \Delta b_{t-1} + \alpha_2 BDE_{t-1} + \epsilon_t \,, \quad \epsilon_t | I_{t-1} \sim N(0, h_t)$$

$$h_t = \beta_0 + \beta_1 \epsilon^2_{t-1} + \beta_2 h_{t-1} + \beta_3 BDE_{t-1} + \beta_4 BD_{t-1} + \nu_t$$

For brevity's sake we report the results only for the bid side of the DM/Dollar, presented in Tables 29 and 30.

Taking first the estimations for the quote revision equations, note that the autoregressive parameter, α_1 , is negative in all cases but with a consistently greater magnitude for the activity scale data, as previously reported when comparing tables 17 and 18, 19 and 21. As before, the deal exhaust indicator has the expected negative effect on quote revisions.

Then next inspecting the volatility estimations, GARCH effects are present in both datasets. As shown in tables 29 and 30 the parameters β_1 and β_2 are significantly different from zero in a standard GARCH(1,1). We then examined whether deals affected quote revisions in an indirect manner through the underlying volatility series. This was done by adding lagged deal and deal exhaust indicators to the simple GARCH framework. For our activity scale data we could not uncover any real effect of deals on volatility. Neither of the previously defined variables, BD_{t-1} and BDE_{t-1}, entered significantly into our estimation, and indeed their negative sign is implausible. But when we moved to the five second dataset the results were markedly different. Both of these variables had a positive impact on volatility, significant at the 5% level. Maybe when the quiet no-change observations are excluded in the activity based data, the slighter persistent effects of deals on volatility become drowned-out in the noisier 'news'.

Indeed in all cases the GARCH estimates are far more significant in the five second, clock time, dataset. Comparison of the t-statistics between the activity and five second data shows those in the latter case to be far greater. This does not, however, imply that GARCH-type phenomena are better addressed in clock-time than in activity-time. It has been suggested that GARCH effects apparent in clock-time data may be the result of the transformation of a uniform, latent process which evolves on a different (activity) scale (see Stock [1988].) This could underlie the diminished significance of the GARCH parameters in the tick time results. This, however, is a subject for further research, and is not pursued further here.

D. A Comparison with Hasbrouck's 1991 NYSE Study

Finally, Hasbrouck studied a bivariate VAR of the interrelationships between deals (and/or deal quantities) and price revision, (taking the middle of the bid-ask quote), in his 1991 study of the NYSE, scaling by activity, tick time. Here we show his main results, Table II on p. 194, and our replication from our own data, both in tick time as he ran the regressions and in clock time, here reported in Table 31.

Since the scales of the price changes in the two markets (NYSE and forex) are markedly different, the differences between the absolute sizes of the coefficients should be ignored, and are not shown, but are available from the authors. What matters is the size and pattern of the t values, as shown in Table 31. This shows that the equation for price quote revisions, the *a* and *b* t-values in the first columns, are qualitatively similar. In both cases, though considerably more strongly in the forex data, both in the clock-time and in the activity-time equations, there is significant negative auto-correlation, and in both cases quote revisions are strongly positively related to prior deals (i.e. a sell causes a drop in prices and a buy an appreciation). Hasbrouck, like several other economists, tended to dismiss the negative auto-correlation, noting that it "may simply arise from measurement error", p. 195; our repeated findings of such negative auto-correlation on high frequency forex data makes us believe that this finding cannot be brushed aside in this fashion. In the activity-based forex equation, (Column B), we can explain considerably more of the fluctuations in quote revisions, than Hasbrouck, but this is primarily due to the stronger auto-correlation. [Hasbrouck does not report the F statistic showing the combined effect of the x_0 variable on r, (in our case it is 10.25,) but a look at the comparable t statistics suggests that the combined effect may be somewhat stronger in his equations].

The main, qualitative, difference between his results and our own comes in the second set of equations for the event of deals. In Hasbrouck's equation, price quote revisions have a significant negative effect on deals, the first two *c* coefficients have t values well below -2; in our own work, as reported earlier in Tables 14 and 16, price quote revisions have little, or no, effect on the probability of deals occurring, and this (negative) finding recurs also here. In both Hasbrouck's results, and our own, there is positive auto-correlation in deal events, slightly stronger in his case than in either of our two runs. So, although the fit in all cases is close to zero, Hasbrouck can 'explain' rather more of deal eventuality than we can. Hasbrouck notes, p. 295, that "A negative relation between trades and lagged quote revisions is consistent with inventory control effects since a monopolistic marketmaker with an inventory surplus would reduce his quotes to elicit more purchases. It is also consistent with the price experimentation hypothesis of Leach and Madhavan (1989) in which the marketmaker sets quotes to extract information optimally from the traders. These possibilities are deserving of further study." In this further study we find that in our data sample from a market with many competing marketmakers there was no indication of any significant (negative) effect between trades and lagged quote revisions.

In addition, we examined whether our results were robust to a longer lag structure (10 instead of 5); the answer was 'yes'. We were also able to replicate with our data the exercises done by Hasbrouck in his Table III, p. 198, and V, p. 203. In Table III Hasbrouck examines the inter-relationships between r, price quote revisions, x_0, the event of a deal, x the size of a deal (- for sales, + for purchases), and $x^2 = x_0.|x|^2$. Our results, (data available on request from the authors,) show generally less effect of the deal (x) variables on quote revisions; unlike Hasbrouck neither the x, nor the x^2 variables have a significant effect on r, only the x_0 variables do. Like Hasbrouck, we find that none of the variables, even the lagged dependent variables, can help much to explain x, the size of deals; indeed like him, the lagged event of a deal x_0 is very slightly better at explaining x, the size of deals, than lags of x themselves. Again, as in Hasbrouck's work, neither the size, nor the squared size, of deals, x and x^2, has any effect on the eventuality of deals, x_0, indeed even less in our data than in his.

Finally we look at the determinants of the spread. In Table V, p. 203, Hasbrouck regresses the spread, for his particular equity share, Ames Department Stores, on its own (5) lags, and the absolute values of the current and five lagged values of x_0, x and x^2. The t statistics for the sums of these variables are as follows, and for comparison on our data, (activity scale only):-

	own lags	x^0	x	x^2
Hasbrouck	32.29	0.98	5.89	-3.24
Our data	138.69	2.72	-0.018	0.118

This shows that the extent of the positive auto-correlation of spreads is even larger in our data than in his. Otherwise the significance of deals in our data set is rather less than in his, and works in our own case primarily through x_0, the event of a deal, rather than its size (or squared size). In particular, Hasbrouck finds some general tendency for the effect of x (on quote revisions and spreads) to be positive and for x^2 to be negative, which we do not find in our data set; but this is very likely because of the manner in which deal size was limited by the usually small size of the quote on offer in our data set, as earlier described.

E. Conclusions

It is now time to summarize this long, and often quite complex, study of the inter-relationships and determinants of the variables that can be extracted from D2000-2, e.g. event, price, and size of deal, and whether it exhausts the prior quote; the frequency of entry, price, size and volatility of prices for both the bid and the ask; and the spread between them. Let us do so by rehearsing our main findings.

(1) Unlike the price quote series, which exhibits highly significant negative auto-correlation at high frequencies, the transaction price series exhibits no strong signs of auto-correlation; (there is an insignificant negative first-order autocorrelation balanced by just

significant higher-order positive auto-correlation). If one could not observe the 'bounce' between deals at the bid and ask, the transactions series would then appear to exhibit weak negative first-order auto correlation.

(2) Tests of length of runs of deals at the bid and ask suggest that these have a fat (long) tail, which in this data set appears to be associated with strong price trends.

(3) Studies of interactions between the many variables available from D2000-2 suggest a close inter-relationship (nexus) between quote frequency and deals (two way causality), and between quote (price) changes and the spread (two way causality). These two nexuses are linked, in that a deal that exhausts the amount offered at a previously quoted price will cause a price change both directly, and indirectly via its effect on the spread (both directly, and again indirectly by raising volatility). Deals that do not exhaust the amount on offer have a much weaker effect. There are only weak relationships (in either direction) between the quantities (posted) and any of the other variables in the system.

(4) Unlike a single dealer system, where the dealer will normally adjust both bid and ask quotes simultaneously, in this multiple competitive dealer system the bids and asks are normally input by different banks. There is no automatic reason why bid quotes should be revised in response to changes in ask quotes (or deals). In practice here, they did not respond much to such activity on the other side. Instead price changes on one side primarily impacted on the spread, and thence gradually on the quote on the other side, with the spread acting as an error correction mechanism between the cointegrated bid and ask series.

(5) The main pattern of relationships reported in (3) above appear to be encouragingly robust, as evidenced by the similarity of t values, to changes in either the periodicity or the scale over which the regressions were run.

(6) On the other hand, the GARCH equations varied considerably when run in clock-time, rather than on an activity scale. The results for the former were more intuitive.

(7) We were able to run an exact comparison, and replication, of Hasbrouck's (1991) study of transaction/quote relationships in the NYSE. The main difference between us is that in his study lagged quote revisions have a significant (negative) effect on deals, whereas there is no such interaction in our data set.

V Tail-piece

We have already summarised our main findings at the ends of Sections 3 and 4 respectively. Here we would wish to emphasize again how short our data period was, only seven hours. Our findings should, therefore, be treated with due caution. By the same token there would be considerable value, not only to academics but also to practitioners, in obtaining additional data of this high quality format. We hope, and expect, that such data will become more widely available soon.

Footnotes

1. According to a report in the Financial Times by James Blitz (Monday, September 13th, 1993, p.19),

2. Readers wanting more up-to-date information should refer directly to Reuters Limited, 85 Fleet Street, London EC4P 4AJ.

3. The total amount thus traded is large in absolute amount, but small relative to reported daily turnover in this market of some $900+ bn. We find it hard to relate the data reported above to the BIS (1993) report in their 1992 survey that "In the United States and the United Kingdom, the share of deals going through such [automated dealing] systems in April 1992 was 32 and 24% respectively" (Table 1, p. 21, and p. 24). Probably definitions of automated dealing systems would have been somewhat wider, including Reuters D2000-1 as well as D2000-2, but, even so, the above percentage seems surprisingly high.

4. According to the report in the Financial Times (ibid.)

5. We are most grateful to Reuters in general, and to Mr Etherington in particular, for allowing us to record the quantitative details reported below.

6. There is, of course, the survey of foreign exchange business which has now been undertaken three times at three year intervals in April 1986, 1989 and 1992 by Central Banks under the aegis of the BIS, but this does not provide time series data. The volumes reported are aggregates for the month of April.

7. We have little doubt that such data will become more plentiful and easily available in future. But for the time being at least they have rarity value. Also, as electronic trading systems mature, it should be of historical interest to observe how they looked and operated in the early stages of their development.

8. Also see Mark D Flood, 'Market structure and inefficiency in the foreign exchange

market' JIMF, 13(2), April 1994, pp 131-158, especially note 6, p.154.

9. We obtained the accompanying FXFX data series from Dr. M. Dacorogna of Olsen and Associates in Zurich.

10. This classification has since been changed.

11. When a new deal has been made, the new transactions price initially for a few seconds shows purple, rather than the standard black, on the screen in order to alert traders to this.

12. When the deal is completed both banks, the hitter and the quoter, will be sent details to whom and where to make the payment, which is then settled in the standard fashion. So, ex post facto, the identity of the counterparty becomes revealed.

13. Unhappily we had a few cases in our data where this directional constraint did not hold. While this could be due to new bid/ask inputs occurring at exactly the same moment, several of these cases probably arise from mistakes in transcribing the video-tape, see Section II. When we had identified these few errors, we removed them from the data set.

14. Reuters had decided to videotape a day (seven hours) of the working of D 2000-2 for their own purposes. We do not know why their operator chose these other five bilateral exchange rates. There is some auto-correlation in volatility and activity in differing rates from day-to-day, and maybe the operator felt that these would provide either more interest and/or a better representation than the other nine available. But basically we do not know, just as we do not know how the characteristics of the observations in this 7 hour snapshot compared with the same hours on other days, or with other hours on the same day, or with other bilateral rates at the same time.

15. The authors were working at Harvard when they sought to take the details of the tape, every entry, from the video onto paper, and then back onto electronic diskette. Since no Betacam video machines were available in the USA, the tapes were first copied onto S-VHS,

and the entries on the S-VHS tapes viewed over a special video player, with adjustable speeds, forward and backward, pause etc.

16. The transcription from video to paper was primarily done by our wives, Mrs Margaret Goodhart and Mrs Keiko Ito, also with the assistance of Ms Yoko Miyao, who did this extremely complex and difficult exercise in a dedicated, patient and conscientious fashion, and we are most grateful to them. But there will inevitably be some errors in variables.

17. There were a couple of cases when we could not marry the two data points, despite several reviews. It is this to which we referred earlier as the only examples of probable errors in the original data.

18. Thus, the cross-check revealed that the accuracy of visually timing the exact moment of an entry on a screen was to within about + or - three seconds. From the adjustments and reviews that had to be made to marry the transaction price data with the bid/ask (and associated quantity) data, it may well be that the final digit in the remaining data is incorrect about once every 30 observations, and the penultimate digit incorrect once every 100 observations. Some of our statistical anomalies, e.g. the few zero and negative spreads and incorrect direction of price movement following a deal, need to be seen in that context. Such inevitable human error could have been eliminated if the data had been available in electronic disk form, but that was not on offer. Moreover, there are some advantages in getting to know the raw data thoroughly before proceeding to econometric testing.

19. Considering that deal size is highly skewed, we wonder whether he meant 'median' when he wrote 'average' here?

20. When we subsequently used this series for econometric work, we changed this rule of thumb, so that when a <u>deal</u> exhausted the quantity offered, and no price was then shown, we took the <u>next</u> reported price as becoming effective. Otherwise the estimated (absolute) price

change, following a deal, would have been biased downwards.

21. At some future date we intend to construct similar tables for the raw data for the Yen/$ and CHF/$ on D2000-2 and FXFX, temporally matched. Time did not allow at this stage.

22. This has been widely noted, e.g. Bessembinder (1994) and Bollerslev and Melvin (1994), and was more extensively described and analyzed in Goodhart and Curcio (1991).

23. Cohen, Maier et al (1981) have persuasively argued that a dealer should always prefer to transact with certainty at a firm bid (ask) quote rather than set an ask (bid) quote at a zero, or tiny, spread distance from it with no immediate certainty of transaction; so on these grounds a zero spread in D2000-2 may also represent a transcription error or a dealer error; indeed most of these occasions lasted for only a very short period of seconds. Nevertheless we intend to discuss with practitioners whether there may be any rationale for the existence of zero spreads on D2000-2 e.g. asymmetric trading (execution) costs between the two sides, and until we have done so, we have decided to let these data stand.

24. N.B. the coefficients will, however, be biased downwards by the interpolation process, forcing the interpolations to take a no change value. The t values will be less affected by such time deformation.

25. We cannot, of course, yet observe any time series of total market transactions. All we have now is a short snapshot of data on transactions over D2000-2. If the temporal profile of transactions over D2000-2 should be an inaccurate and biased proxy for the total volume of transactions, then the question of whether the indicative FXFX data provide a good predictor of concurrent D2000-2 deals would not have much importance.

26. We also ran a similar exercise, using hourly data, for the CHF/$ series, but, with only 51 deals in our data period, this was too affected by small sample problems to provide a useful cross-check. Data on this are available from the authors.

27. Our computer could not handle a general to specific exercise with parameters of this size, though there was relatively little multicollinearity, or auto-correlation, (apart from the spread, S, which was strongly positively auto-correlated in D2000-2). We ran a simple cross-correlation matrix, which is too large to reproduce, but is available from the authors

28. Note that the split of the period into sub-divisions differs slightly between Tables 10 and 15.

29. Such volatility variables were usually AV12, or sometimes BV60, in the ask price change, DA, equation, and ADB in the bid price change, DB, equation; rather counter-intuitively this latter variable was positive in the DB equation, and when it entered, AV12 was negative in the DA equation, implying that higher volatility led to finer, more competitive prices being posted, but the significance level of this is not high.

30. The absolute size of the coefficients on the lagged dependent variables increased by a factor of over three times for bid prices, but nearer eight times for ask prices. With their standard errors rising by a factor of over five times in both cases, the t values of the lagged dependent variables fell for bid price changes, but rose for ask price changes, (relative to those in Table 19). As before the t values of the deal exhaust variables fell from nearly 20 to about 5. By contrast, the coefficient on the lagged spread variable rose sharply in the bid price equation, where the size of the coefficient rose by a factor of 10 and the t value also increased. (N.b. we did test that the spread with six lags entered more strongly, than the spread lagged once, in the Ask price change equation.) Otherwise the residual variables that entered significantly changed around slightly; a variety of volatility variables still entered weakly without any clear, or intuitive, direction of effect, and again the effects of previous large quantities of Ask deals (AD6 and ADQ24) tended to raise both bid and ask quotes.

31. Much of the literature on spreads, especially for spreads in the NYSE, seeks to

distinguish between the effects of trading costs, inventory costs and information asymmetry, e.g. Madhavan and Smidt (1991). We cannot attempt a similar exercise as we have no measure of inventories, unlike Lyons (1993a.)

32. Obviously the exhaustion of the quote by a deal would cause a jump in prices, so, in the equations to explain the absolute change in prices in D2000-2, ADB and ADA, BDE and ADE were entered into their respective equations. The lagged dependent variable, and the absolute change in quote revision on the other side, e.g. ADA in the ADB equation, were quite strongly significant. The prior event of deals (AD and BD), but not their size (BDQ and ADQ), and the frequency of price revision (AF and BF) were also a positive, but somewhat weaker, influence on the absolute value (volatility) of price change. The size of ask quotes (AQ) appeared to affect the absolute value of ask price changes, though the two lags that entered had offsetting effects. Two of our (better) representative equations are given in Table 25. Again, we undertook the companion exercise of looking at absolute price changes on FXFX. Apart from the lagged dependent variables, the spread entered with a significant positive coefficient. Presumably this is picking up some (expected) determinants of volatility (not otherwise caught by the lagged dependant variables). The change in ask prices enters the equation explaining the absolute change in ask prices, whereas the frequency of quote entries enters the similar equation for the bid prices. With price movements in the bid and ask being much more closely tied together and similar for FXFX, than for D2000-2, we only here show the former equation in Table 26, since the latter (apart from the substitution of FXBF for DFXA) is almost identical.

33. We have no good explanation for the negative values for AD24 or ADA24 in the equation shown in 27A, and we would again be inclined to regard these as chance findings.

34. This volatility variable was the absolute change in prices over the preceding half minute (ADFXA in the Ask equation and ADFXB in the Bid equation).

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Tables and Graphs
for
One Day in June 1993:
A Study of the Working of Reuters 2000-2 Electronic Foreign Exchange Trading System

C. Goodhart, T. Ito, and R. Payne

Table 1

D2000-2

Screen at 10.17.40 on June 16th, 1993

Currency	Bid	Ask	Quantity Columns	Blank Columns	Latest Price
USD/JPY	106.16	106.25	2 X 1	X X	106.26
DEM/JPY	/	/	/ /	X X	64.59
USD/CHF	1.4672	1.4679	4 2	X X	1.4676
DEM/CHF	0.8925	0.8933	3 2	X X	0.8929
USD/DEM	1.6439	1.6443	2 1	X X	1.6443
DEM/FRF	3.3633	/	M /	X X	3.3634

Table 2

Periods of Appreciation of US$

BST	Bid	Ask	No. of Obs
13.38	1.6474	1.6481	7
13.39	1.6486	1.6494	6
13.40	1.6494	1.6503	6
13.41	1.6500	1.6506	5
13.42	1.6503	1.6512	6
13.43	1.6525	1.6535	7
13.44	1.6540	1.6550	6
13.45	1.6553	1.6564	7
13.46	1.6552	1.6560	7
14.42	1.6571	1.6580	8
14.43	1.6575	1.6584	8
14.44	1.6594	1.6602	5
14.45	1.6600	1.6606	5
14.46	1.6601	1.6611	5

Table 3

News on US and German Economies

BST	AAMM Report
12:13:18	'German unemployment could top 4 million - - Rexrodt'
12:34:40	'Next Bundesbank rate cut seen most likely in July'
12:53:12	'German industry says economy still declining'
13:01:44	'German institute sees no recovery before mid-1994'
13:32:04	'US May Housing Starts rose 2.4%'
13:37:04	'US Home Building in May is strongest in 5 months'
13:46:54	'Bonn can live with current mark-dollar rate'
13:56:30	'German Govt source sees no danger for mark'
14:15:40	'Dlr opens firm in US,-surges on German comments'
14:20:12	'US May Industrial Output rose, capacity use steady'
14:32:04	'Bonn wants lower short-term rates - - Source'
14:33:48	'US May Housing Starts Rise is modest - analysts say'
14:41:08	'Mark falls against dollar after govt comments'

Table 4

Analysis of Deals and Quotes

	# Quotes		# Deals		Ave size of deals*	
	Bid	Ask	Bid	Ask	Bid	Ask
Yen/$	93	127	12	17	2.33	1.55
Yen/Dm	99	54	15	2	1.91 (3.15)	2.13 (3.50)
CHF/$	142	134	18	33	1.125	1.67
CHF/Dm	121	168	19	45	1.26 (2.08)	2.71 (4.45)
FFr/Dm	98	79	14	11	2.71 (4.45)	2.97 (4.88)

*Based on assumption that M = 8, L = 15

Table 5

Relationship between Direction of Deals and Currency Change

	# of Deals		Currency Value		% Change
	Bid	Ask	Start	Finish	
Dm/$	186	251	1.6450	1.6585	+0.82%
Yen/$	12	17	106.25	106.70	+0.42%
Yen/DM	15	2	64.63	64.27	-0.56%
CHF/$	18	33	1.4690	1.4840	+1.02%
CHF/DM	19	45	0.8935	0.8953	+0.20%
FR/DM	14	11	3.3648	3.3623	-0.07%

Table 6

BST

Best estimated Start Times for Tapes*

	Bid	Ask
Tape 4	13:40.47	13:41.07
Tape 3	11:59.10	11:59.30
Tape 2	10:15.37	10:15.57
Tape 1	8:31.40	8:32.00

* In each case the finish of Tape t-1 was about one second before the start of Tape t. For Tape 1 the start time is given from the first quote, of DM/$ bid and ask: the tape starts with a blank screen almost exactly 8 minutes before.

Table 7

Statistical Characteristics of the D2000-2 and FXFX Time Series Compared

Dm/$

		D2000-2	FXFX
1 Bid, No of Obs[a]		799	3484
Mean		1.649007	1.6482
SD		0.006060	0.0058
Skew		0.63670	0.9392
Kurtosis		-1.31504	2.1507
2 Diff Bid[c]		798	3483
Mean		0.00000994	0.000003646
SD		0.000389	0.0004012
Skew		0.57095	0.0845
Kurtosis		9.35931	6.393
Autocorrelation coefficients	1	-0.6173 (-17.3)[b]	-0.6236 (-36.77)
	2	-0.1437 (-3.44)	-0.3488 (-17.49)
	3	-0.1105 (-2.63)	-0.1917 (-9.32)
	4	0.0031 (0.07)	-0.0802 (-4.02)
	5	0.0758 (2.13)	-0.0365 (-2.16)
GARCH[d]	A_0	-0.000 (-1.48)	-0.000 (-0.22)
	A_1	-0.514 (-16.97)	-0.481 (-31.92)
	B_0	0.000 (3.89)	0.000 (4.10)
	B_1	0.198 (3.92)	0.116 (6.96)
	B_2	0.728 (14.07)	0.849 (38.14)
3 Average of Bid/Ask, No of Obs 1581[c]			3484
Mean		1.649511	1.6486
SD		0.006052	0.0058
Skew		0.55846	0.9400
Kurtosis		-1.40521	2.1503
4 Diff of Average[c]		1580	3483
Mean		0.00000515	0.000003646
SE		0.000192	0.000371
Skew		0.45549	0.0920
Kurtosis		13.3980	9.1457
Autocorrelation coefficients	1	-0.366 (-14.52)	-0.6094 (-35.91)
	2	-0.169 (-6.32)	-0.3278 (-16.51)
	3	-0.109 (-4.06)	-0.1659 (-8.12)
	4	-0.082 (-3.08)	-0.0586 (-2.56)
	5	-0.043 (-1.72)	-0.0045 (-0.26)
GARCH[d]	A_0	0.000 (3.04)	0.000 (1.56)
	A_1	-0.179 (-9.19)	-0.026 (-1.40)
	B_0	0.000 (0.23)	0.000 (6.75)
	B_1	0.536 (38.93)	0.268 (9.01)
	B_2	0.540 (89.49)	0.621 (16.05)

		D2000-2	FXFX
5 Spread No of Obs		1556	3484
Mean		6.8464	7.090
SD		8.0955	2.689
Skew		4.034	2.604
Kurtosis		27.063	39.380
Autocorrelation	1	0.4686 (18.44)	-0.0118 (-0.70)
coefficients	2	0.1098 (3.91)	0.0173 (1.02)
	3	0.1322 (4.72)	0.047 (2.81)
	4	-0.0027 (-0.09)	0.042 (2.49)
	5	0.0500 (1.97)	0.044 (2.58)
GARCH	A_0	1.4778 (11.18)	0.006 (185.8)
	A_1	0.6890 (29.68)	0.032 (5.58)
	B_0	1.0234 (4.30)	0.000 (0.70)
	B_1	0.6591 (43.67)	0.287 (77.40)
	B_2	0.6454 (43.84)	0.643 (247.02)

a Since the results for the Ask series are almost identical to those for the Bid, we have omitted the former to save space.

b t values in brackets

c This is the first difference of the level

d We ran the system,

$$\Delta x_t = \alpha_0 + \alpha_1 \Delta x_{t-1} + \epsilon_t, \quad \epsilon_t | I_{t-1} \sim N(0, h_t)$$

$$h_t = \beta_0 + \beta_1 h_{t-1} + \beta_2 \epsilon_t^2 + v_t$$

e Since the bids and the asks were put in at separate times, the numbers of calculated means and spreads will be approximately equal to the <u>sum</u> of the number of bids <u>plus</u> the number of asks.

Table 8

Regressions between FXFX and D2000-2 Series

LHS Variable	RHS Variable	Constant	Coefficient on	$\bar{R}^2$ (SE)	Dickey-Fuller t Statistic†
FX Mean	2000 Mean	-0.0018	1.0011	0.995	-18.07
		(0.0016)*	(0.0010)	(0.0004)	
2000 Mean	FX Mean	0.0101	0.9938	0.995	-18.04
		(0.0016)	(0.0010)	(0.0004)	
FX Bid	2000 Bid	-0.0267	1.0162	0.992	-16.16
		(0.0022)	(0.0013)	(0.0005)	
2000 Bid	FX Bid	0.0397	0.9759	0.992	-16.16
		(0.0021)	(0.0013)	(0.0005)	
FX Ask	2000 Ask	0.0315	0.9810	0.991	-17.12
		(0.0021)	(0.0013)	(0.0005)	
2000 Ask	FX Ask	-0.0175	1.0105	0.991	-17.11
		(0.0022)	(0.0013)	(0.0005)	

* Standard errors in brackets

† MacKinnon critical 1% value -3.896

Table 9

Error Correction Mechanism

		FXFX Dependent		D2000-2	
		Coefficient	t value	Coefficient	t value
Lagged	-1	-0.207	-12.8	-0.009	-6.28
Dependent	-2	-0.184	-11.4	-0.004	-2.64
	-3	-0.136	-8.7	-0.002	-1.50
	-4	0.002	-1.9	-0.001	-0.93
	-5	-0.001	-0.9	-0.007	-4.81
Lagged	-1	-0.107	-4.25	-0.002	-2.25
Independent	-2	-0.004	-1.95	-0.002	-1.92
	-3	-0.000	-0.10	-0.002	-1.73
	-4	-0.003	-1.48	0.001	0.64
	-5	-0.004	-1.54	0.001	0.64
ECM		-0.180	-15.47	-0.006	-8.44

Table 10

Dm/$: Half hour periods

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
[SD] S2 Deals†	9.8	7.5	4.5	6.7	4.8	5.7	3.4	4.1	5.5	6.2	10.75	11.7	11.7	7.3
S2 Deals ave size	1.42	1.64	1.41	2.14	2.00	1.25	2.31	1.625	2.04	1.83	1.96	1.42	1.57	2.24
[SF] S2 Frequency† price entry	8.3	8.4	5.4	7.4	6.6	3.7	3.6	4.1	4.7	5.9	11.5	11.2	11.45	7.65
[SV] S2 Volatility*	0.083	0.05	0.05	0.041	0.066	0.033	0.007	0.10	0.05	0.074	0.612	0.132	0.314	0.116
[SS] S2 Spread	6.41	4.04	5.34	4.32	5.15	4.41	2.51	5.95	4.07	4.82	17.5	8.43	7.17	8.33
[FF] FX Frequency†	8.04	7.68	7.78	7.95	7.02	7.02	5.09	6.42	6.48	7.38	7.32	7.91	7.25	6.65
[FV] FX Volatility*	0.110	0.070	0.061	0.057	0.062	0.042	0.079	0.091	0.059	0.058	0.696	0.152	0.374	0.140
[FS] FX Spread	6.65	6.36	6.83	6.60	6.89	7.15	7.32	7.05	7.15	7.08	7.92	7.36	7.80	7.30

† As % of total

* Divided by volatility of whole period

Table 11
Dm/$: Half hour relationships, D2000-2 and FXFX

	LHS Variable	RHS Variables	Constant	b_1	b_2	b_3	$\bar{R}^2$
(1)	SF	FF	-6.8	1.95			0.25
			(-1.1)	(2.32)			
(2)	SD	FF	-6.9	1.96			0.25
			(-1.1)	(2.32)			
(3)	SD	SF	0.4	0.94			0.86
			(0.8)	(9.12)			
(4)	SV	FV	-0.0	0.88			0.98
			(-0.7)	(27.11)			
(5)	SD	SV	5.7	11.30			0.36
			(7.14)	(3.95)			
(6)	SD	SV,SF	0.3	-0.46	0.96		0.85
			(0.3)	(-0.17)	(6.41)		
(7)	SD	FF,FV	-6.9	1.78	9.30		0.59
			(-1.5)	(2.83)	(3.33)		
(8)	SS	FS	-31.1	5.27			0.34
			(-2.3)	(2.80)			
(9)	SS	SV	3.7	21.23			0.85
			(7.7)	(8.67)			
(10)	FS	FV	6.8	1.79			0.51
			(64.4)	(3.82)			
(11)	SD	FF,FV,FS	-33.0	2.45	3.46	3.11	0.64
			(-1.9)	(3.34)	(0.75)	(1.54)	
(12)	SD	SF,SV,SS	0.3	0.96	-0.64	0.01	0.84
			(0.2)	(6.06)	(-0.11)	(0.03)	

Notation: Initial F stands for FXFX series; initial S for System D2000-2. Second letter F represents Frequency of quote entry; D is number of Deals; V Volatility; and S Spread. So SF is frequency of quote entry over System D2000-2; FF is frequency of quote entry over FXFX; SD is the number of deals on D2000-2; SV is the volatility of D2000-2, etc.

Table 12

Transactions in Dm/$

		Bid	Ask	Bid + Ask
Number		186	251	437
Av Size		$2.51 mn	$2.49 mn	$2.5 mn
Levels Mean		1.64946	1.64978	1.6496
SD		0.0062	0.0061	0.0061
Skew		0.5541	0.5571	0.5518
Kurtosis		-1.4346	-1.3617	-1.3910
1st Differences				
Mean		0.000042	0.000034	0.000019
SD		0.00054	0.00030	0.000269
Skew		5.096	-0.575	1.273
Kurtosis		38.556	10.164	15.326
Autocorrelation	-1	-0.084 (-1.11)	-0.086 (-1.32)	-0.1406 (-2.90)
Coefficient	-2	-0.069 (-0.90)	0.138 (2.13)	0.0949 (1.96)
	-3	0.155 (2.07)	-0.085 (-1.30)	0.0185 (0.38)
	-4	-0.009 (-0.12)	0.050 (0.77)	0.054 (1.12)
	-5	0.003 (0.04)	0.042 (0.66)	0.026 (0.54)
GARCH	A_0	-0.000 (-0.63)	0.000 (1.70)	0.000 (0.52)
	A_1	-0.004 (-0.55)	-0.159 (-1.89)	-0.365 (-17.49)
	B_0	0.000 (2.89)	0.000 (4.11)	0.000 (0.32)
	B_1	0.415 (20.26)	0.572 (4.21)	0.553 (19.49)
	B_2	0.491 (44.87)	0.246 (2.47)	0.478 (56.46)
Dickey-Fuller Test with 5 lags		-643.34	-91.22	-301.3

Table 13

Transaction Runs, Price Changes and Sample Probability of Occurrence.

% price change represents the percentage difference in the quotes on the stated side of the market at which the first and last transaction in each run took place. Sample probability is simply the probability, given the sample frequency of each type of deal, of observing n successive transactions on one side of the market, assuming that they are independent events.

Run Length	Side of Market	% price change	Sample Probability
21	Ask	0.272	$8\ 8\text{x}10^{-6}$
17	Ask	0.516	$8\text{x}10^{-5}$
15	Ask	0.103	$2.4\text{x}10^{-4}$
14	Ask	0.122	$4.2\text{x}10^{-4}$
12	Bid	-0.030	$3.6\text{x}10^{-5}$
11	Bid	-0.097	$8.4\text{x}10^{-5}$
9	Ask	0.121	$6.8\text{x}10^{-3}$
8	Ask	0.055	0.0018
8	Ask	0.018	0.0018
7	Bid	-0.090	0.0025
7	Bid	-0.055	0.0025
7	Ask	0.018	0.0205

Table 14

Probability of Observing Deals

A. Bid

Probit Estimates

Number of obs	=	4980
chi2(7)	=	96.1
Prob > chi2	=	0.000
Pseudo R2	=	0.061

Log Likelihood = -732.90769

bd	Coef.	Std. Err.	t	P>|t|
bf6	.1663953	.0329075	5.056	0.000
bf12	.1275713	.0328465	3.884	0.000
bd36	.1151307	.0427033	2.696	0.007
db6	154.4183	81.54656	1.894	0.058
s	-431.2308	91.80828	-4.697	0.000
ad6	-.2524728	.1295843	-1.948	0.051
_cons	-1.893544	.069593	-27.209	0.000

B. Ask

Probit Estimates

Number of obs	=	4980
chi2(10)	=	96.2
Prob > chi2	=	0.000
Pseudo R2	=	0.048

Log Likelihood = -952.29651

ad	Coef.	Std. Err.	t	P>|t|
af6	.0737124	.0311327	2.368	0.018
af12	.0777921	.030167	2.579	0.010
adq6	.0508467	.0205937	2.469	0.014
Lag6 s	88.19644	39.06158	2.258	0.024
bd6	-.212043	.0811112	-2.614	0.009
bd24	.1275771	.0381741	3.342	0.000
db6	107.5494	68.76905	1.564	0.118
db12	197.6548	66.76211	2.961	0.003
db24	154.0204	58.16457	2.648	0.008
db36	116.271	54.50788	2.133	0.033
_cons	-1.940738	.0564778	-34.363	0.000

Table 15

Spreads:
A Comparison of Spreads at Ordinary Times
with those at Transaction Times

A. DM/$ bid-ask spread

	Bid-ask, all samples			Bid-ask, transaction time only		
Hour	Mean unit=DM/$	Median unit=DM/$	No. of Observ	Mean Unit=DM/$	Median unit=DM/$	No. of Observ
0	0.0004214	0.00030	607	0.0004125	0.00020	72
1	0.0004992	0.00040	708	0.0003587	0.00030	46
2	0.0003791	0.00030	671	0.0002391	0.00020	46
3	0.0005388	0.00040	577	0.0003700	0.00030	30
4	0.0005110	0.00040	647	0.0003113	0.00030	44
5	0.0011005	0.00070	656	0.0010630	0.00060	92
6	0.0007651	0.00070	602	0.0004777	0.00040	72
7	0.0007530	0.00050	49	0.0004000	0.00040	6

B. Yen/$ bid-ask spread

	Bid-ask, all samples			Bid-ask, transaction time only		
Hour	Mean unit=Yen/$	Median unit=Yen/$	No. of Observ	Mean Unit=Yen/$	Median unit=Yen/$	No. of Observ
0	0.11213	0.15000	136	0.01000	0.02000	2
1	0.10996	0.13000	720	0.08000	0.09000	3
2	0.14967	0.20000	720	0.08833	0.09500	6
3	0.18212	0.20000	720	0.14000	0.14000	2
4	0.15825	0.19000	554	0.04500	0.05000	4
5	0.14814	0.15000	199			0
6	0.10598	0.10000	112	0.08333	0.03000	6
7	0.08000	0.08000	14			0

Notes: (1) Each hour has a maximum of 720 observations (5 second intervals). If an ask or bid is missing, then that bracket is not counted in the left-hand-side panels of "all" observations. (2) Transaction time bid-ask spread is the bid-ask spread of the 5-second bracket, preceding the 5-second bracket where a transaction occurs. There are instances where transactions occur even without one of the bid or ask being shown on the screen (just before the transaction is recorded). These are treated as missing observations in the right-hand-side panels.

Table 16

Ordered Probit Analysis on data at one minute intervals

(1) Bid deals

Number of Obs	= 403
Chi2(4)	= 38.1
Prob>Chi2	= 0.000
Pseudo R2	= 0.056

Log Likelihood = -320.24

bd	**Coeff**	s.e.	t	P>t
bf6	0.0357	0.0133	2.67	0.008
bf24	0.0259	0.0079	3.28	0.001
db24	64.45	31.34	2.05	0.041
Lagl s	-180.0	89.27	-2.02	0.044

(2) Ask deals

Number of Obs	= 391
Chi2(4)	= 34.4
Prob>Chi2	= 0.000
Pseudo R2	= 0.040

Log Likelihood = -408.15

ad	**Coeff**	**s.e.**	**t**	**P>t**
af6	0.0351	0.0117	2.993	0.003
ada6	198.20	59.49	3.331	0.000
da12	-69.07	49.96	-1.383	0.168

Table 17

Basic Determinants of Quote Revision

A. Bid Quote Revision

Number of obs	=	4976
F(7, 4969)	=	87.9
Prob > F	=	0.000
R-square	=	0.110
Adj R-square	=	0.109
Root MSE	=	.0002

db	Coef.	Std. Err.	t	P>|t|
Lag1 db	-.11656	.0136231	-8.556	0.000
Lag2 db	-.1176993	.0137196	-8.579	0.000
Lag3 db	-.1320021	.0138006	-9.565	0.000
Lag4 db	-.0546471	.0137991	-3.960	0.000
Lag5 db	-.0210431	.0137147	-1.534	0.125
Lag6 db	-.0776679	.0136245	-5.701	0.000
Lag1 bde	-.0003729	.0000189	-19.745	0.000
_cons	.0000157	3.21e-06	4.881	0.000

B. Ask Quote Revision

Number of obs	=	4976
F(7, 4969)	=	114.1
Prob > F	=	0.000
R-square	=	0.138
Adj R-square	=	0.137
Root MSE	=	.0002

da	Coef.	Std. Err.	t	P>|t|
lag1 da	-.111342	.0134768	-8.262	0.000
lag2 da	-.08533	.0133953	-6.370	0.000
lag3 da	-.0669398	.0134363	-4.982	0.000
lag4 da	-.0322129	.0134368	-2.397	0.017
lag5 da	-.1609648	.0133957	-12.016	0.000
lag6 da	-.0400806	.0134622	-2.977	0.003
lag1 ade	.0003769	.0000161	23.339	0.000
_cons	-8.79e-06	3.06e-06	-2.871	0.004

Table 18

Basic Determinants of Quote Revision:
Zero Changes Omitted: Tick by Tick

A. Bid Quote Revision

Number of obs	= 727
F(7, 720)	= 34.2
Prob > F	= 0.000
R-square	= 0.249
Adj R-square	= 0.242
Root MSE	= .0005

db	Coef.	Std. Err.	t	P>|t|
Lag1 db	-.4204473	.0687554	-6.115	0.000
Lag2 db	-.4810583	.0717263	-6.707	0.000
Lag3 db	-.5284103	.0692662	-7.629	0.000
Lag4 db	-.2811608	.0843628	-3.333	0.000
Lag5 db	-.0902551	.0788967	-1.144	0.253
Lag6 db	-.4268289	.0869281	-4.910	0.000
Lag1 bde	.0004502	.0000513	-8.783	0.000
_cons	.0000989	.0000223	4.432	0.000

B. Ask Quote Revision

Number of obs	= 747
F(7, 740)	= 43.1
Prob > F	= 0.000
R-square	= 0.289
Adj R-square	= 0.283
Root MSE	= .0004

da	Coef.	Std. Err.	t	P>|t|
Lag1 da	-.7198426	.0813796	-8.845	0.000
Lag2 da	-.3373846	.0585086	-5.766	0.000
Lag3 da	-.4080851	.0765337	-5.332	0.000
Lag4 da	-.2991646	.075899	-3.942	0.000
Lag5 da	-.53916	.0578206	-9.325	0.000
Lag6 da	-.1875199	.0644919	-2.908	0.004
Lag1 ade	.0004132	.0000445	9.295	0.000
_cons	-.0000571	.0000209	-2.729	0.007

Table 19

The Determinants of Quote Revision

A. Bid Quote Revision

Number of obs	=	4976
F(13, 4963)	=	64.4
Prob > F	=	0.000
R-square	=	0.144
Adj R-square	=	0.142
Root MSE	=	.0002

db	**Coef.**	**Std. Err.**	**t**	**P>|t|**
Lag1 db	-.1199148	.0139002	-8.627	0.000
Lag2 db	-.127044	.0139954	-9.078	0.000
Lag3 db	-.1449427	.0140143	-10.342	0.000
Lag4 db	-.0792908	.0141885	-5.588	0.000
Lag5 db	-.0478669	.0140588	-3.405	0.000
Lag6 db	-.1040509	.0140001	-7.432	0.000
Lag1 bde	-.0003474	.0000196	-17.734	0.000
db12	-.0503687	.0076551	-6.580	0.000
bdq6	-.0000108	3.32e-06	-3.240	0.001
adb6	.0375697	.0086841	4.326	0.000
adb24	.0103388	.00735	1.407	0.160
adq24	5.36e-06	1.70e-06	3.148	0.002
Lag1 s	.0375859	.0048246	7.790	0.000
_cons	-.0000196	4.76e-06	-4.116	0.000

B. Ask Quote Revision

Number of obs	=	4975
F(11, 4964)	=	76.5
Prob > F	=	0.000
R-square	=	0.145
Adj R-square	=	0.143
Root MSE	=	.0002

da	Coef.	Std. Err.	t	P>|t|
Lag1 da	-.0946171	.0140177	-6.750	0.000
Lag2 da	-.0699815	.0138121	-5.067	0.000
Lag3 da	-.053245	.0138313	-3.850	0.000
Lag4 da	-.018927	.0138015	-1.371	0.170
Lag5 da	-.1497416	.0136565	-10.965	0.000
Lag6 da	-.0278212	.0135895	-2.047	0.041
Lag1 ade	.0003646	.0000176	20.663	0.000
ad6	.00001	5.83e-06	1.723	0.085
16db	-.0307674	.0127157	-2.420	0.016
bv60	.0000389	.0000135	2.881	0.004
Lag1 s	-.0278851	.0048746	-5.720	0.000
_cons	-2.63e-06	4.68e-06	-0.563	0.574

Table 20

Quote Revisions

A. Bid Reaction to Changes in Ask Quotes

Number of obs	=	4975
F(16, 4959)	=	48.1
Prob > F	=	0.000
R-square	=	0.134
Adj R-square	=	0.131
Root MSE	=	.0002

db	Coef.	Std. Err.	t	P>|t|
Lag1 db	-.1428408	.0136389	-10.473	0.000
Lag2 db	-.1473166	.0137856	-10.686	0.000
Lag3 db	-.1631221	.0139074	-11.729	0.000
Lag4 db	-.0939637	.0140831	-6.672	0.000
Lag5 db	-.0619189	.0140772	-4.399	0.000
Lag6 db	-.1211814	.0141262	-8.578	0.000
db12	-.067737	.0084264	-8.039	0.000
db24	-.0103636	.0070925	-1.461	0.144
db36	-.0191648	.0065055	-2.946	0.003
Lag1 bde	-.0003716	.0000187	-19.894	0.000
da6	.0162051	.0072949	2.221	0.026
da12	.029355	.0076464	3.839	0.000
da24	.0231173	.006233	3.709	0.000
da36	.0232844	.0060726	3.834	0.000
bv12	.0001046	.0000154	6.778	0.000
av12	6.26e-06	.0000158	0.397	0.692
_cons	-1.06e-06	4.26e-06	-0.248	0.804

B. Ask Reactions to Changes in Bid Quotes

Number of obs	=	4975
F(16, 4959)	=	51.6
Prob > F	=	0.000
R-square	=	0.142
Adj R-square	=	0.140
Root MSE	=	.0002

da	Coef.	Std. Err.	t	P>|t|
Lag1 da	-114878	.013517	-8.499	0.000
Lag2 da	-.088986	.0134761	-6.603	0.000
Lag3 da	-.0702402	.0135679	-5.177	0.000
Lag4 da	-.0350031	.0136022	-2.573	0.010
Lag5 da	-.1631024	.0136826	-11.920	0.000
Lag6 da	-.0421156	.0138858	-3.033	0.002
da12	-.0055925	.0074358	-0.752	0.452
da24	-.0156702	.0059864	-2.618	0.009
da36	-.0039288	.0058462	-0.672	0.502
Lag1 ade	.0003776	.0000163	23.221	0.000
db6	-.0027777	.0075712	-0.367	0.714
db12	.0160504	.0079987	2.007	0.045
db24	.0206124	.0068112	3.026	0.002
db36	.0064569	.0062616	1.031	0.303
av12	-.0000359	.0000152	-2.361	0.018
bv12	.0000147	.0000148	0.997	0.319
_cons	-6.30e-06	4.08e-06	-1.542	0.123

Table 21

The Determinants of Quote Revision:
Zero Changes Omitted: Tick by Tick

A. Bid Quote Revision

Number of obs	= 727
F(14, 713)	= 40.6
Prob > F	= 0.000
R-square	= 0.444
Adj R-square	= 0.433
Root MSE	= .0004

db	Coef.	Std. Err.	t	P>|t|
Lag1 db	-.2573243	.0662203	-3.886	0.000
Lag2 db	-.4178523	.0650541	-6.423	0.000
Lag3 db	-.4402707	.0644304	-6.833	0.000
Lag4 db	-.253194	.0779863	-3.247	0.001
Lag5 db	-.0483614	.0720124	-0.672	0.502
Lag6 db	-.3135134	.0784248	-3.998	0.000
Lag1 bde	-.0002782	.000057	-4.881	0.000
db12	-.1727642	.0426325	-4.052	0.000
bd6	-.0000829	.0000325	-2.554	0.011
Lag1 s	.3735075	.0334393	11.170	0.000
adb12	-.1342426	.0479387	-2.800	0.005
adq24	.0000298	9.69e-06	3.075	0.002
ada6	-.0906233	.0417378	-2.171	0.030
ada24	.1076248	.0440883	2.441	0.015
_cons	-.000137	.0000306	-4.471	0.000

B. Ask Quote Revision

Number of obs	=	747
F(11, 736)	=	33.7
Prob > F	=	0.000
R-square	=	0.335
Adj R-square	=	0.325
Root MSE	=	.0004

da	Coef.	Std. Err.	t	P>|t|
Lag1 da	-.7993277	.0805063	-9.929	0.000
Lag2 da	-.4331602	.0587267	-7.376	0.000
Lag3 da	-.4928082	.076277	-6.461	0.000
Lag4 da	-.422294	.0766422	-5.510	0.000
Lag5 da	-.5945421	.0571305	-10.407	0.000
Lag6 da	-.1588786	.0634126	-2.505	0.012
Lag1 ade	.0003121	.0000558	5.595	0.000
adq24	.0000411	8.78e-06	4.684	0.000
ad6	.0000926	.0000305	3.040	0.002
Lag6 s	-.125264	.0230924	-5.424	0.000
adb6	.1099008	.0436925	2.515	0.012
_cons	-.0000683	.0000277	-2.466	0.014

Table 22

The Determination of Quote Changes over FXFX

A. Bid Prices

Number of obs	=	4983
F(10, 4973)	=	96.1
Prob > F	=	0.000
R-square	=	0.162
Adj R-square	=	0.160
Root MSE	=	.0002

dfxb	Coef.	Std. Err.	t	P>|t|
Lag1 dfxb	-.3652674	.0140455	-26.006	0.000
Lag2 dfxb	-.298141	.0148757	-20.042	0.000
Lag3 dfxb	-.2499072	.0153796	-16.249	0.000
Lag4 dfxb	-.1231102	.0155578	-7.913	0.000
Lag5 dfxb	-.0775751	.0154255	-5.029	0.000
Lag6 dfxb	-.05442	.015174	-3.586	0.000
fxb12	-.0198112	.0096738	-2.048	0.041
Lag6 s	.2664089	.0266012	10.015	0.000
adfxa6	-.0256695	.011956	-2.147	0.032
adfxa24	.0275647	.0097646	2.823	0.005
_cons	.0001859	.000019	-9.770	0.000

B. Ask Prices

Number of obs	=	4983
F(9, 4974)	=	117.5
Prob > F	=	0.000
R-square	=	0.175
Adj R-square	=	0.173
Root MSE	=	.0002

dfxa	Coef.	Std. Err.	t	P>|t|
Lag1 dfxa	-.3707797	.0141493	-26.205	0.000
Lag2 dfxa	-.3252713	.0149596	-21.743	0.000
Lag3 dfxa	-.2448494	.0155451	-15.751	0.000
Lag4 dfxa	-.1190115	.0155936	-7.632	0.000
Lag5 dfxa	-.0820493	.015018	-5.463	0.000
Lag6 dfxa	-.0497289	.0142814	-3.482	0.000
adfxa6	-.0317825	.0130013	-2.445	0.015
adfxa24	.0523204	.0105903	4.940	0.000
Lag6 s	-.2650965	.0292663	-9.058	0.000
_cons	.0001846	.0000209	8.831	0.000

Table 23

Spreads

A. With Lagged Dependent, S_{t-6}

Number of obs	=	4980
F(16, 4964)	=	953.3
Prob > F	=	0.000
R-square	=	0.754
Adj R-square	=	0.753
Root MSE	=	.0003

s	Coef.	Std. Err.	t	P>|t|
Lag6 s	.4768366	.0120753	39.489	0.000
Lag1 bde	.0002891	.0000298	9.691	0.000
Lag1 ade	.0003563	.000027	13.184	0.000
bv12	.0002113	.0000277	7.634	0.000
bv60	.0002813	.0000269	10.450	0.000
av12	.0001099	.000028	3.919	0.000
av60	.0003531	.000024	14.688	0.000
bd12	-.0000393	.0000107	-3.679	0.000
db6	-.672806	.0127785	-52.652	0.000
db12	-.2537867	.0154748	-16.400	0.000
db24	-.1797322	.0128506	-13.986	0.000
db36	-.0684526	.0107952	-6.341	0.000
da6	.7448953	.0117689	63.293	0.000
da12	.3830915	.0148889	25.730	0.000
da24	.2522268	.0118793	21.232	0.000
da36	.1455865	.0104181	13.974	0.000
_cons	.0001214	8.33e-06	14.578	0.000

B. With Lagged Dependant, S_{t-1}

Number of obs	=	4980
F(16, 4964)	=	1460.7
Prob > F	=	0.000
R-square	=	0.824
Adj R-square	=	0.824
Root MSE	=	.0003

s	Coef.	Std. Err.	t	P>|t|
Lag1 s	.8807202	.0136244	64.643	0.000
Lag1 bde	.0003409	.0000252	13.517	0.000
Lag1 ade	.0003596	.0000228	15.750	0.000
bv12	-.0000139	.0000239	-0.582	0.560
bv60	.000057	.0000233	2.449	0.014
av12	.0000297	.0000237	1.252	0.210
av60	.0000282	.0000216	1.310	0.190
bd12	-8.43e-06	9.02e-06	-0.934	0.350
db6	.042907	.0150085	2.859	0.004
db12	.0280221	.0144781	1.935	0.053
db24	-.0019636	.0115459	-0.170	0.865
db36	.0107807	.0092818	1.161	0.245
da6	-.0089642	.0153301	-0.585	0.559
da12	.0435953	.0146797	2.970	0.003
da24	.021478	.0112872	1.903	0.057
da36	.009385	.0093128	1.008	0.314
_cons	.00003	7.33e-06	4.099	0.000

Table 24

Determination of FXFX Spreads

Number of obs	=	4927
F(5, 4967)	=	180.3
Prob > F	=	0.000
R-square	=	0.153
Adj R-square	=	0.152
Root MSE	=	.0002

s	Coef.	Std. Err.	t	P>|t|
Lag1 s	.377904	.0131287	28.785	0.000
Lag4 s	.0300787	.013117	2.293	0.022
fxaf12	4.58e-06	2.76e-06	1.660	0.097
fxaf36	-4.94e-06	1.76e-06	-2.803	0.005
adfxb24	.0353665	.0089404	3.956	0.000
_cons	.0004243	.0000179	23.654	0.000

Table 25

The Determinants of Absolute Price Changes

A. In Bid Prices: ADB

Number of obs = 4980
F(7, 4973) = 78.3
Prob > F = 0.000
R-square = 0.099
Adj R-square = 0.098
Root MSE = .0002

adb	Coef.	Std. Err.	t	P>|t|
adb6	.0638526	.0082624	7.728	0.000
adb12	.0190271	.0083937	2.267	0.023
abd24	.0366817	.0073459	4.994	0.000
LagI bde	.0003333	.0000181	18.460	0.000
ada12	.0178956	.0078319	2.285	0.022
ada36	.0156567	.0064971	2.410	0.016
af24	6.13e-06	2.02e-06	3.037	0.002
_cons	3.55e-06	5.04e-06	0.705	0.481

B. In Ask Prices: ADA

Number of obs = 4980
F(11, 4969) = 82.2
Prob > F = 0.000
R-square = 0.154
Adj R-square = 0.152
Root MSE = 0002

ada	Coef.	Std. Err.	t	P>|t|
ada6	.0621732	.0079386	7.832	0.000
ada12	.0244177	.0076472	3.193	0.001
ada24	.0184217	.0063198	2.915	0.004
ad24	.0000145	3.37e-06	4.308	0.000
ad36	.0000113	3.35e-06	3.392	0.000
adel	.0003508	.0000155	22.667	0.000
af6	5.86e-06	3.17e-06	1.851	0.064
adb36	.0210127	.0069293	3.032	0.002
bf36	5.46e-06	2.00e-06	2.726	0.006
aq12	8.91e-07	3.79e-07	2.348	0.019
aq24	-7.22e-07	2.14e-07	-3.365	0.000
_cons	-6.84e-06	7.87e-06	-0.869	0.385

Table 26

The Determinants of Absolute Price Changes on FXFX

Number of obs	=	4972
F(5, 4966)	=	51.7
Prob > F	=	0.000
R-square	=	0.049
Adj R-square	=	0.048
Root MSE	=	.0002

adfxa	Coef.	Std. Err.	t	P>|t|
adfxa6	.1366876	.0117699	11.613	0.000
adfxa12	.0338006	.011855	2.851	0.004
adfxa36	.0267606	.0095021	2.816	0.005
s6	.0990903	.0258231	3.837	0.000
dfxa6	.0375036	.008251	4.545	0.000
_cons	.0000414	.0000187	2.220	0.026

Table 27

The Frequency of Quote Entry on D2000-2

A. Of Bid Prices: BF

Number of obs	=	4980
F(11, 4969)	=	26.6
Prob > F	=	0.000
R-square	=	0.055
Adj R-square	=	0.053
Root MSE	=	.3435

bf	Coef.	Std. Err.	t	P>|t|
bf6	-.0093551	.0059631	-1.569	0.117
bf12	-.0000455	.0053486	-0.008	0.993
bf24	.0109553	.0034244	3.199	0.001
bf36	.0078274	.0033847	2.313	0.021
bd6	.1440359	.0111967	12.864	0.000
af24	.0149482	.0037679	3.967	0.000
ad24	-.0157613	.0062909	-2.505	0.012
ada24	-24.13405	10.76621	-2.242	0.025
bv12	.0900122	.0254729	3.534	0.000
bq24	.001001	.0003442	2.908	0.004
bq36	-.0008411	.0003457	-2.433	0.015
_cons	.0607582	.0143452	4.235	0.000

B. Of Ask Prices: AF

Number of obs	=	4980
F(8, 4972)	=	32.2
Prob > F	=	0.000
R-square	=	0.049
Adj R-square	=	0.047
Root MSE	=	.3484

af	Coef.	Std. Err.	t	P>|t|
af6	.0166517	.005561	2.994	0.003
ad6	.0963283	.0092722	10.389	0.000
bf12	.0118653	.0051196	2.318	0.021
bf36	.0109036	.0033706	3.235	0.001
adq24	.0049921	.0026929	1.854	0.064
adq36	.0070069	.0027153	2.581	0.010
av60	.0510773	.0199153	2.565	0.010
aq24	-.0006868	.0003179	-2.160	0.031
_cons	.0705923	.0133874	5.273	0.000

Table 28

The Determinants of Quote Size

A. Bid Quote Size

Number of obs	=	4980
F(9, 4971)	=	329.2
Prob > F	=	0.000
R-square	=	0.373
Adj R-square	=	0.372
Root MSE	=	1.393

bq	Coef.	Std. Err.	t	P>|t|
bq6	.1505502	.0032501	46.321	0.000
bq12	-.0257189	.0030404	-8.459	0.000
bq24	.0081696	.0014368	5.686	0.000
bd6	-.1266831	.0414378	-3.057	0.002
bf12	-.0550551	.0215234	-2.558	0.011
bf24	.0343499	.0134897	2.546	0.011
bv12	.217296	.0993405	2.187	0.029
af24	-.0533222	.0133771	-3.986	0.000
af36	.0394126	.0135053	2.918	0.004
_cons	.6453671	.058449	11.042	0.000

B. Ask Quote Size

Number of obs	=	4981
F(11, 4970)	=	235.6
Prob > F	=	0.000
R-square	=	0.342
Adj R-square	=	0.341
Root MSE	=	1.458

aq	Coef.	Std. Err.	t	P>|t|
aq6	.1242625	.0029287	42.430	0.000
aq24	.0095996	.0014215	6.753	0.000
ad6	-.1941901	.0391663	-4.958	0.000
ad24	-.0502285	.0234261	-2.144	0.032
af6	.0641108	.0231159	2.773	0.006
bf6	-.0892569	.0230461	-3.873	0.000
bdq6	.053556	.0222602	2.406	0.016
bdq12	.0597338	.0208646	2.863	0.004
bdq36	-.0569668	.0140248	-4.062	0.000
bq6	.0089876	.0034053	2.639	0.008
bq12	-.0097294	.0029193	-3.333	0.000
_cons	.7090902	.0635584	11.157	0.000

TABLE 29

Presentation of the estimated parameters of the specification described on page 34 for the five second dataset, plus extended specifications including lagged deal and deal exhaust indicators in the volatility expression.

	a_0	a_1	a_2	b_0	b_1	b_2	b_3	b_4
GARCH	1.2e-5 [a]	-0.166 [a]	-2.2e-4 [a]	1.2e-9 [c]	0.291 [a]	0.874 [a]	-	-
$+bde_{t-1}$	1.4e-5 [a]	-0.144 [a]	-2.6e-4 [a]	5.7e-9 [b]	0.113 [a]	0.734 [a]	2.4e-8 [b]	-
$+bd_{t-1}$	1.3e-5 [a]	-0.148 [a]	-2.8e-4 [a]	7.1e-9 [a]	0.213 [a]	0.667 [a]	-	2.7e8 [b]

a: significantly different from zero at 1%

b: significantly different from zero at 5%

c: insignificantly different from zero

TABLE 30

Presentation of the estimated parameters of the specification described on page 34 for the activity based dataset, plus extended specifications including lagged deal and deal exhaust indicators in the volatility expression.

	α_0	α_1	α_2	β_0	β_1	β_2	β_3	β_4
GARCH	5.4e-5 [a]	-0.436 [a]	-3.3e-4 [a]	1.1e-8 [a]	0.332 [a]	0.681 [a]	-	-
$+bde_{t-1}$	5.4e-5 [a]	-0.423 [a]	-3.1e-4 [a]	1.3e-8 [c]	0.252 [a]	0.724 [a]	-1.2e-8 [c]	-
$+bd_{t-1}$	5.5e-5 [a]	-0.433 [a]	-3.1e-4 [a]	1.4e-8 [c]	0.241 [a]	0.730 [a]	-	-1.2e-8 [c]

a: significantly different from zero at 1%

b: significantly different from zero at 5%

c: insignificantly different from zero

Table 31

Estimates of the Bivariate Vector Autoregressive Model

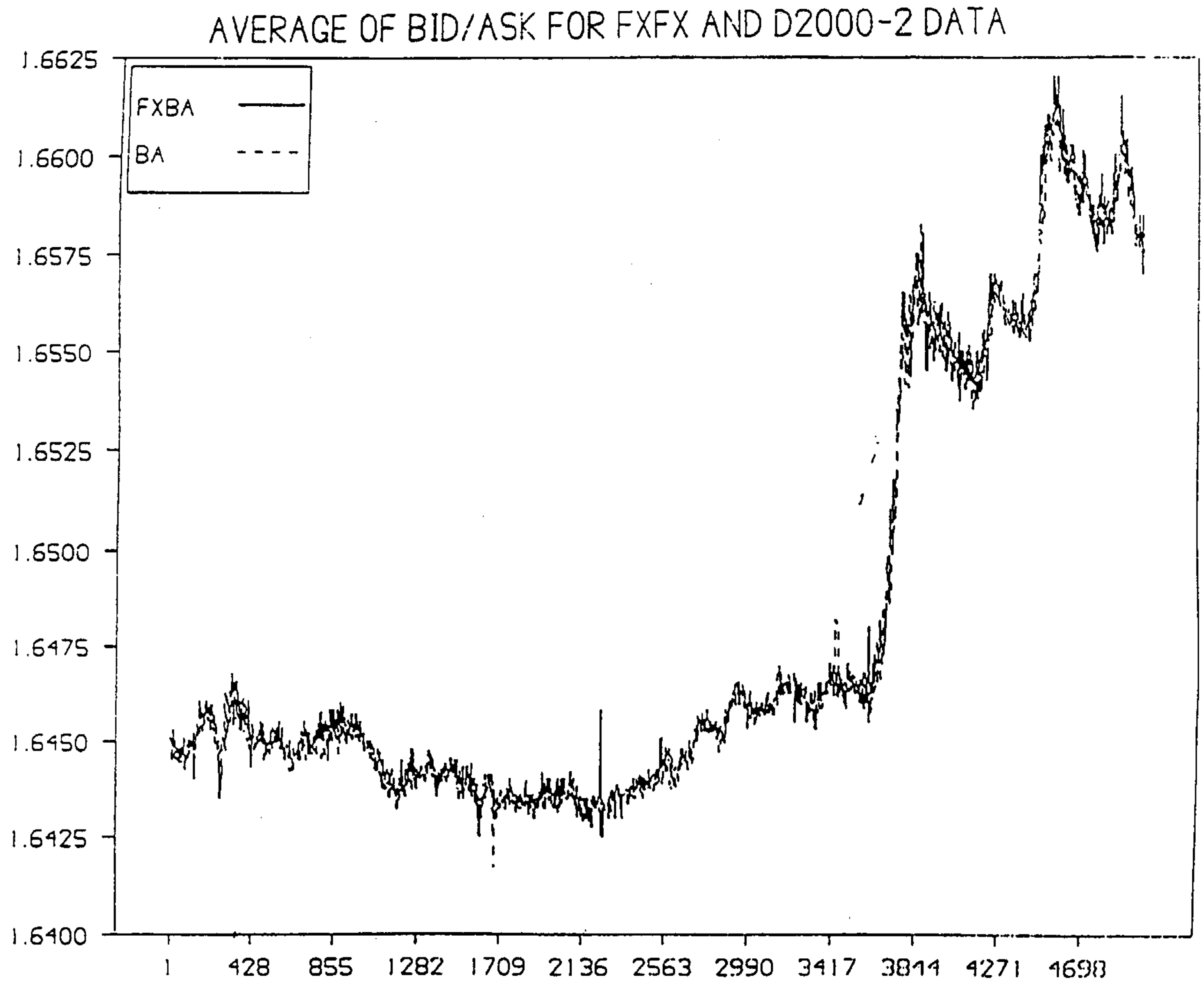
We estimate a five-lag near-VAR involving r_t, the revision in the quote midpoint and x_{0t}, the trade indicator variable. The VAR is not exact as the trade indicator is assumed to have a contemporaneous effect on quote revisions, as shown in the system below.

$$r_t=\sum_{i=1}^{5} a_i r_{t-i}+\sum_{i=0}^{5} b_i x_{0t-i}+v_{1t}\ ,\quad x_{0t}=\sum_{i=1}^{5} c_i r_{t-i}+\sum_{i=1}^{5} d_i x_{0t-i}+v_{2t}$$

T-statistics are reported below for each of the estimated parameters. Column A reproduces Hasbroucks result's, column B gives our equivalent activity scale results and column C our results on a clock time basis.

	A	B	C		A	B	C
a_1	-7.22	-16.16	-8.19	c_1	-13.44	-1.47	-1.33
a_2	-0.67	-7.38	-7.09	c_2	-6.05	-0.07	0.94
a_3	-0.17	-5.36	-7.22	c_3	-1.80	-0.72	0.59
a_4	-1.31	-6.39	-1.65	c_4	-0.46	0.57	-0.25
a_5	-0.14	-3.00	-5.65	c_5	0.41	1.21	0.79
b_0	15.15	7.57	-0.69	-	-	-	-
b_1	6.83	2.87	13.53	d_1	10.16	4.82	2.07
b_2	0.46	3.09	0.42	d_2	7.20	2.45	2.53
b_3	0.87	0.13	1.87	d_3	4.66	4.15	1.25
b_4	-0.30	2.61	0.69	d_4	1.24	0.67	3.73
b_5	0.94	2.36	3.55	d_5	2.03	0.87	1.85
R^2	0.096	0.175	0.068	R^2	0.085	0.038	0.005

Chart 1



AVERAGE OF BID/ASK FOR FXFX AND D2000-2 DATA
FXBA
BA
1.6625
1.6600
1.6575
1.6550
1.6525
1.6500
1.6475
1.6450
1.6425
1.6400
1
428
855
1282
1709
2136
2563
2990
3417
3814
4271
4698

Chart 2

Quantities offered at Bid (DM/$)

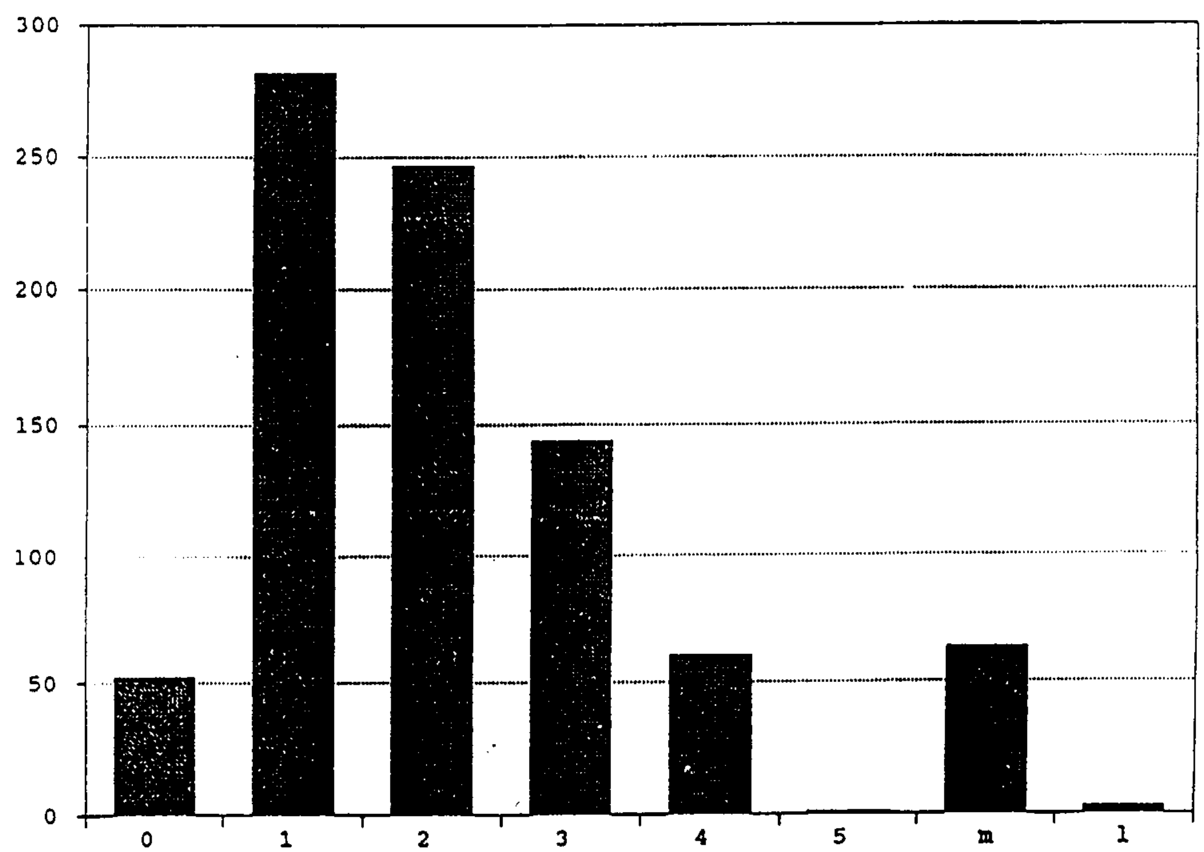


Chart 3

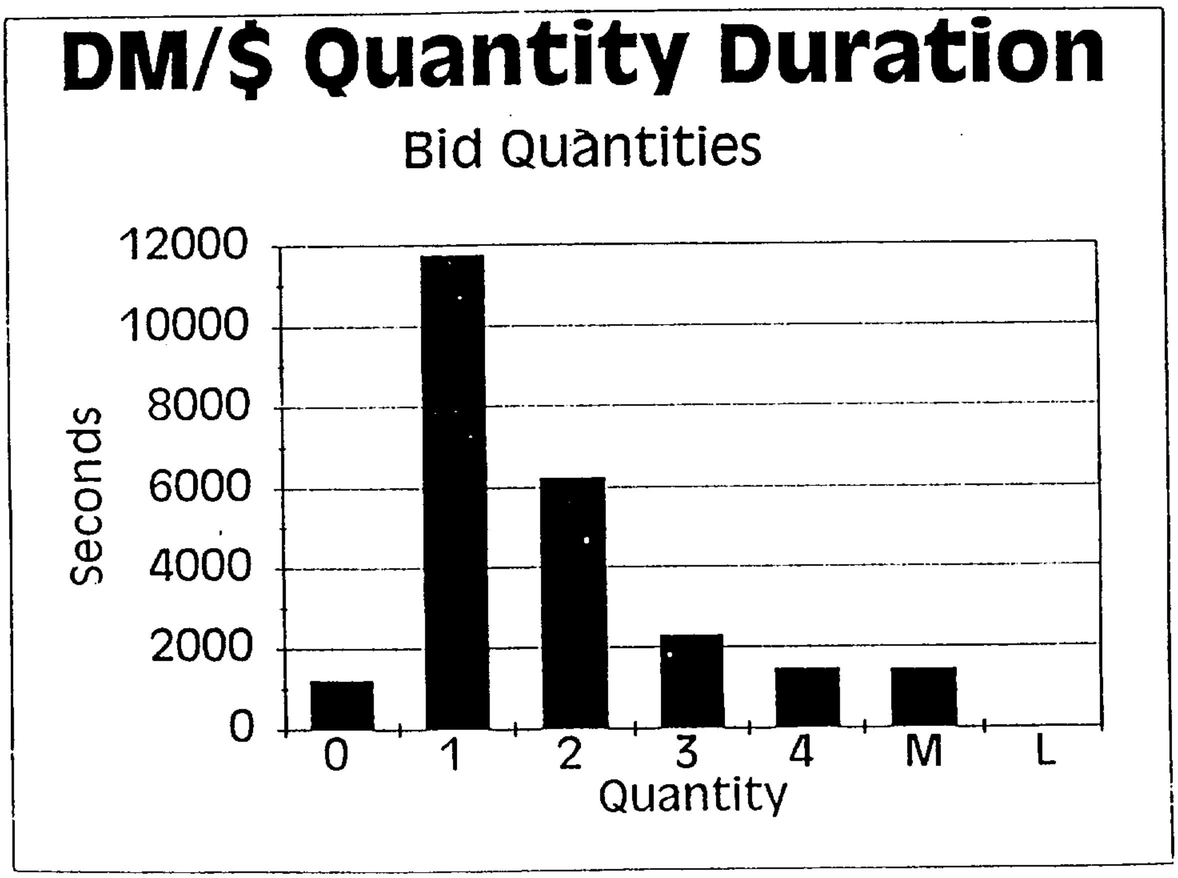
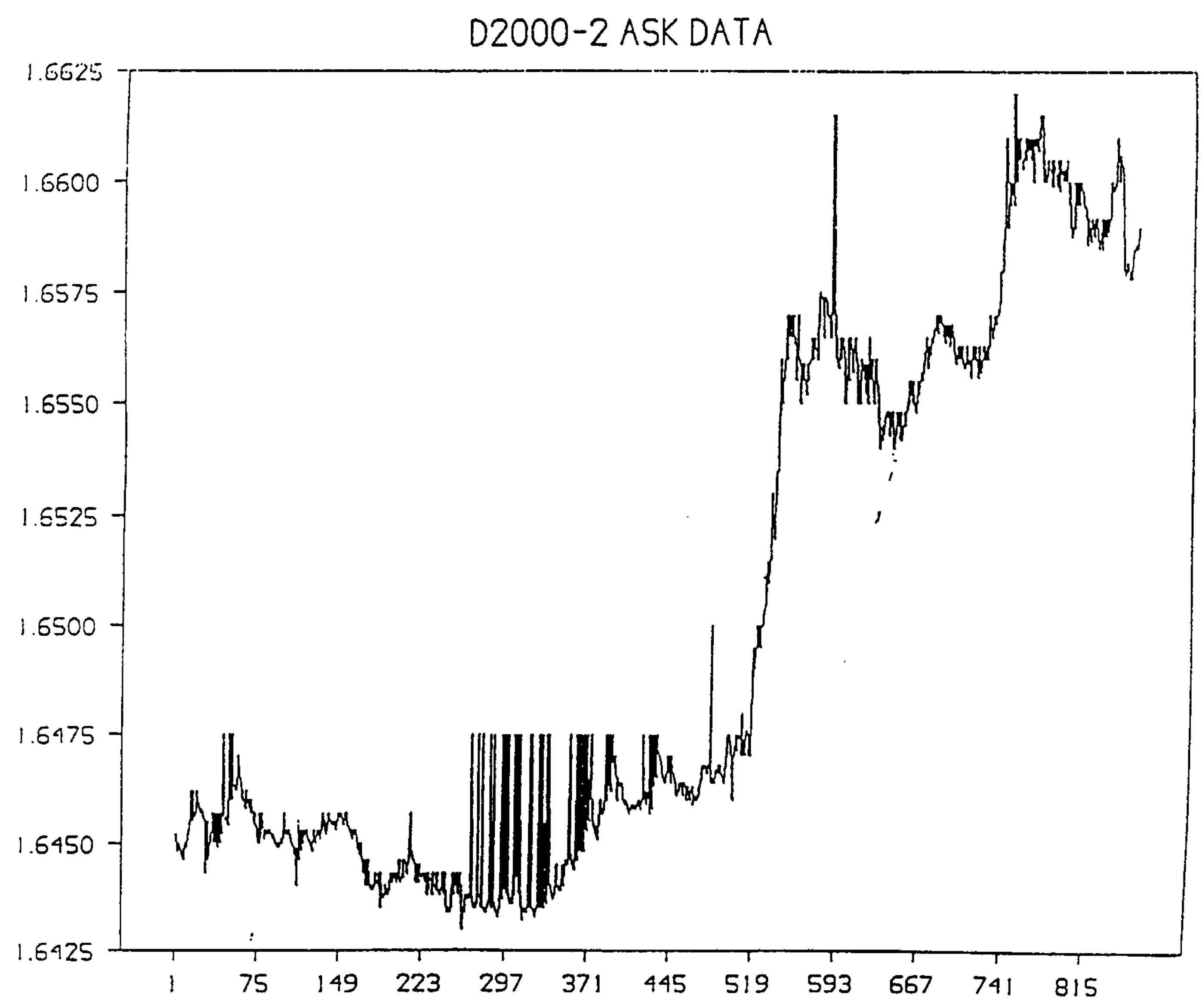

DM/$ Quantity Duration
Bid Quantities
12000
10000
8000
6000
4000
2000
0
Seconds
0
1
2
3
4
M
L
Quantity

Chart 4



D2000-2 ASK DATA
1.6625
1.6600
1.6575
1.6550
1.6525
1.6500
1.6475
1.6450
1.6425
1
75
149
223
297
371
445
519
593
667
741
815

Chart 5

FILTERED D2000-2 ASK DATA

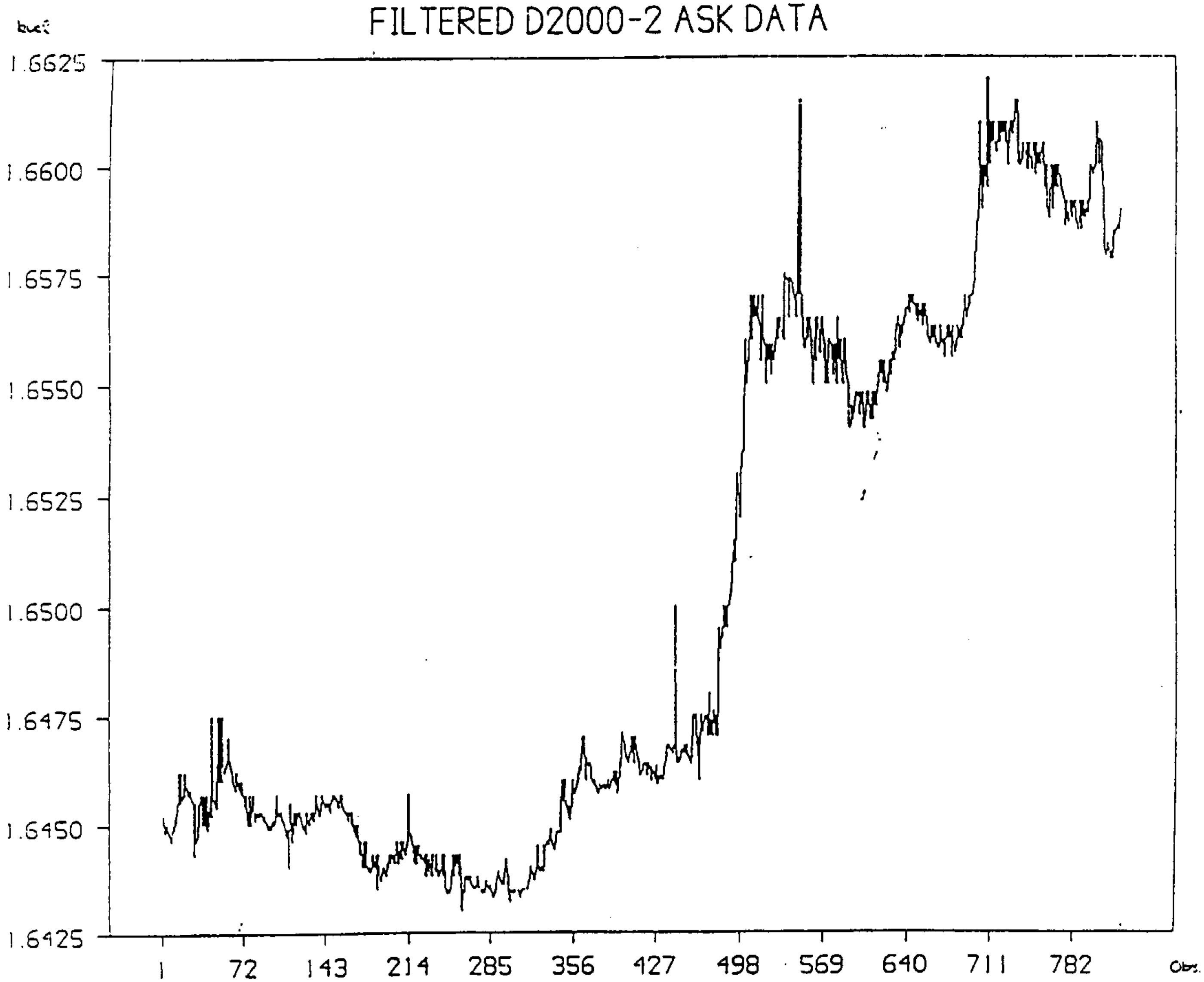


Chart 6

Dollar/Yen Bid Quantities

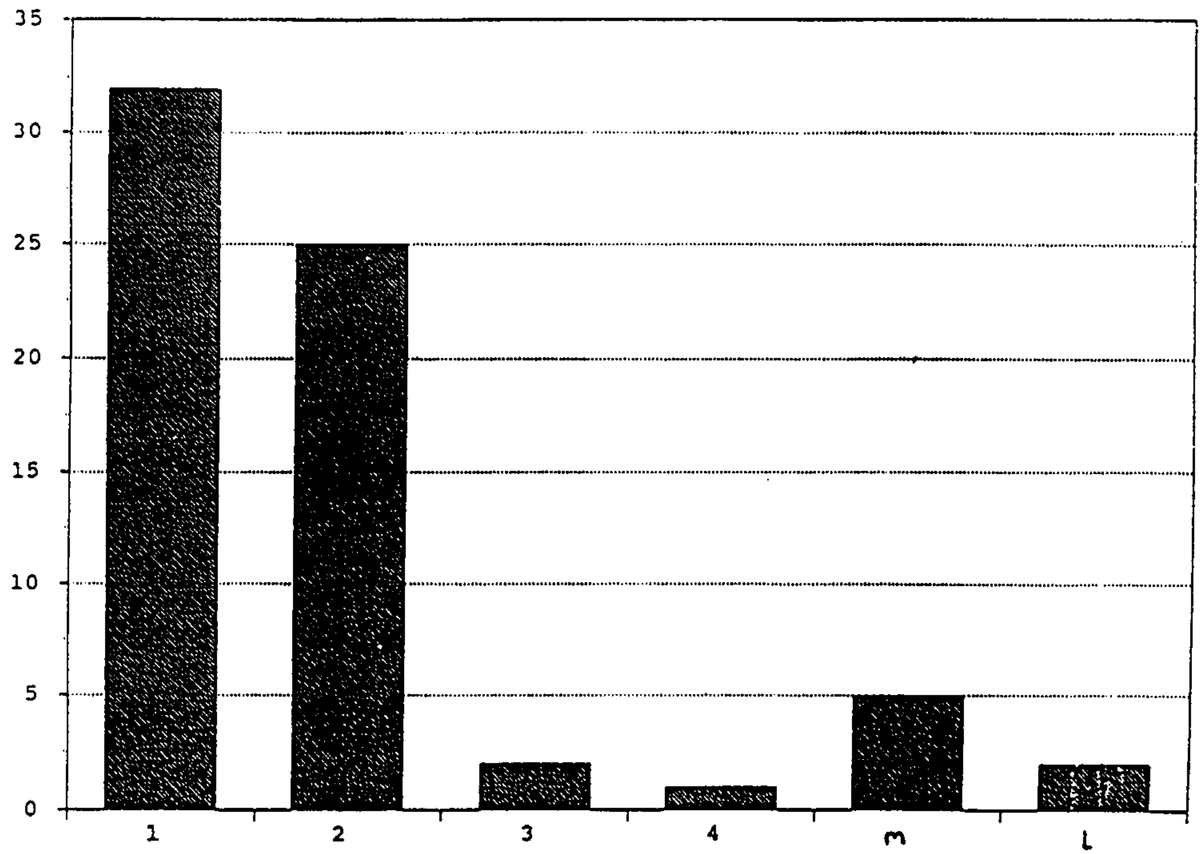


Chart 7

DMk/Yen Bid Quantities

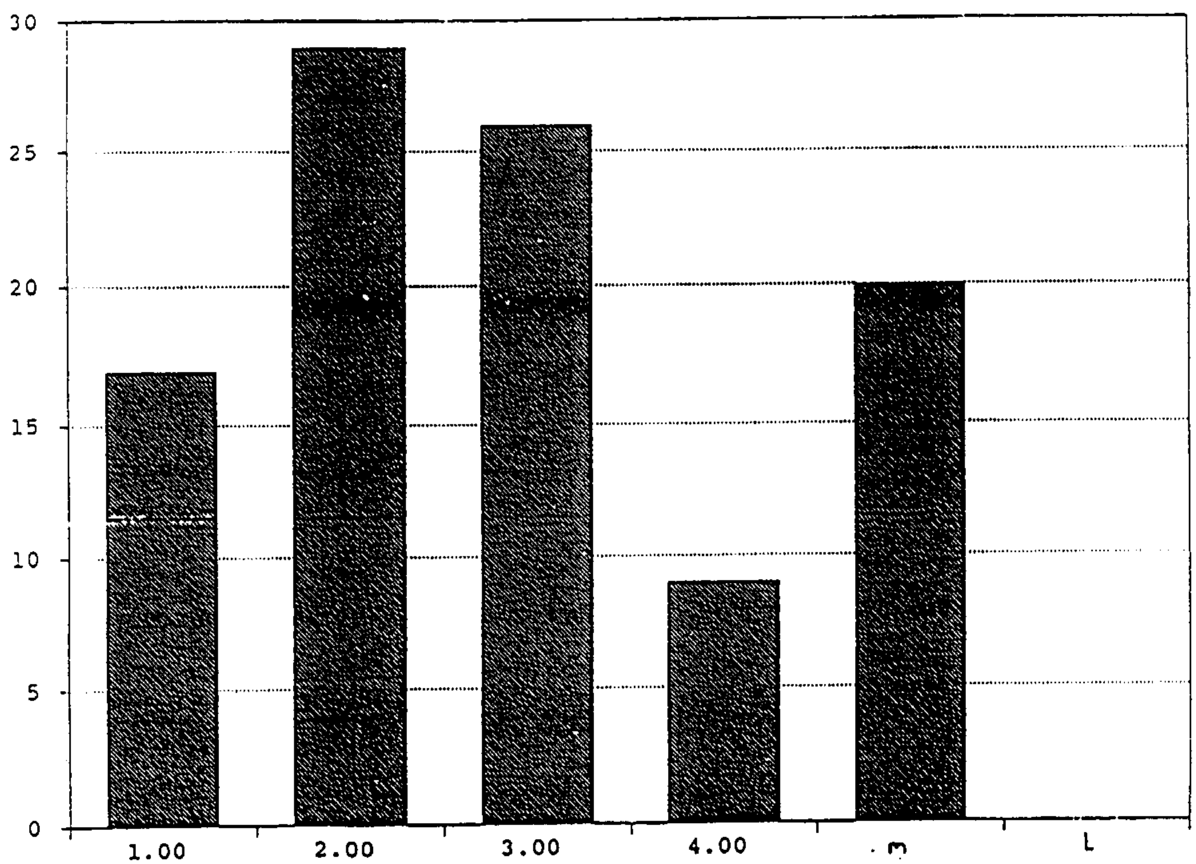
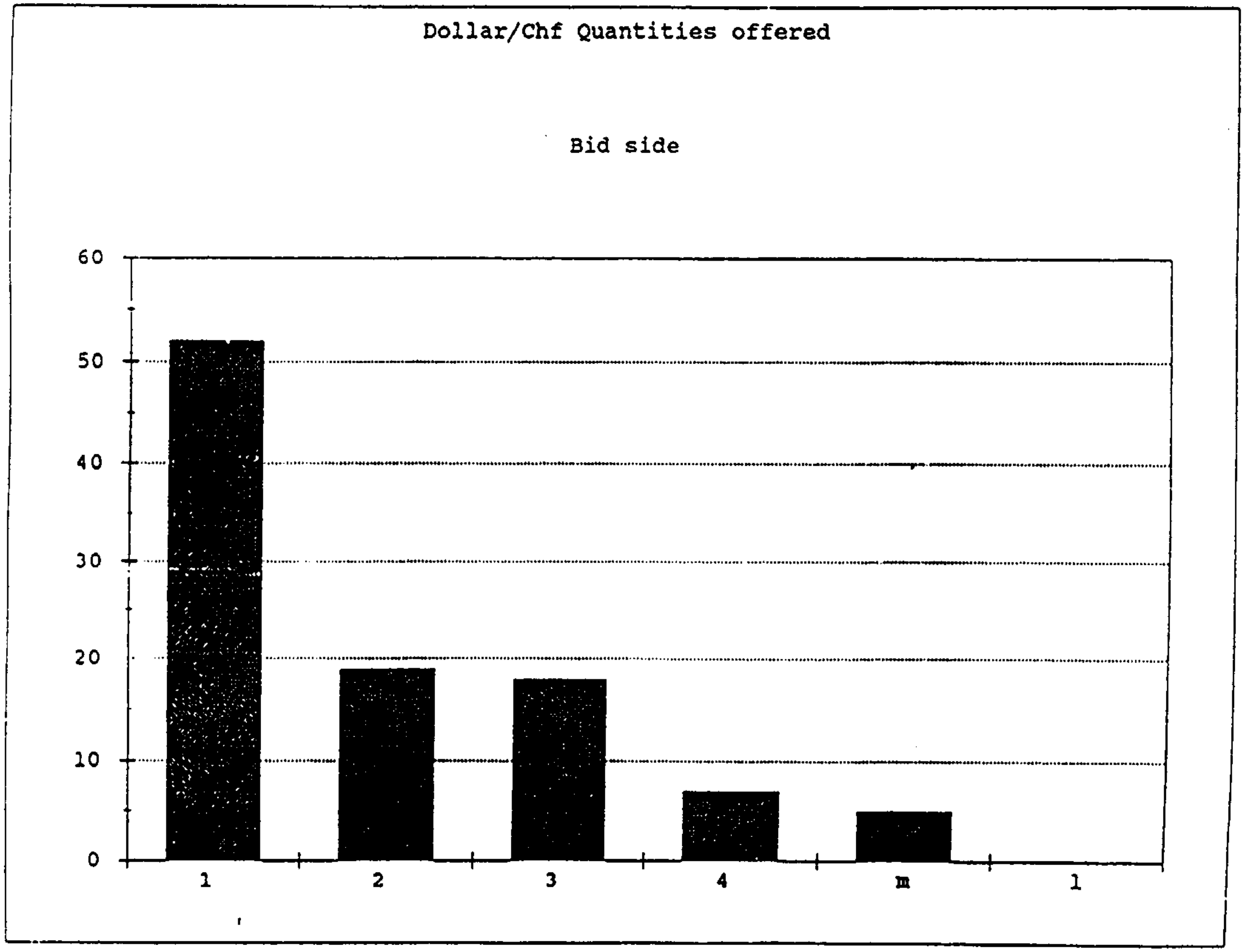


Chart 8



Dollar/Chf Quantities offered
Bid side
60
50
40
30
20
10
0
1
2
3
4
m
l

Chart 9

Dmk/FF Bid Quantities

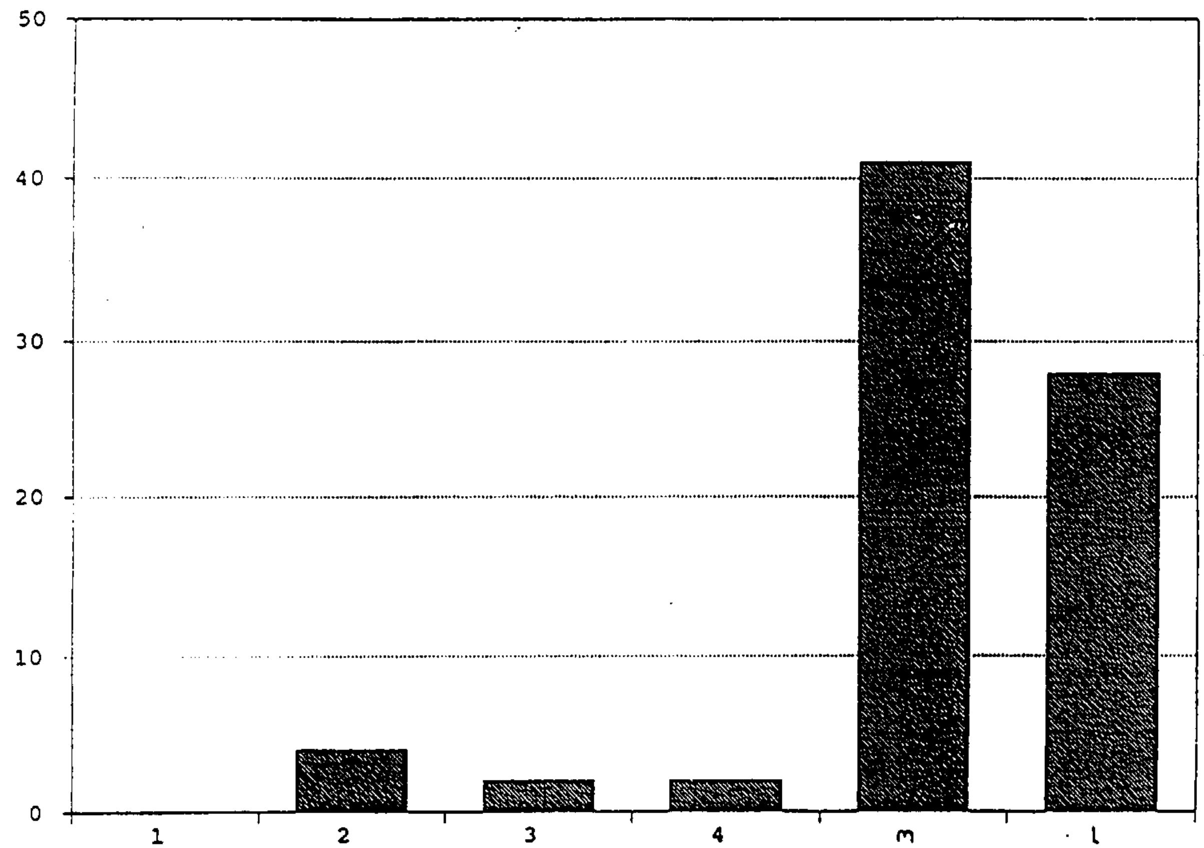


Chart 10

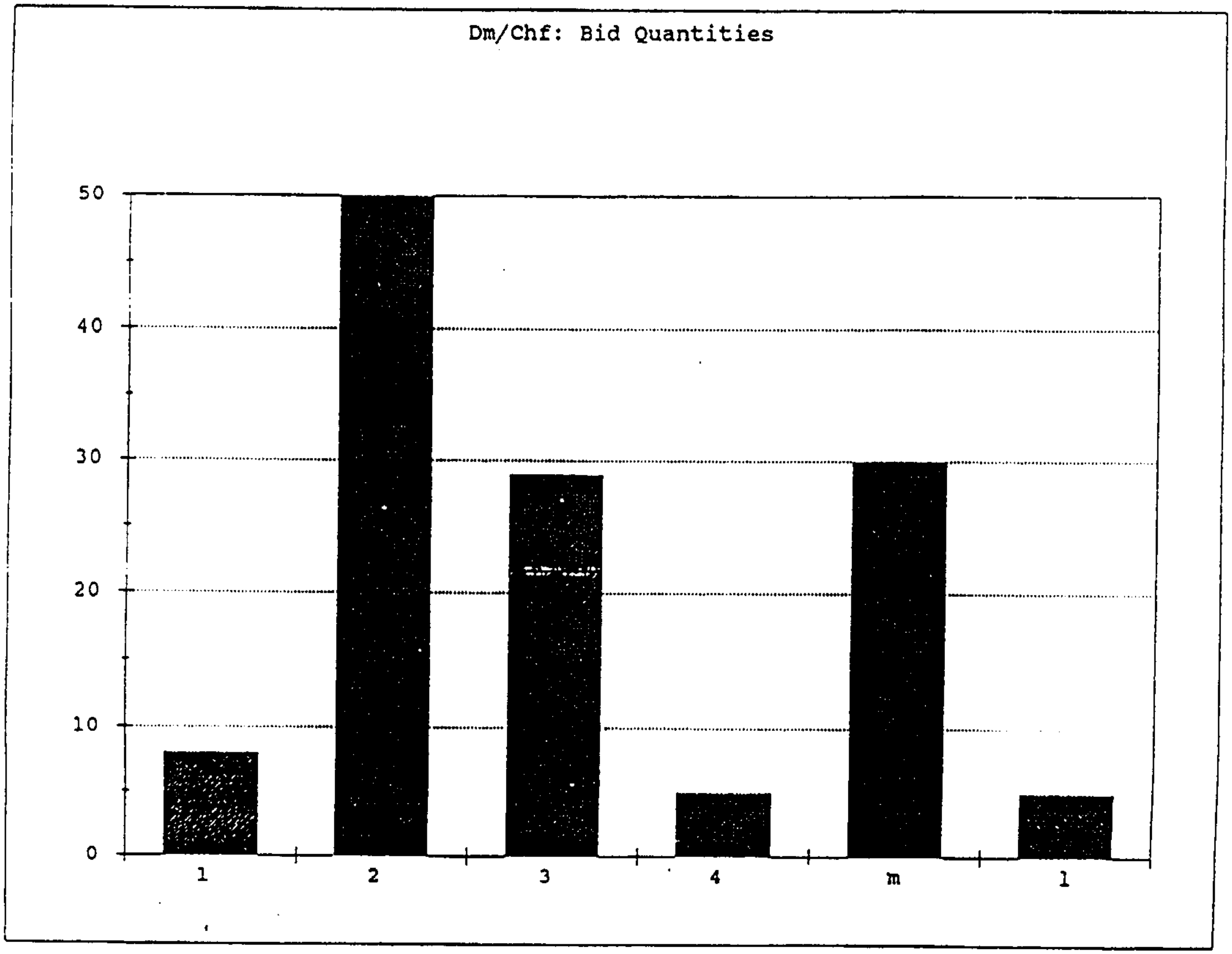


Chart 11

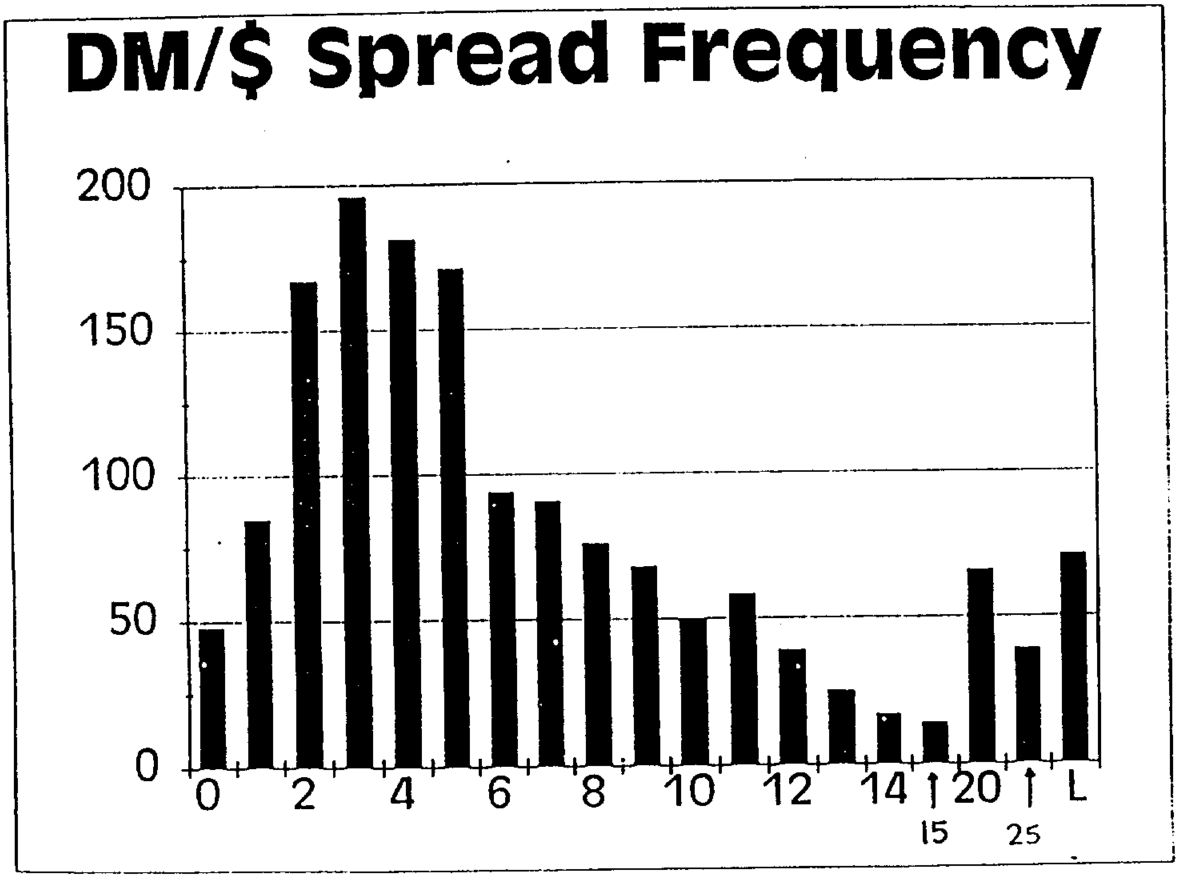
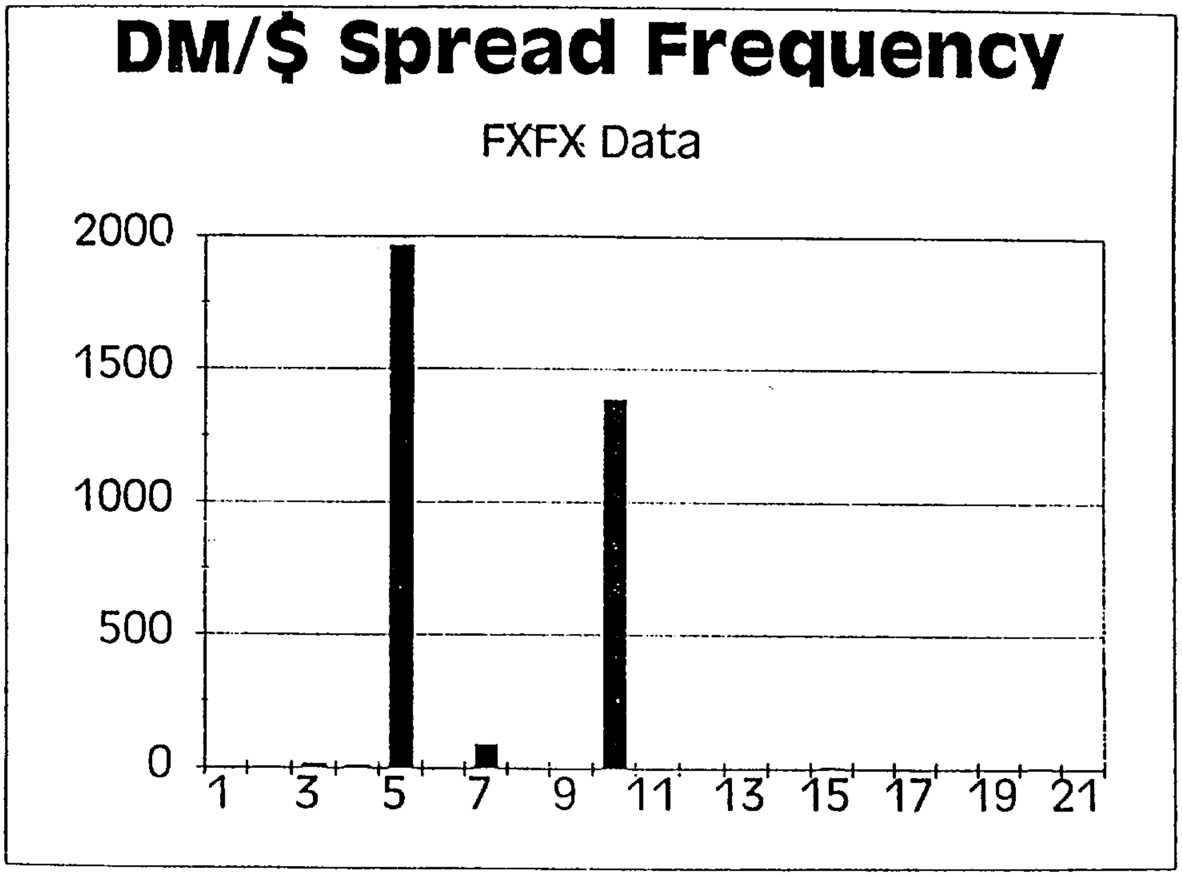
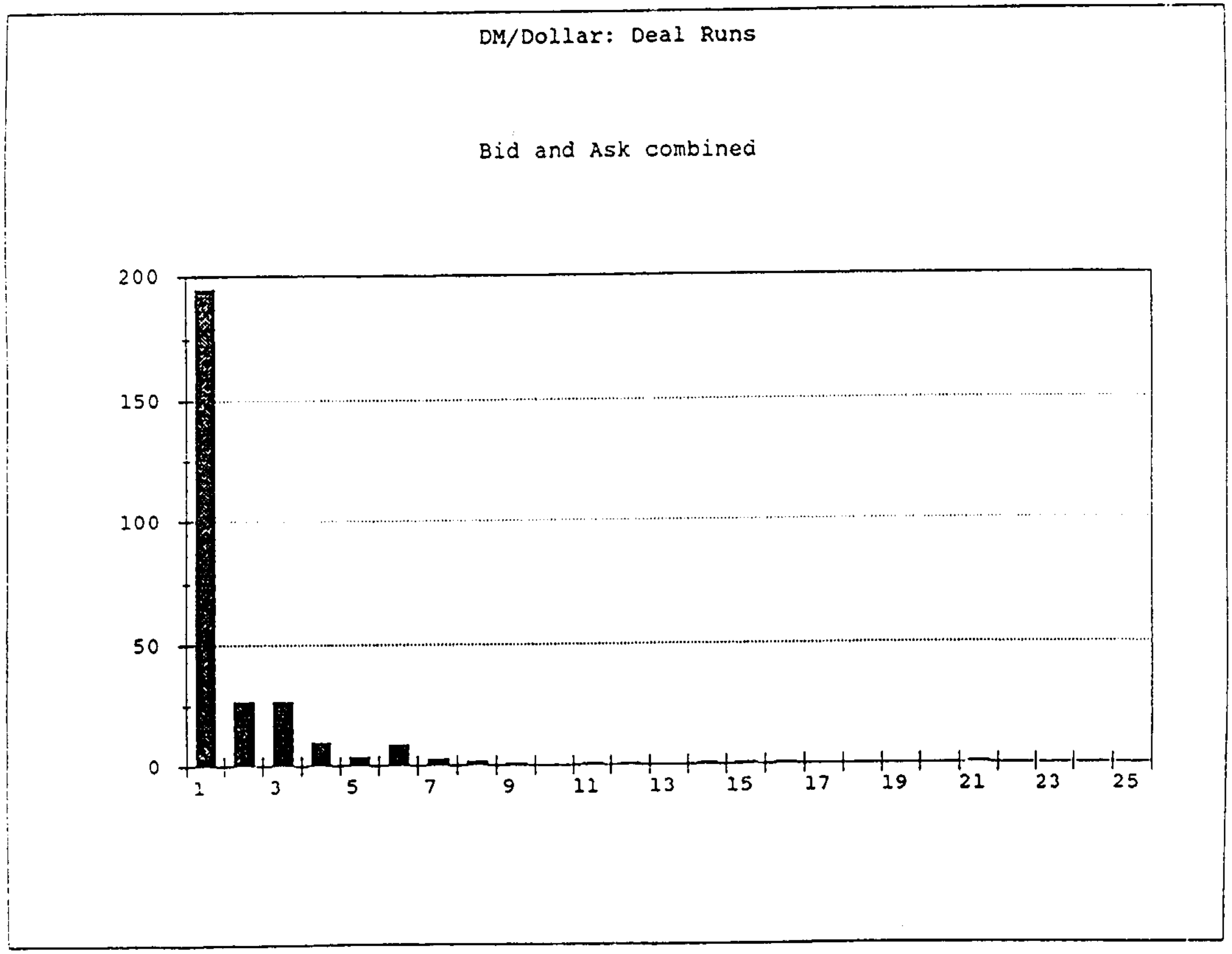


Chart 12



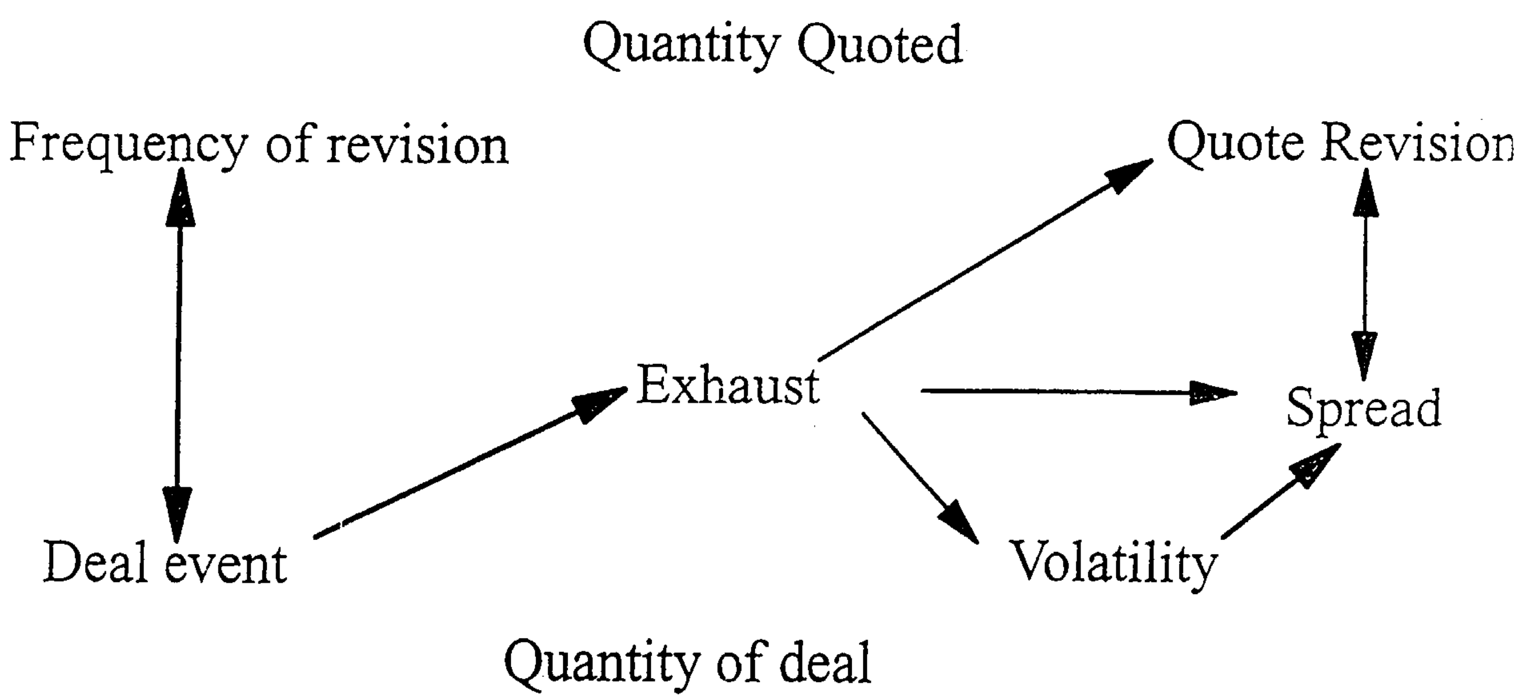
DM/$ Spread Frequency
FXFX Data
2000
1500
1000
500
0
1
3
5
7
9
11
13
15
17
19
21

Chart 13

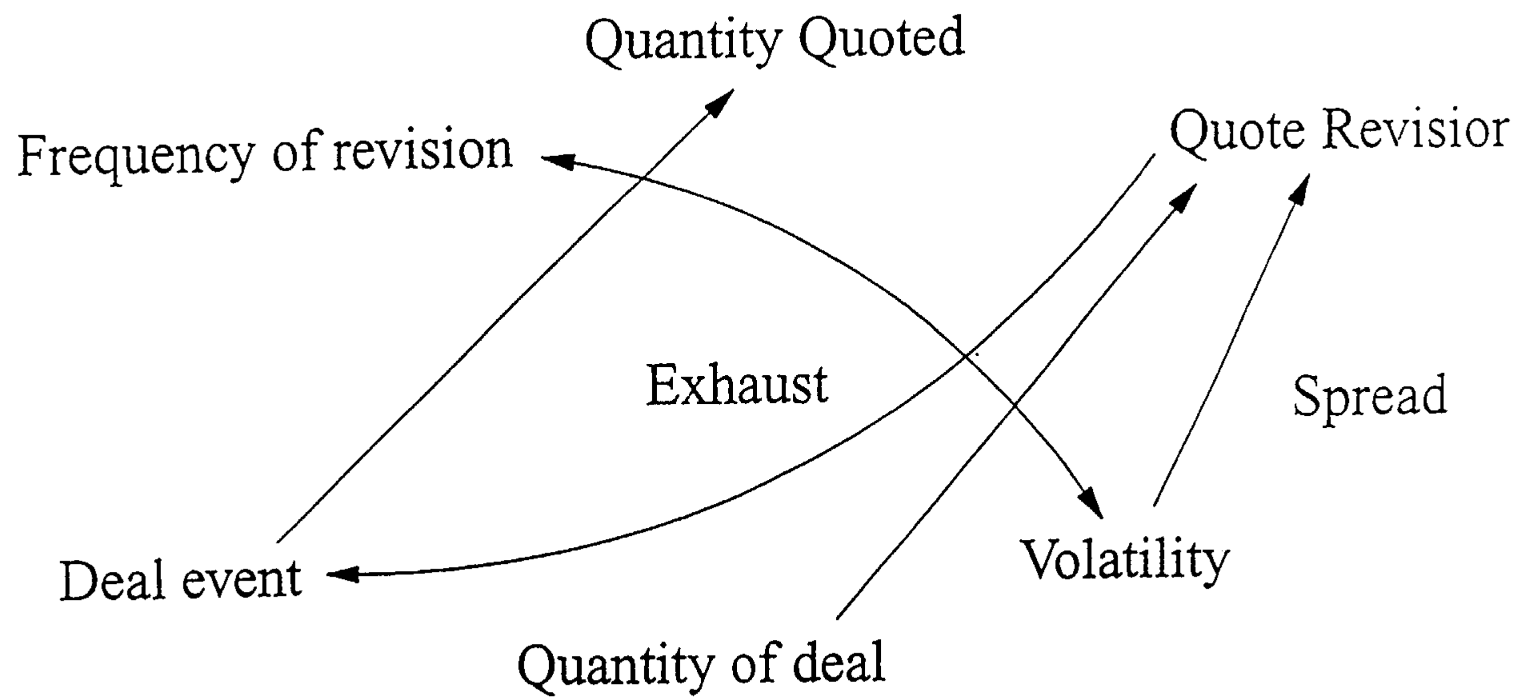


DM/Dollar: Deal Runs
Bid and Ask combined
200
150
100
50
0
1
3
5
7
9
11
13
15
17
19
21
23
25

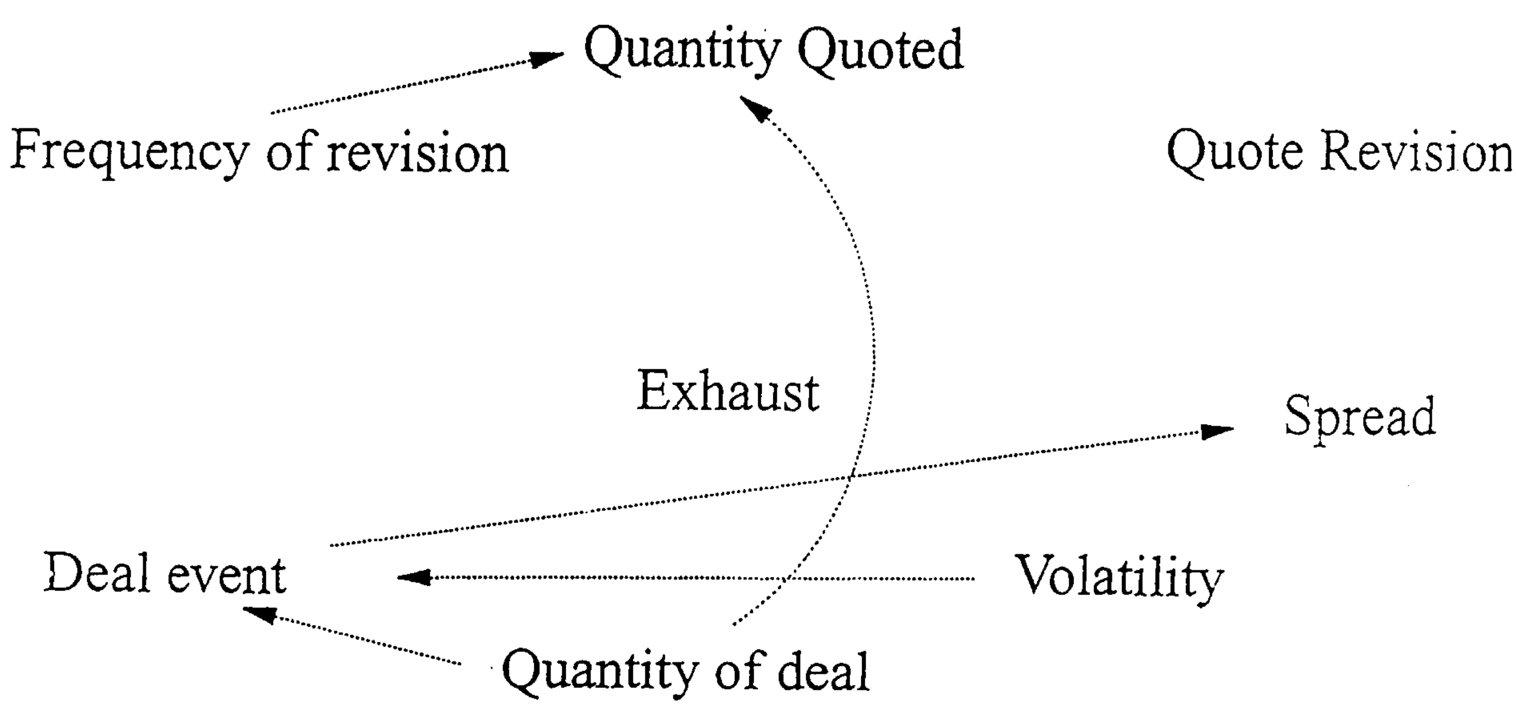
a) Strong Relationships : Main Transmission Channels



b) Weak Relationships : but some clear effect.

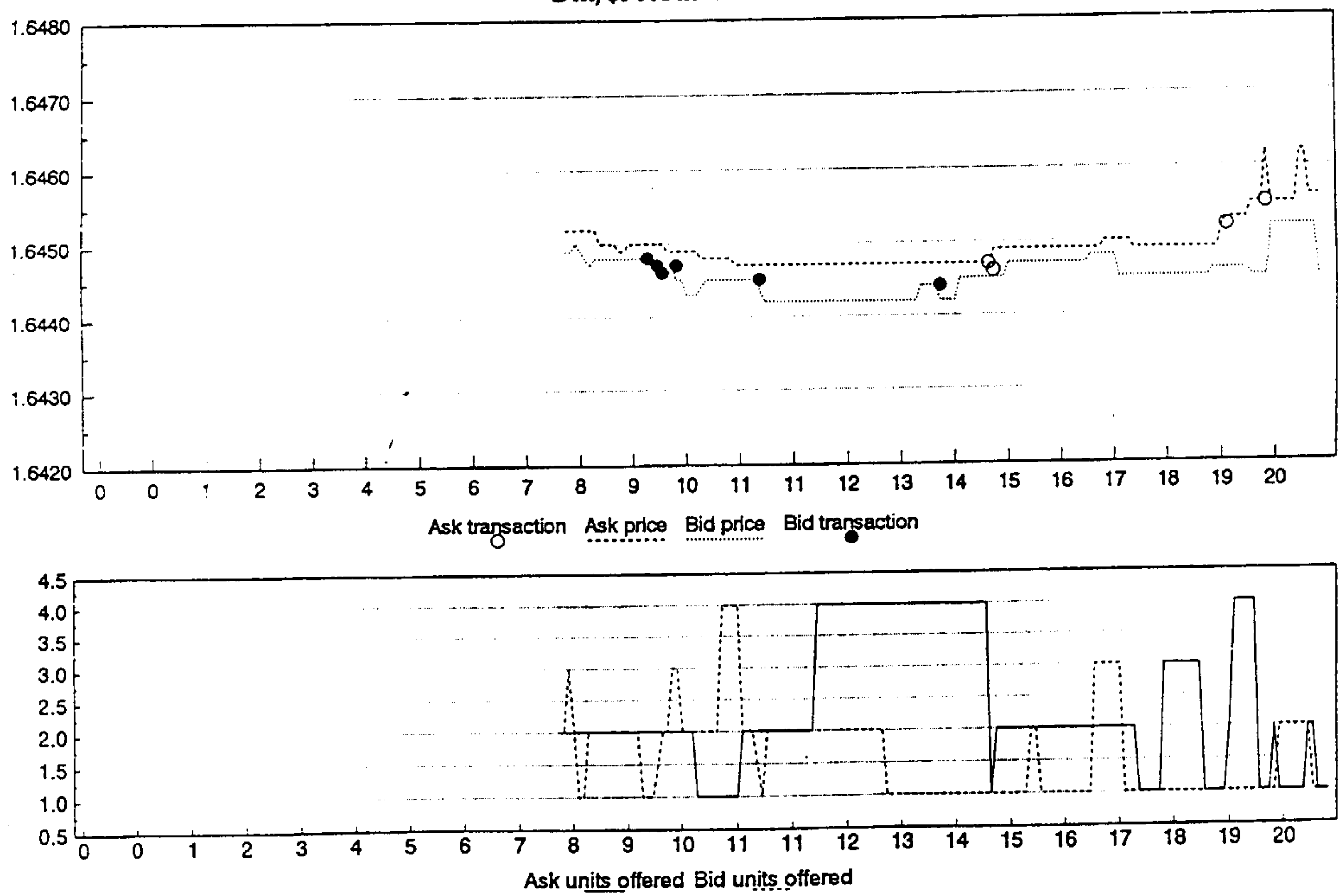


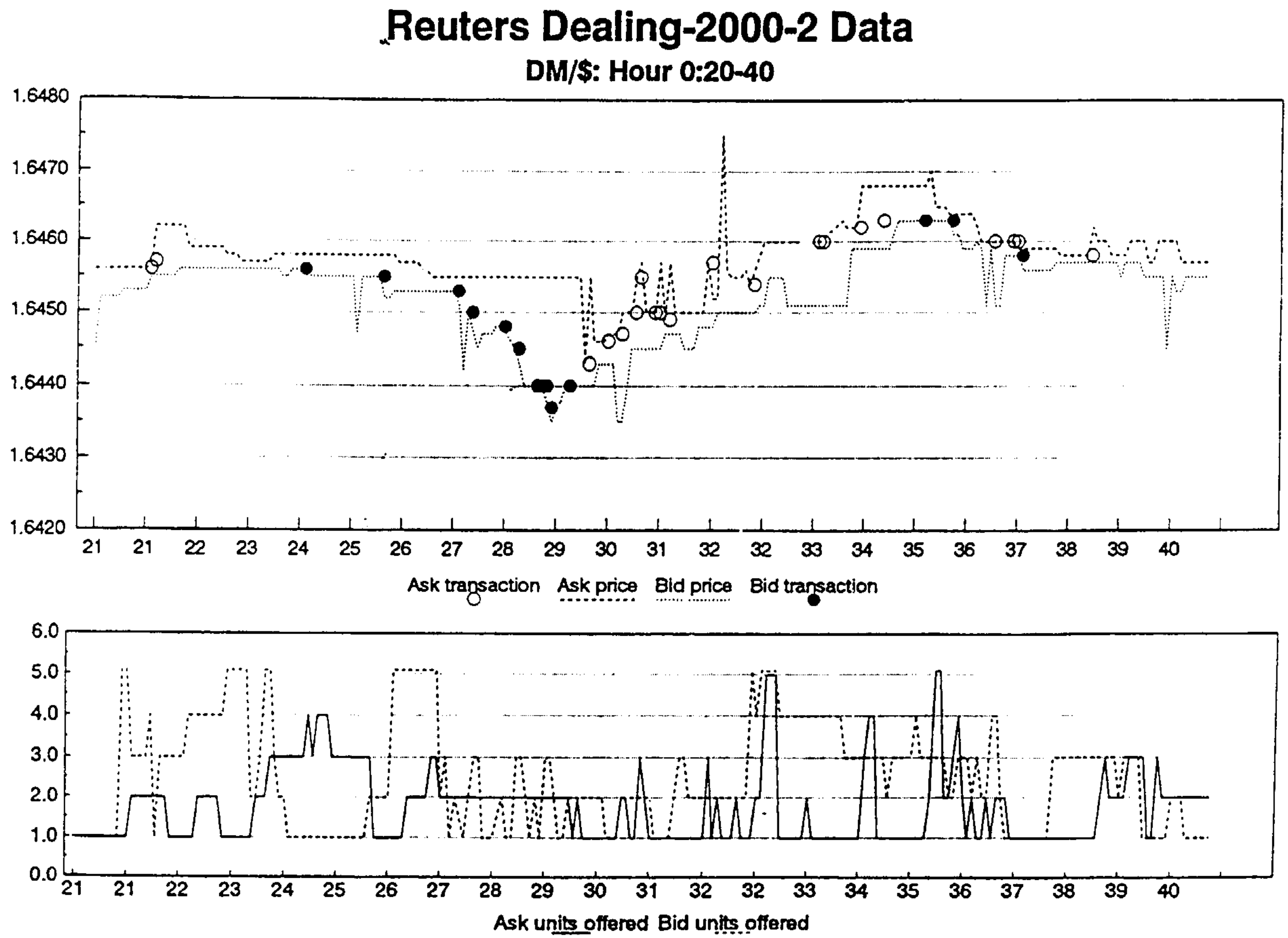
c) Questionable Relationships.



Reuters Dealing-2000-2 Data

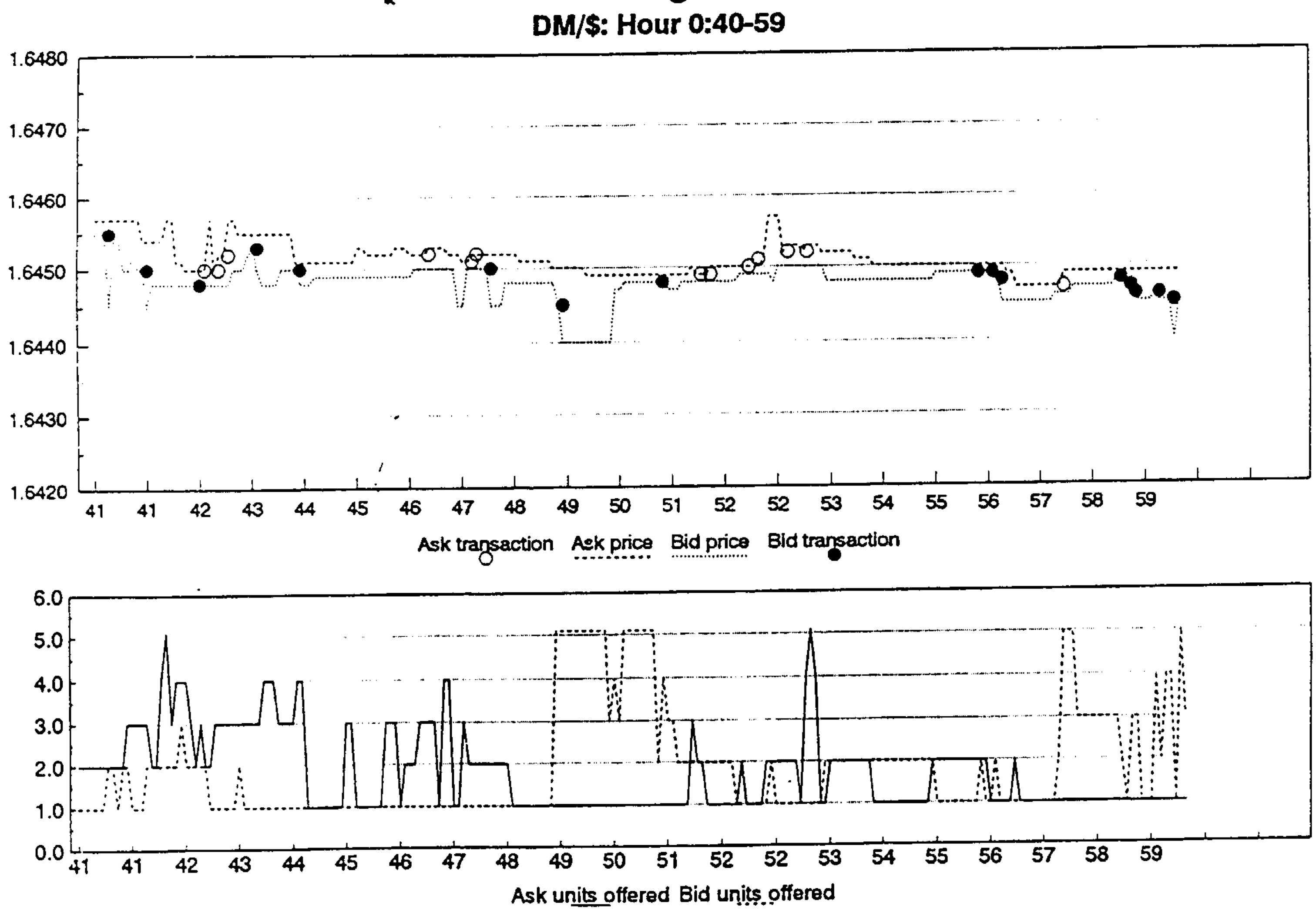
DM/$: Hour 0:0-20





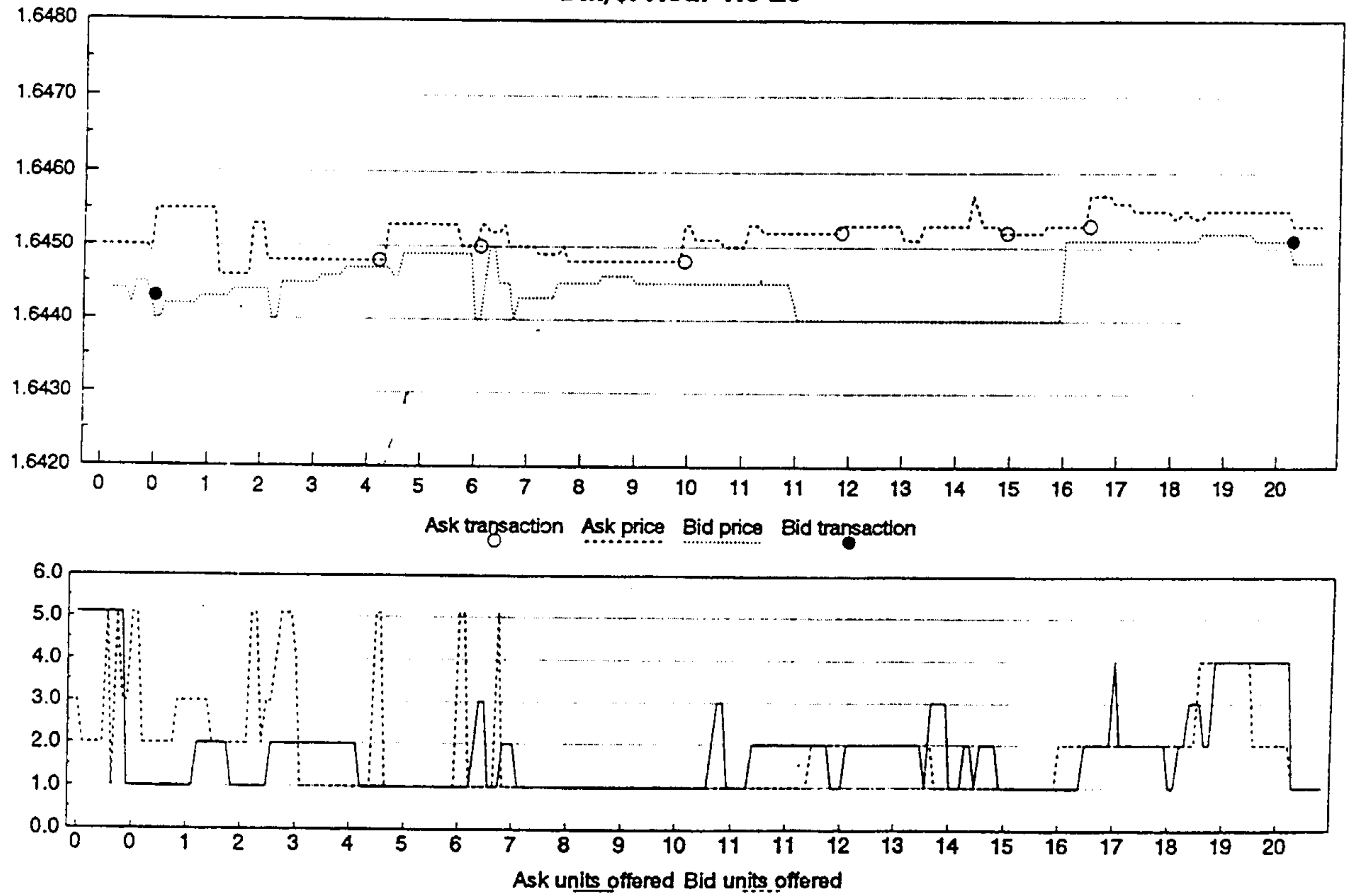
Reuters Dealing-2000-2 Data
DM/$: Hour 0:20-40
1.6480
1.6470
1.6460
1.6450
1.6440
1.6430
1.6420
21 21 22 23 24 25 26 27 28 29 30 31 32 32 33 34 35 36 37 38 39 40
Ask transaction
Ask price
Bid price
Bid transaction
6.0
5.0
4.0
3.0
2.0
1.0
0.0
21 21 22 23 24 25 26 27 28 29 30 31 32 32 33 34 35 36 37 38 39 40
Ask units offered
Bid units offered

Reuters Dealing-2000-2 Data



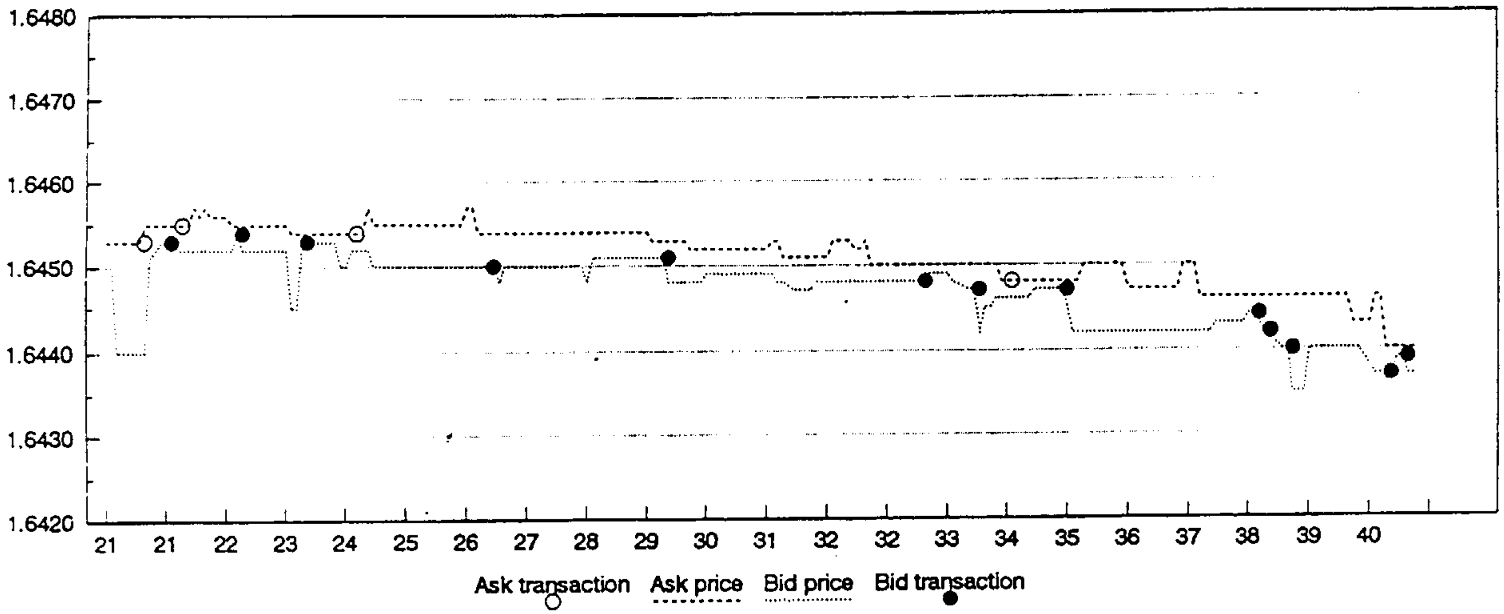
Reuters Dealing-2000-2 Data

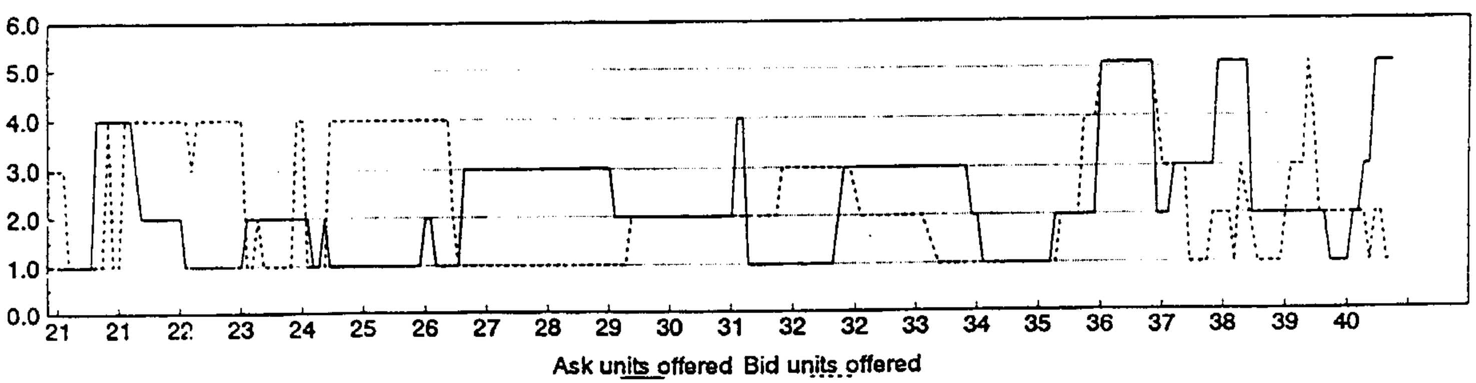
DM/$: Hour 1:0-20



Reuters Dealing-2000-2 Data

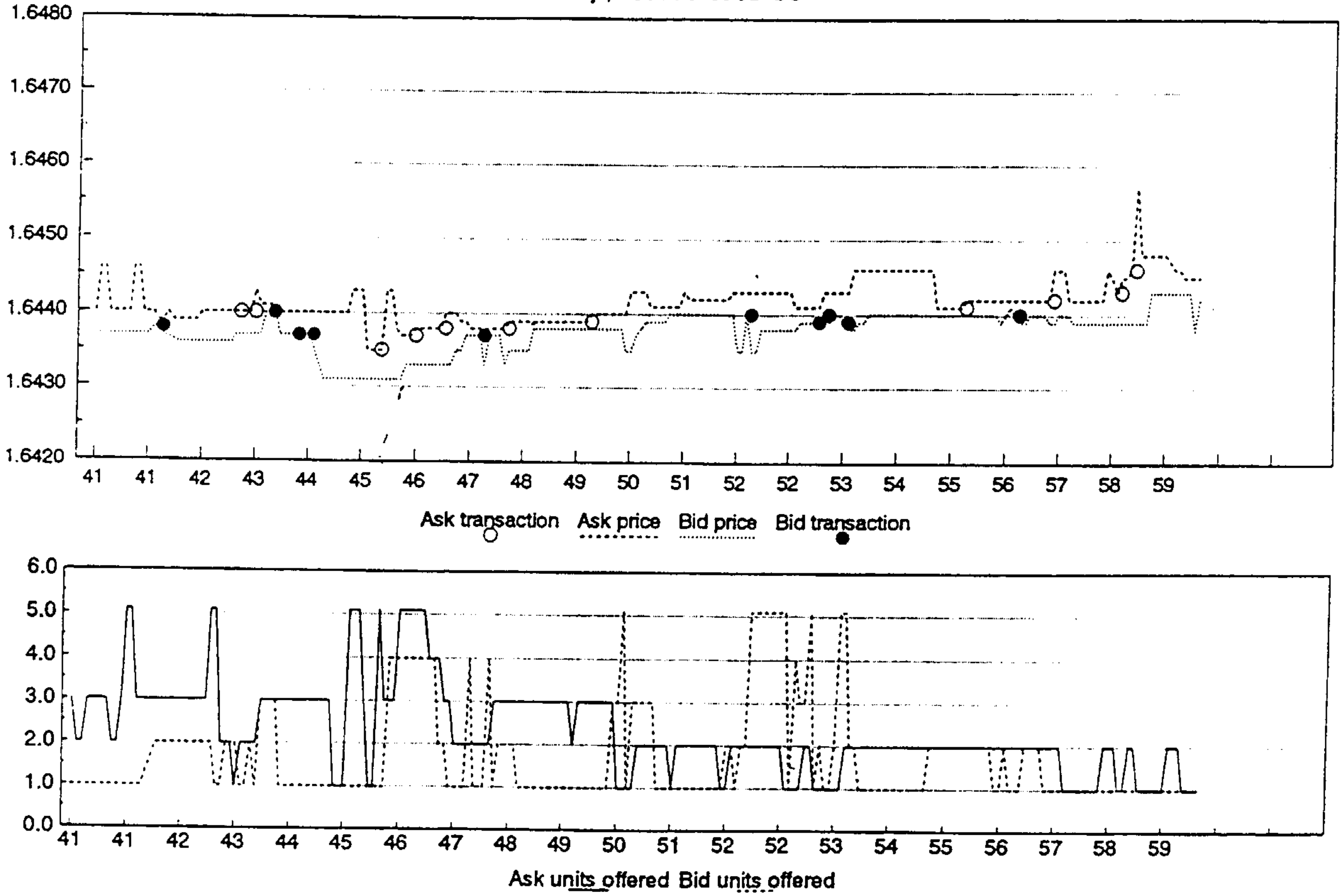
DM/$: Hour 1:20-40





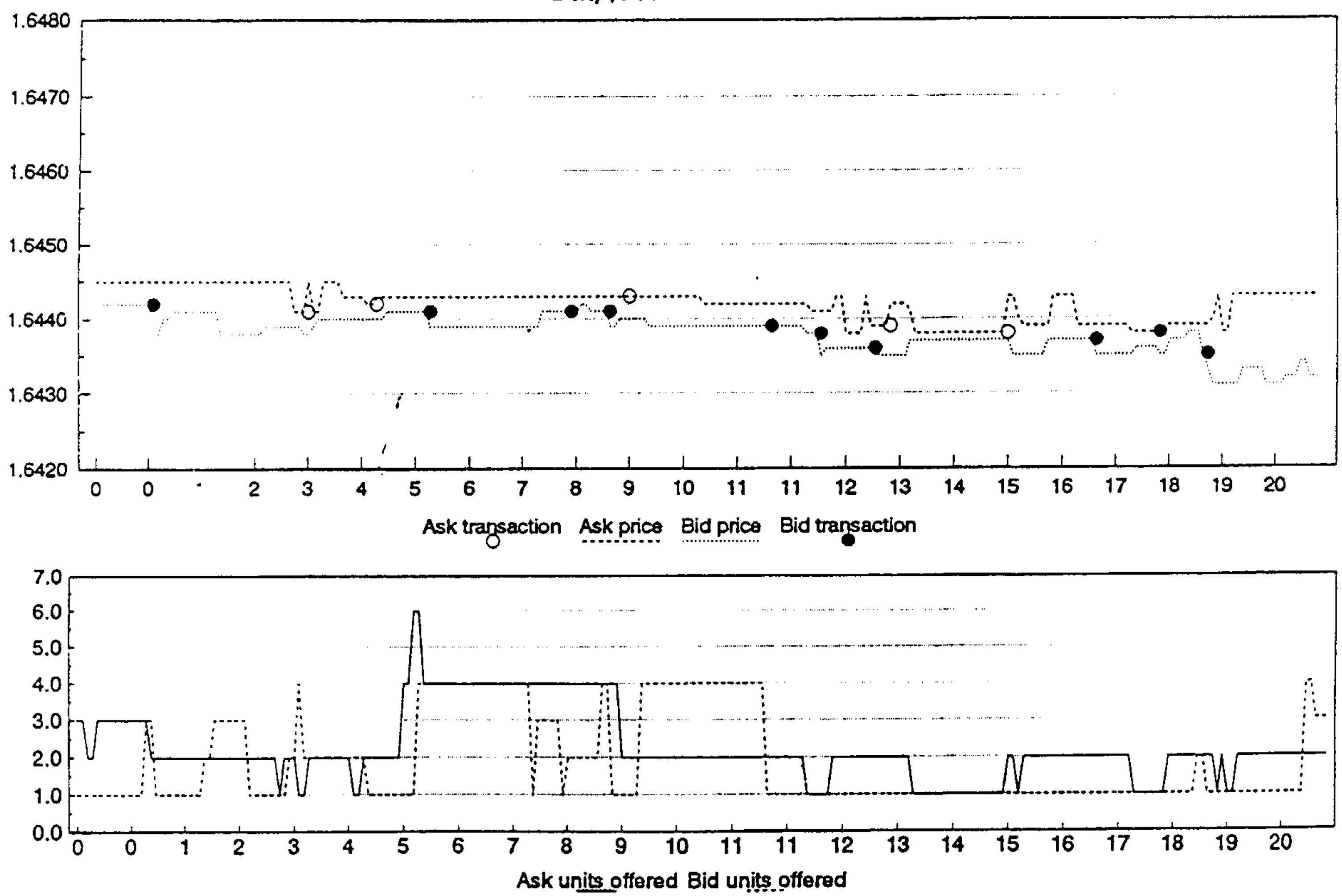
Reuters Dealing-2000-2 Data

DM/$: Hour 1:40-59



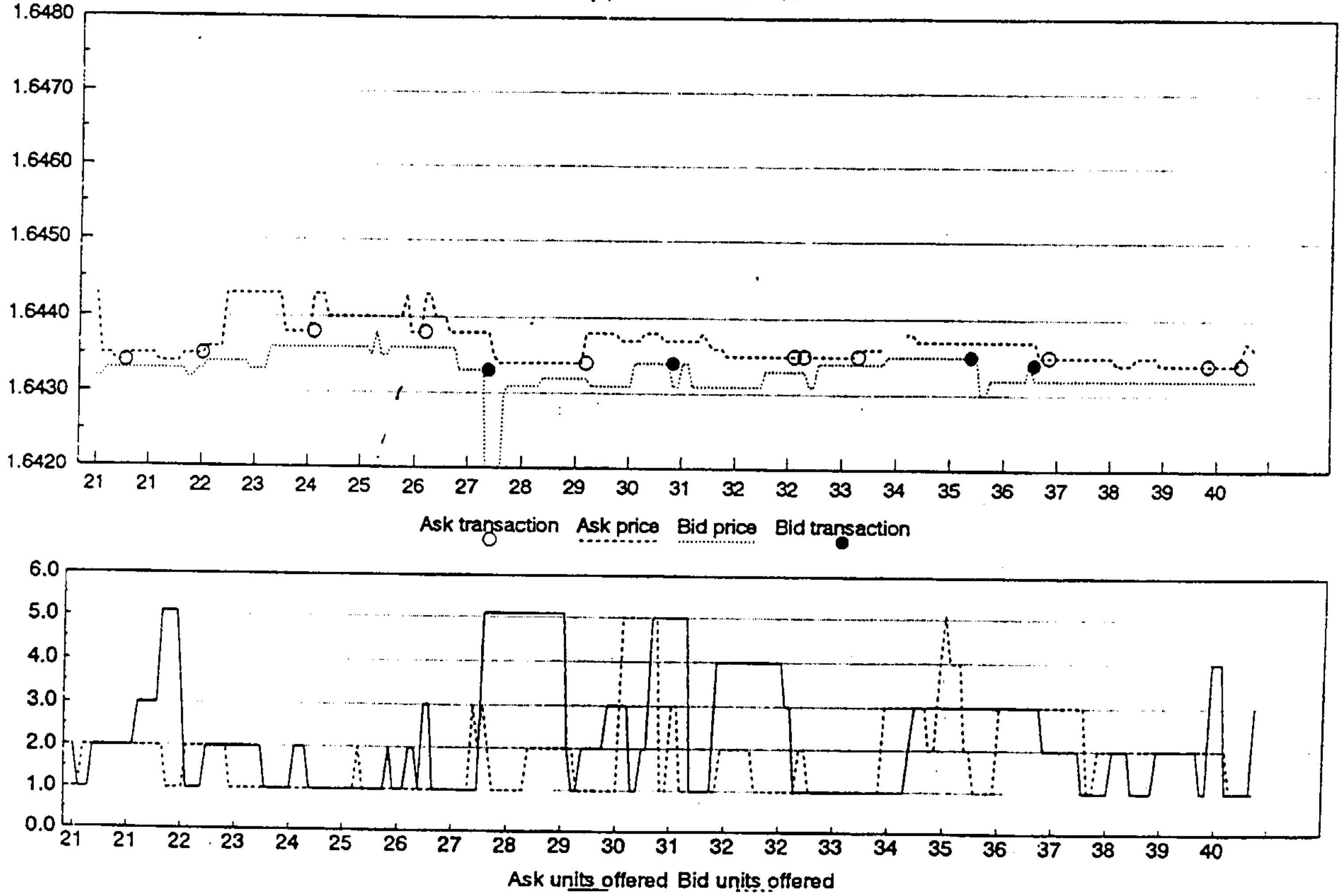
Reuters Dealing-2000-2 Data

DM/$: Hour 2:0-20



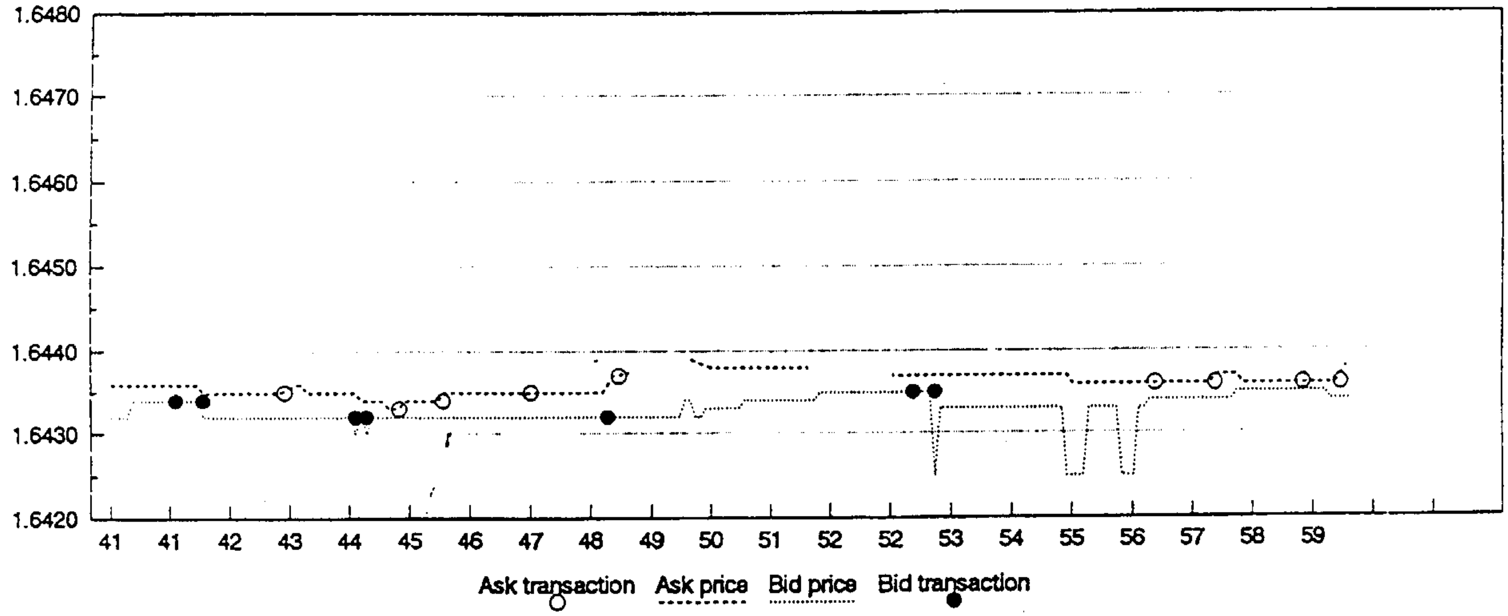
Reuters Dealing-2000-2 Data

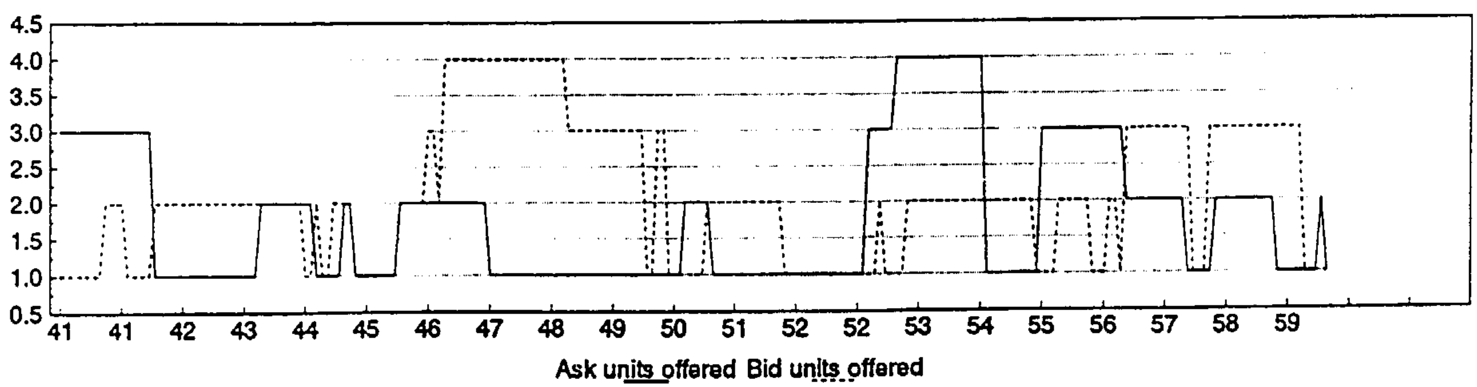
DM/$: Hour 2:20-40



Reuters Dealing-2000-2 Data

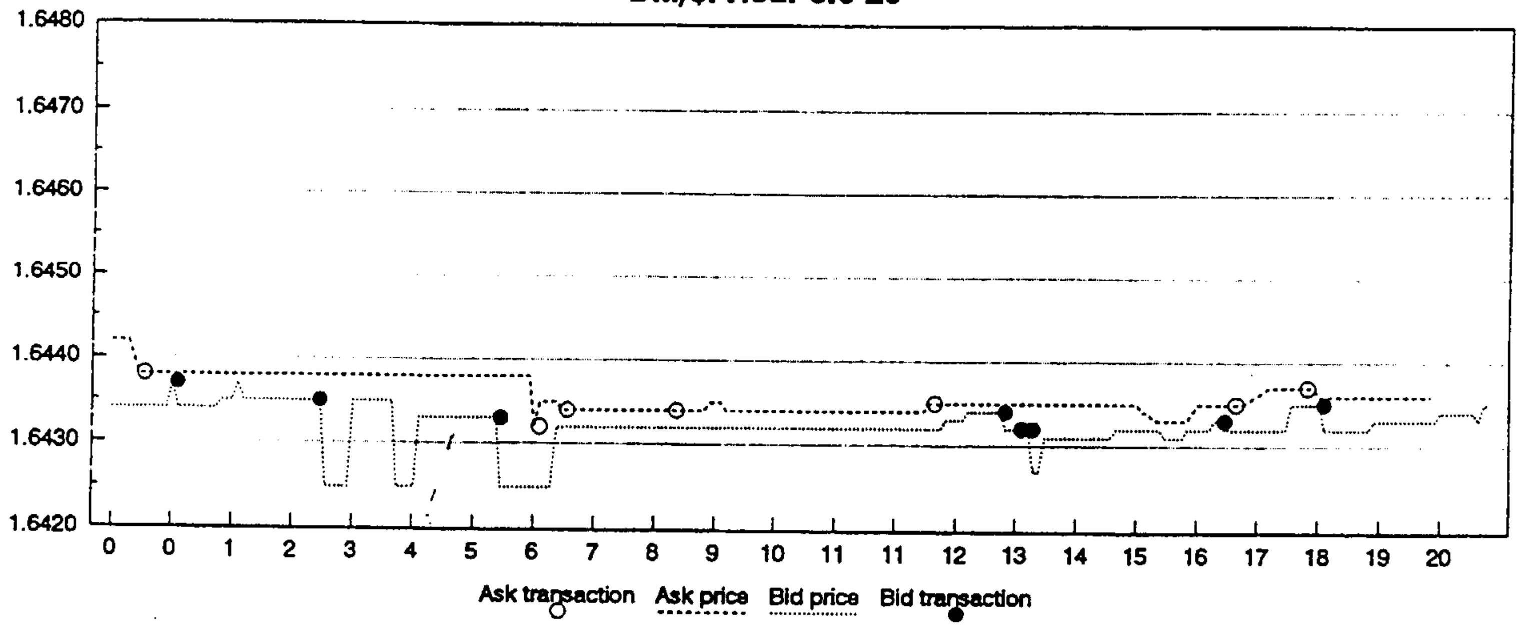
DM/$: Hour 2:40-59

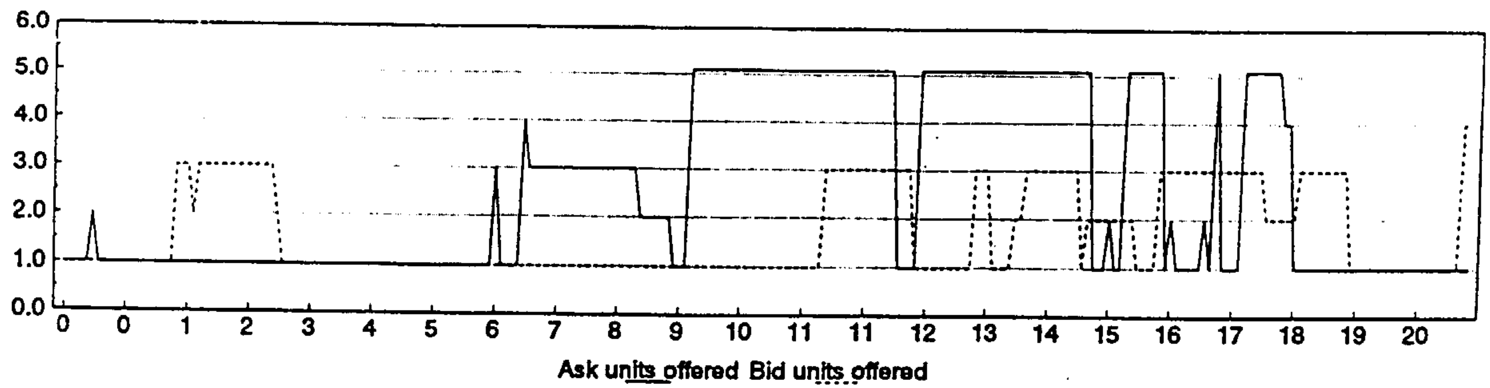




Reuters Dealing-2000-2 Data

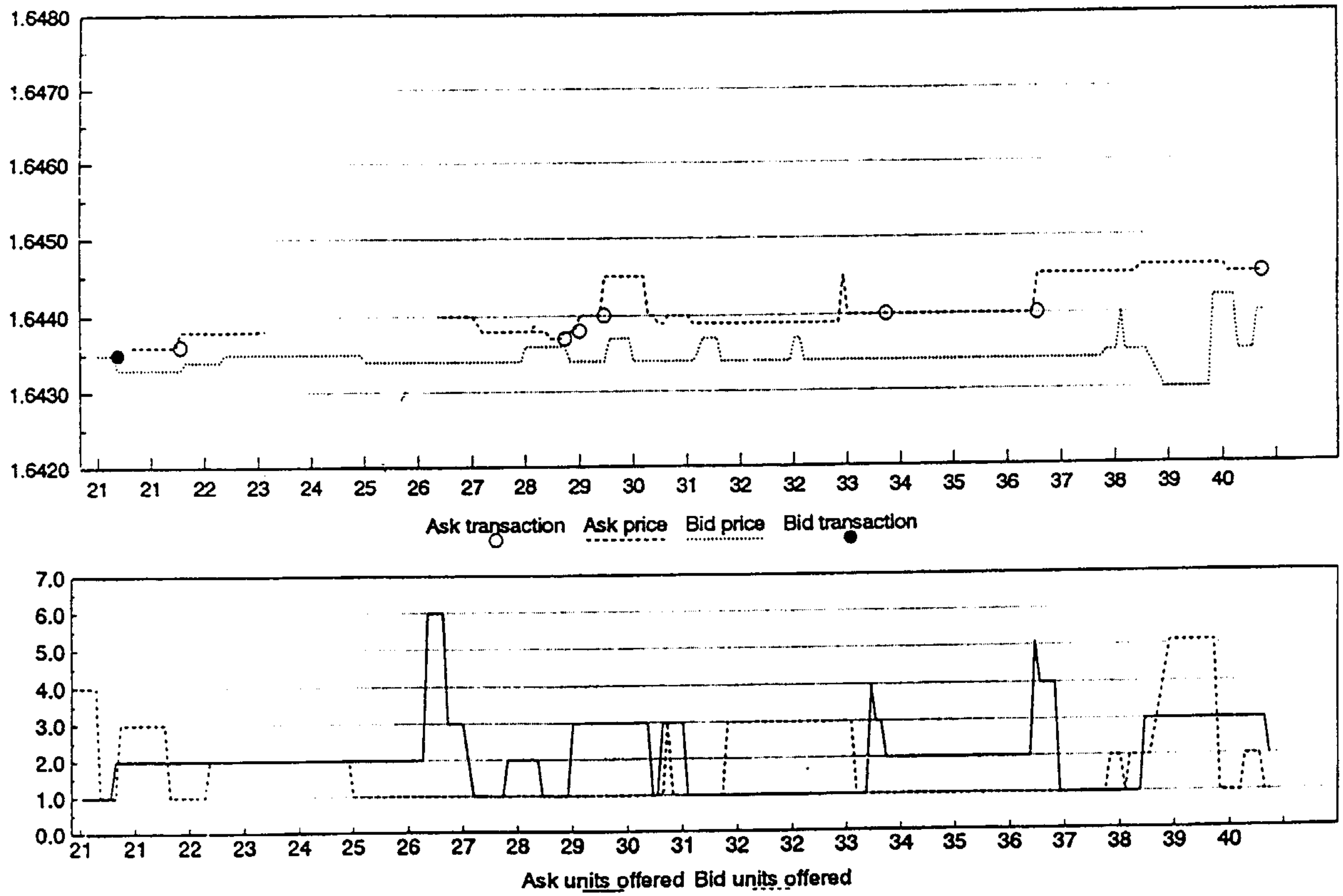
DM/$: Hour 3:0-20





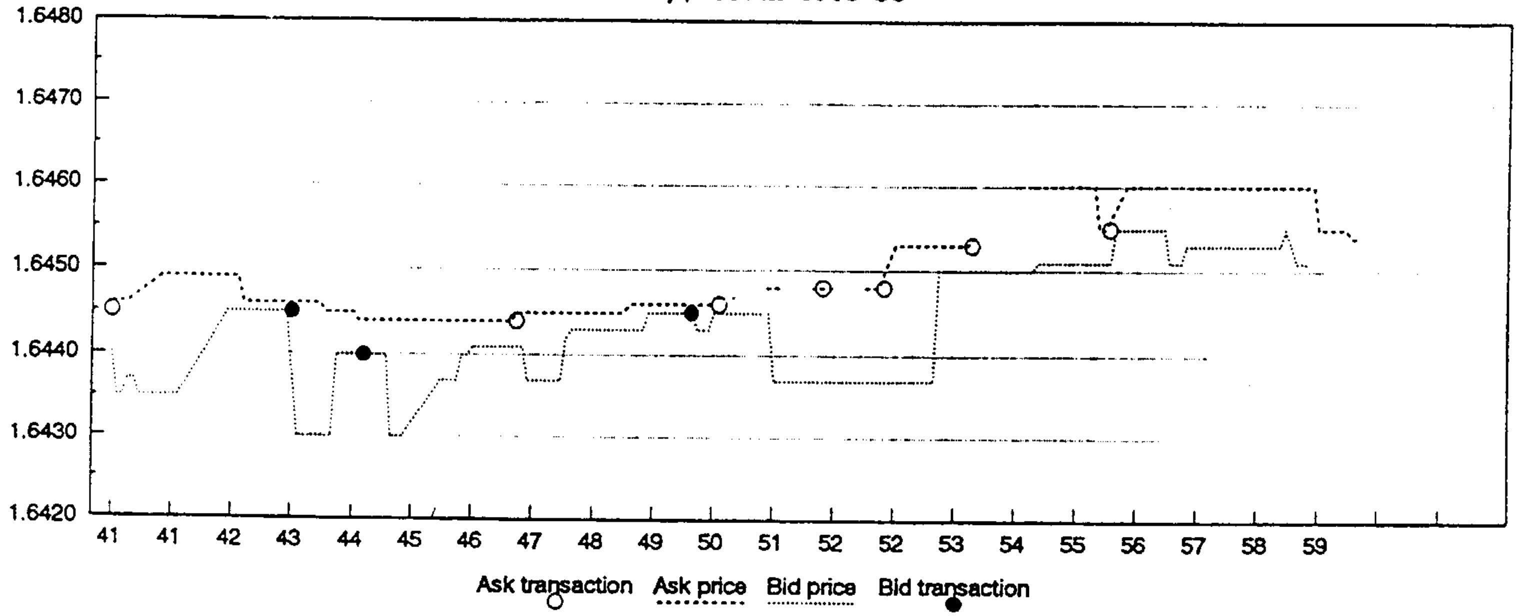
Reuters Dealing-2000-2 Data

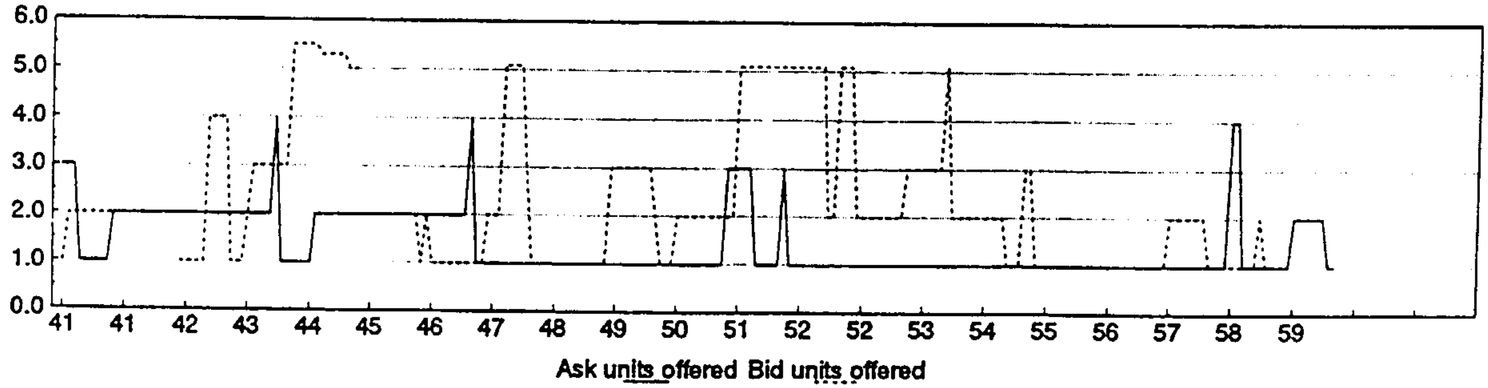
DM/$: Hour 3:20-40



Reuters Dealing-2000-2 Data

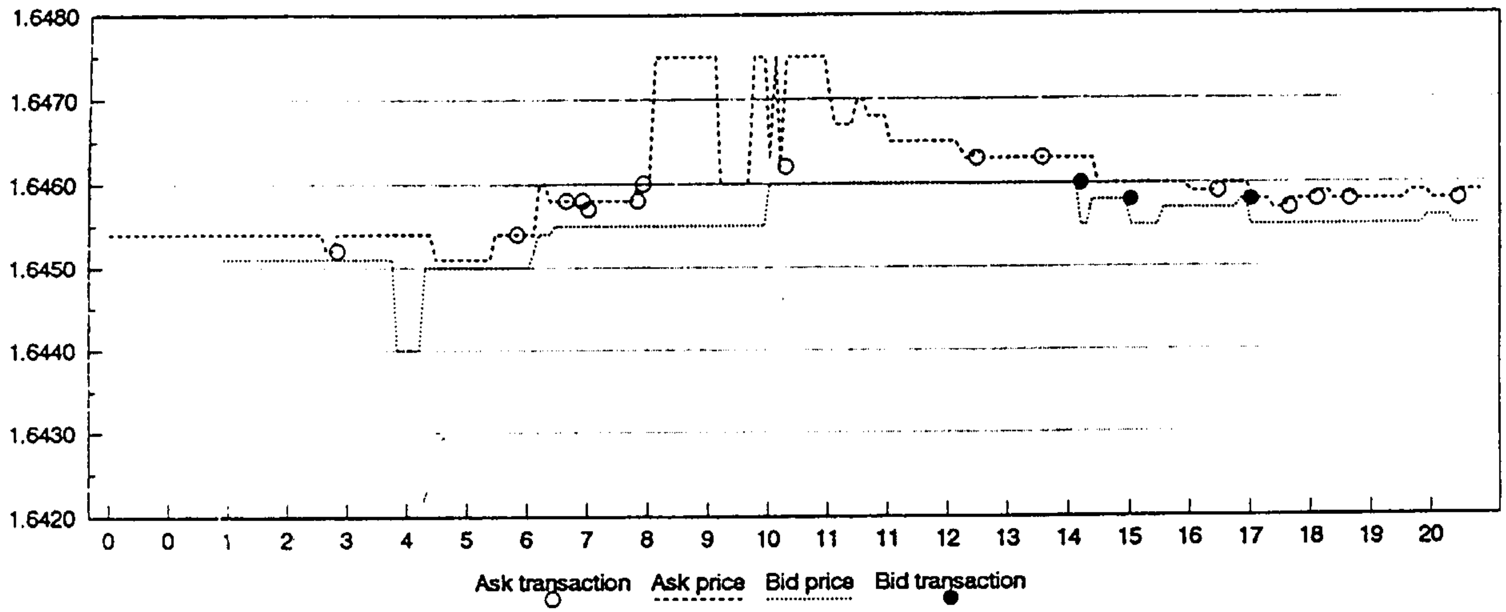
DM/$: Hour 3:40-59

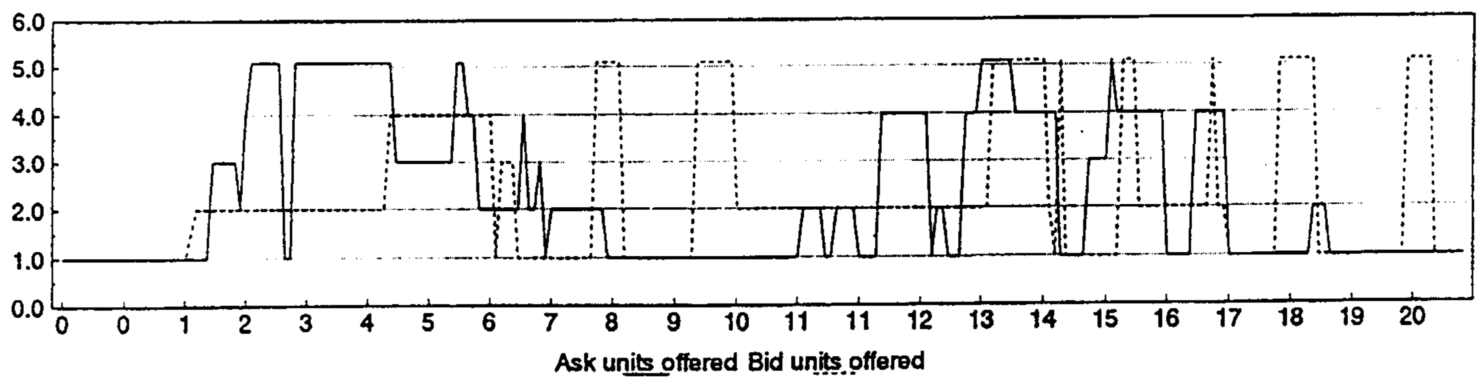




Reuters Dealing-2000-2 Data

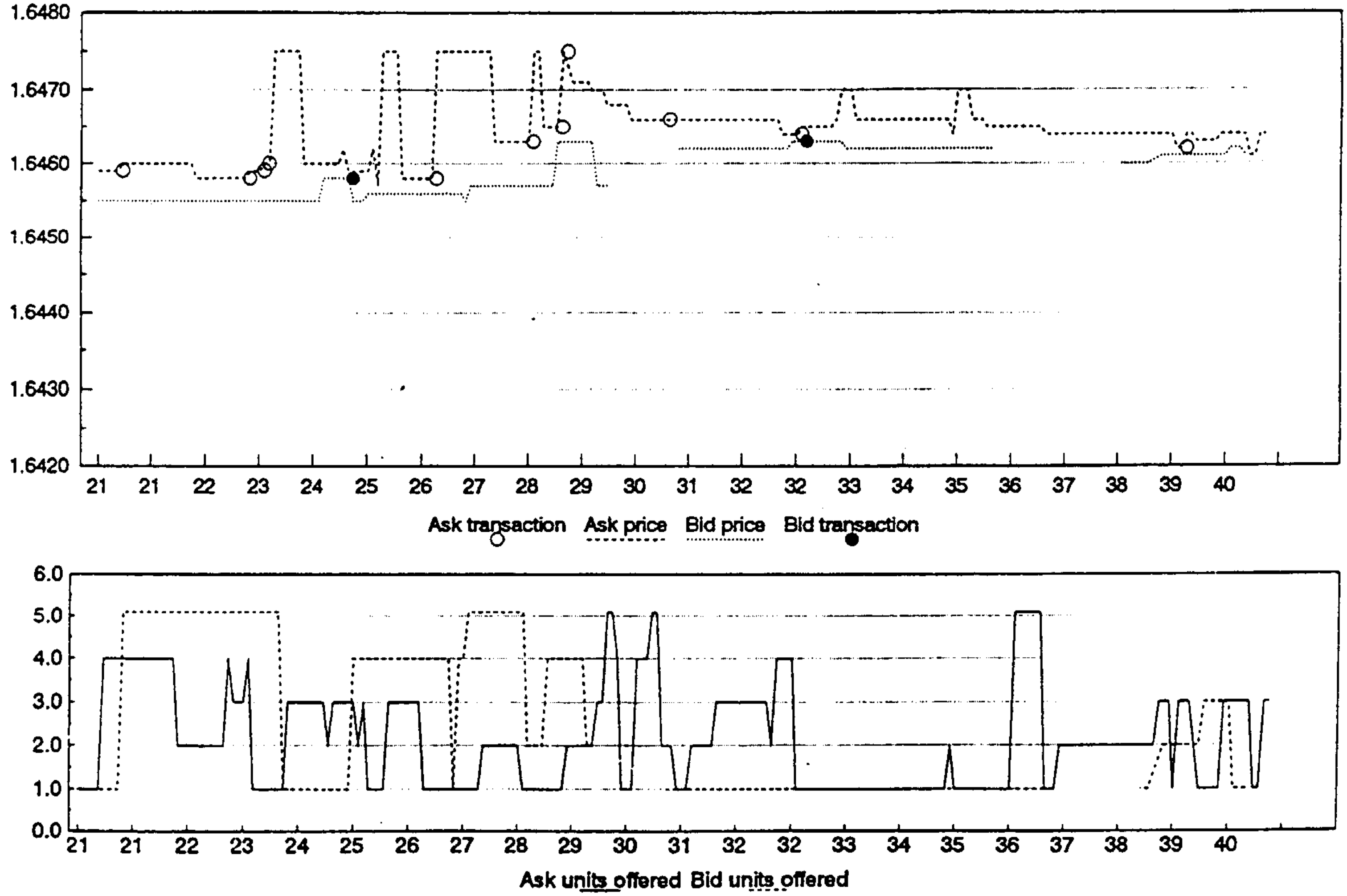
DM/$: Hour 4:0-20





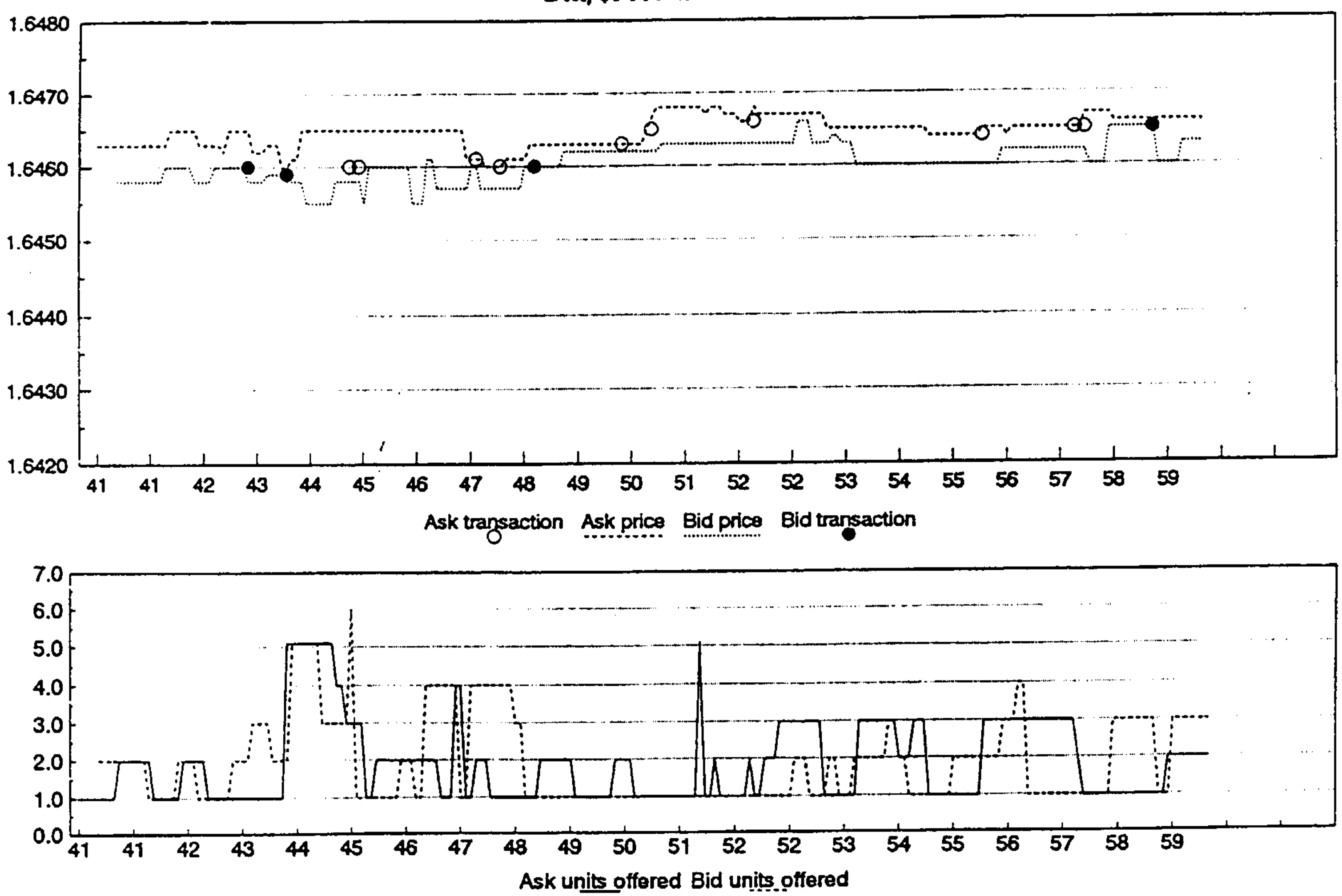
Reuters Dealing-2000-2 Data

DM/$: Hour 4:20-40



Reuters Dealing-2000-2 Data

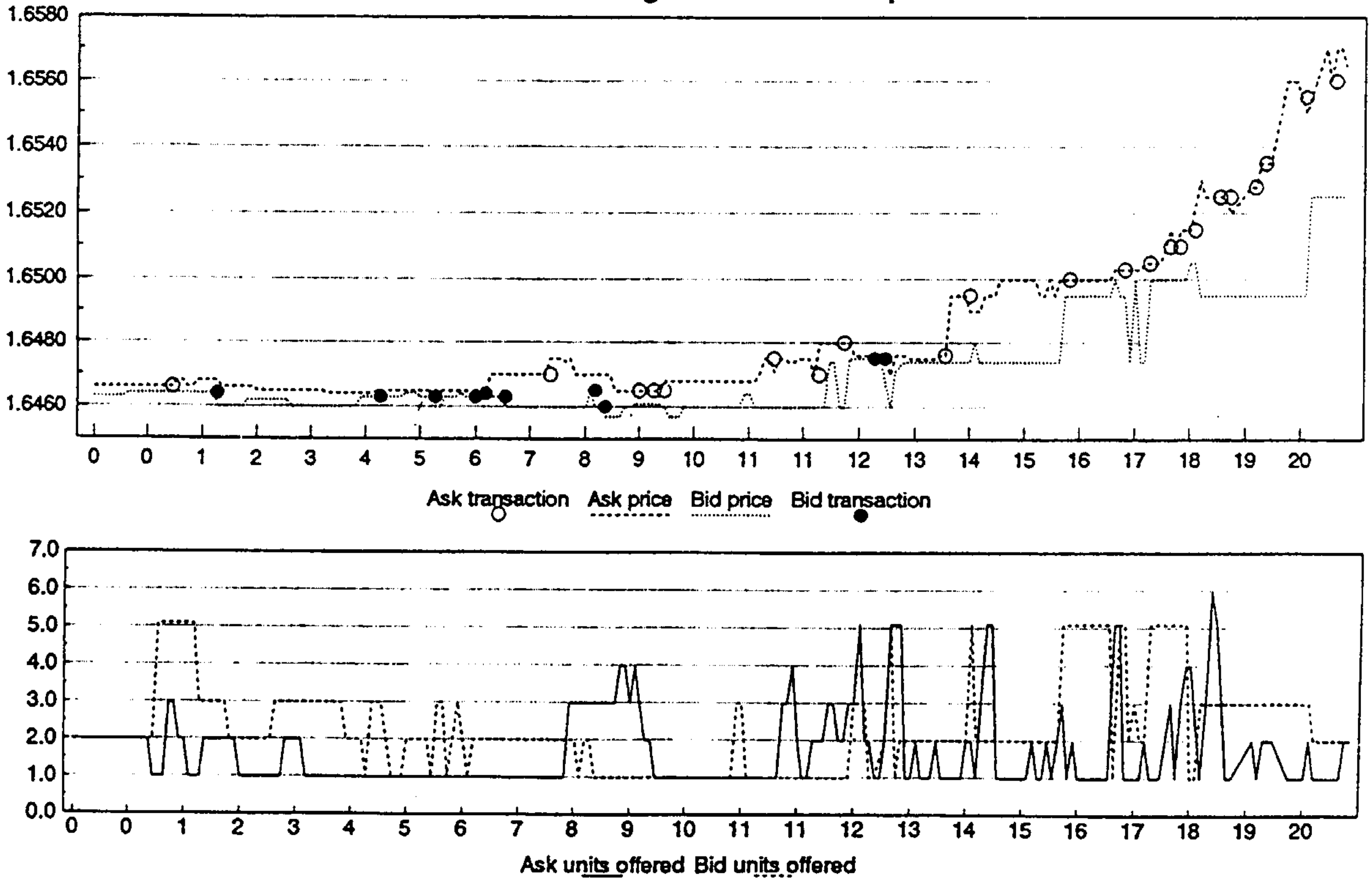
DM/$: Hour 4:40-59



Reuters Dealing-2000-2 Data

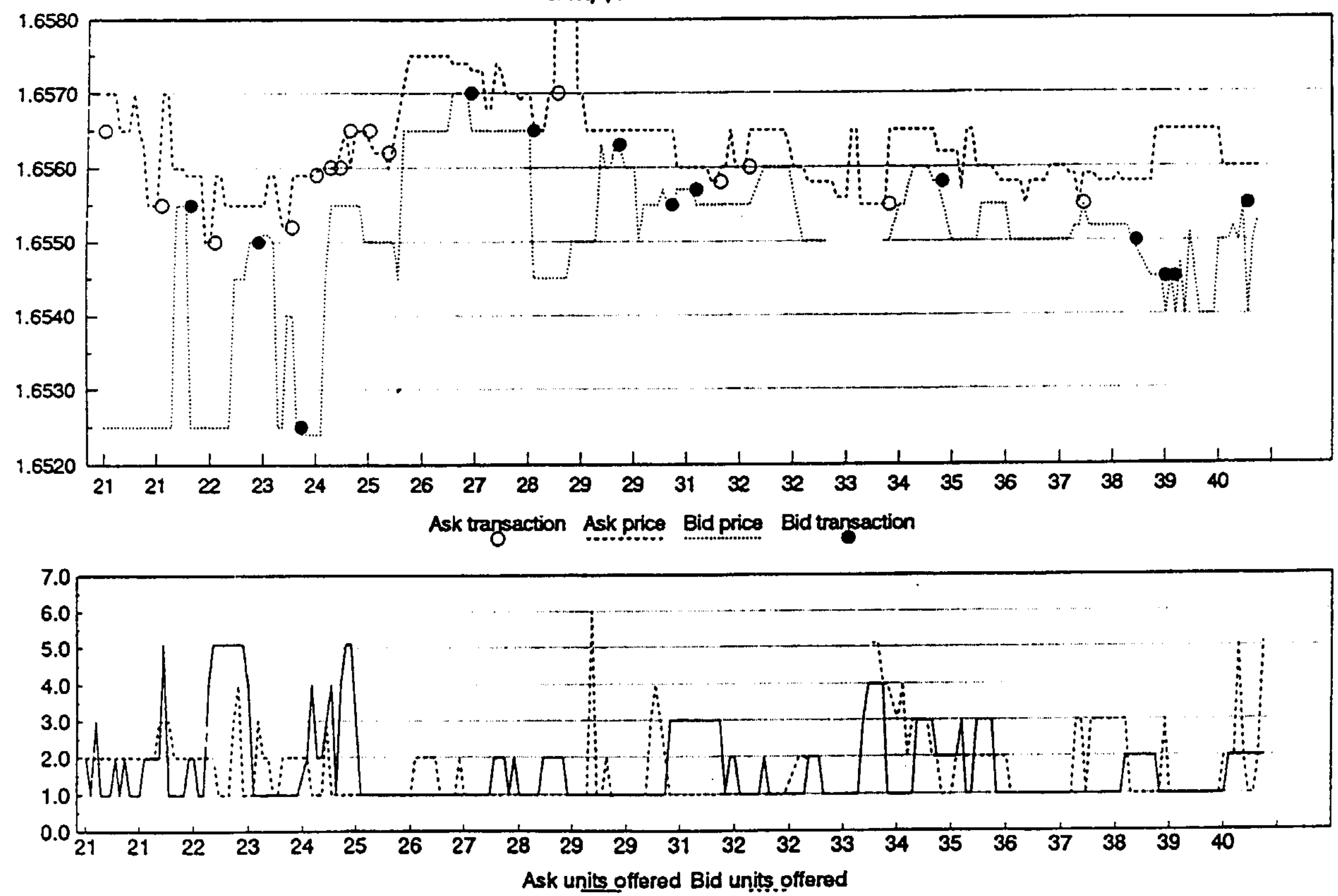
DM/$: Hour 5:0-20

Note: scale is larger than on other plots



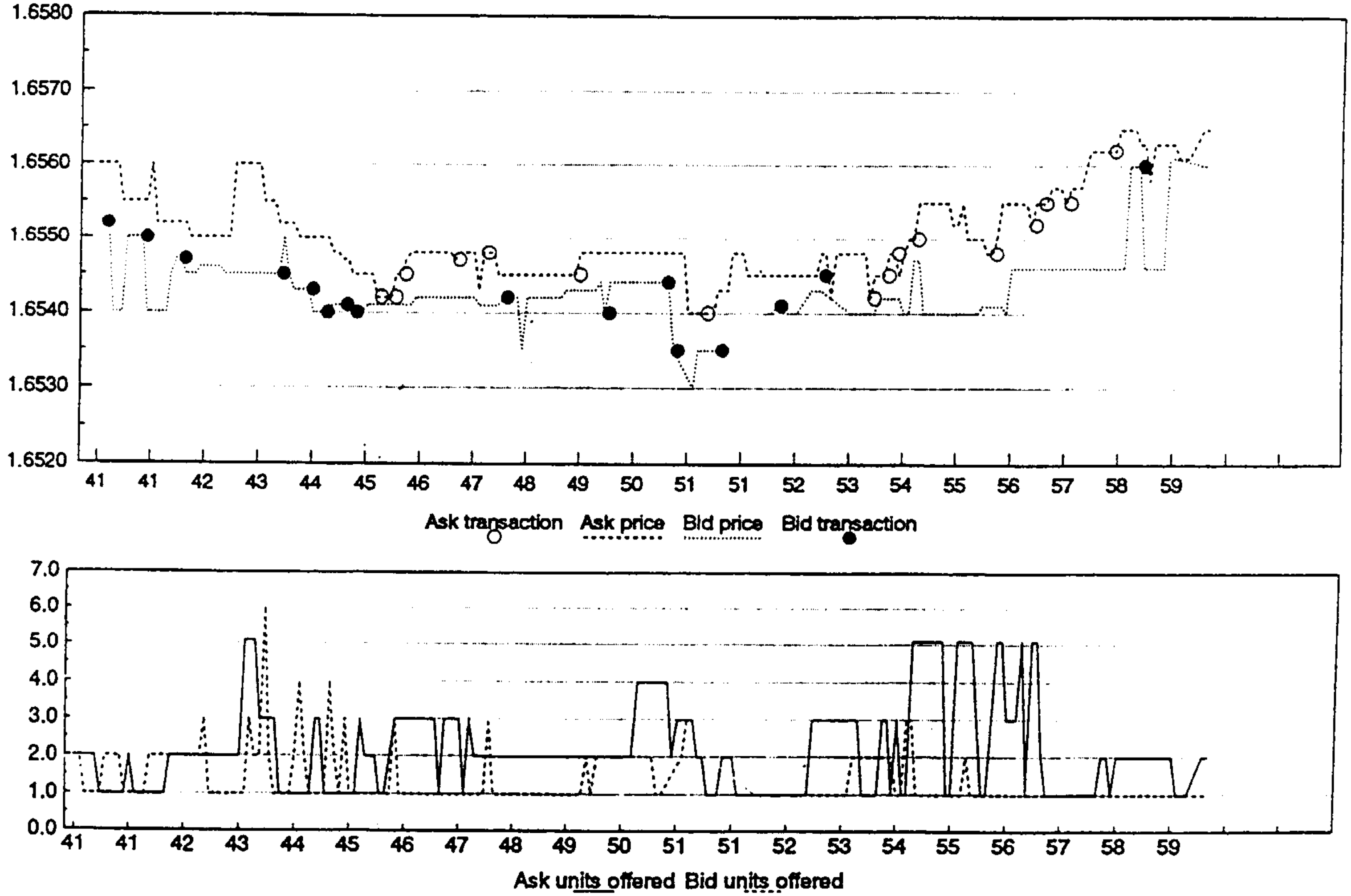
Reuters Dealing-2000-2 Data

DM/$: Hour 5:20-40



Reuters Dealing-2000-2 Data

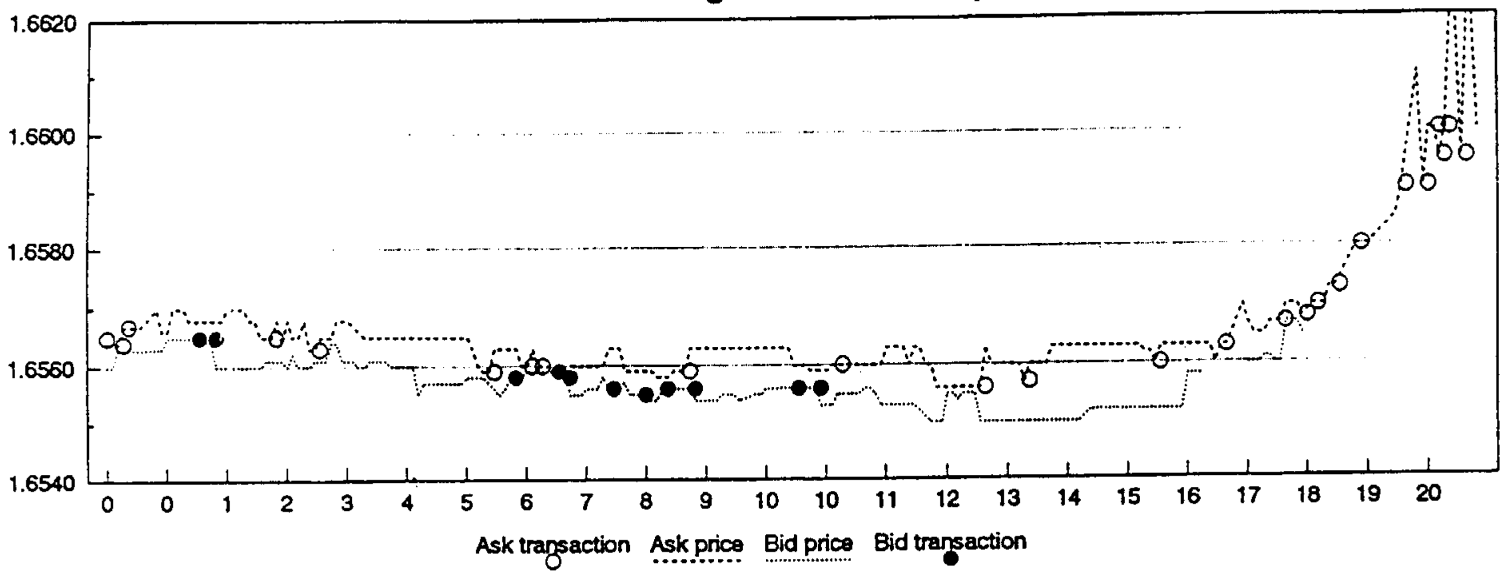
DM/$: Hour 5:40-59

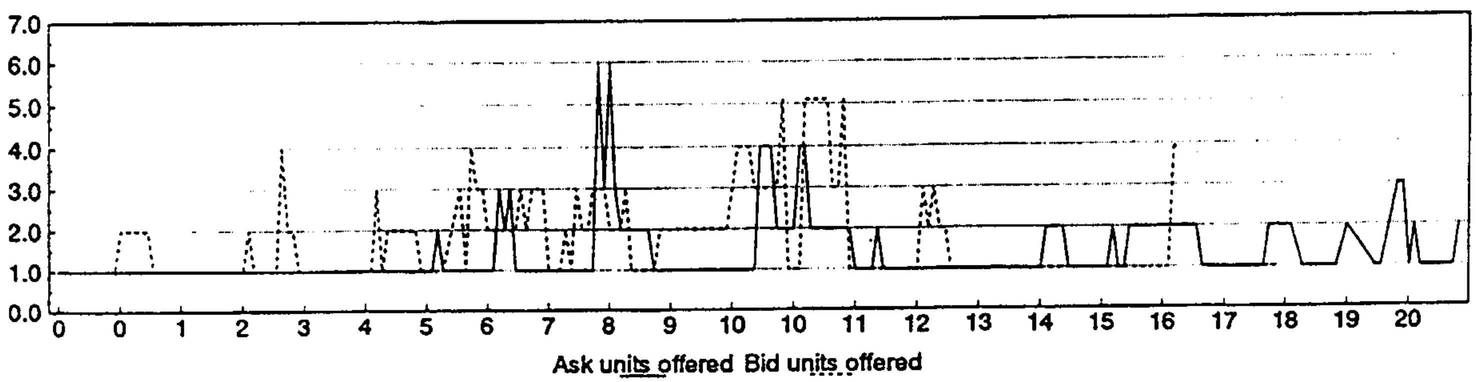


Reuters Dealing-2000-2 Data

DM/$: Hour 6:0-20

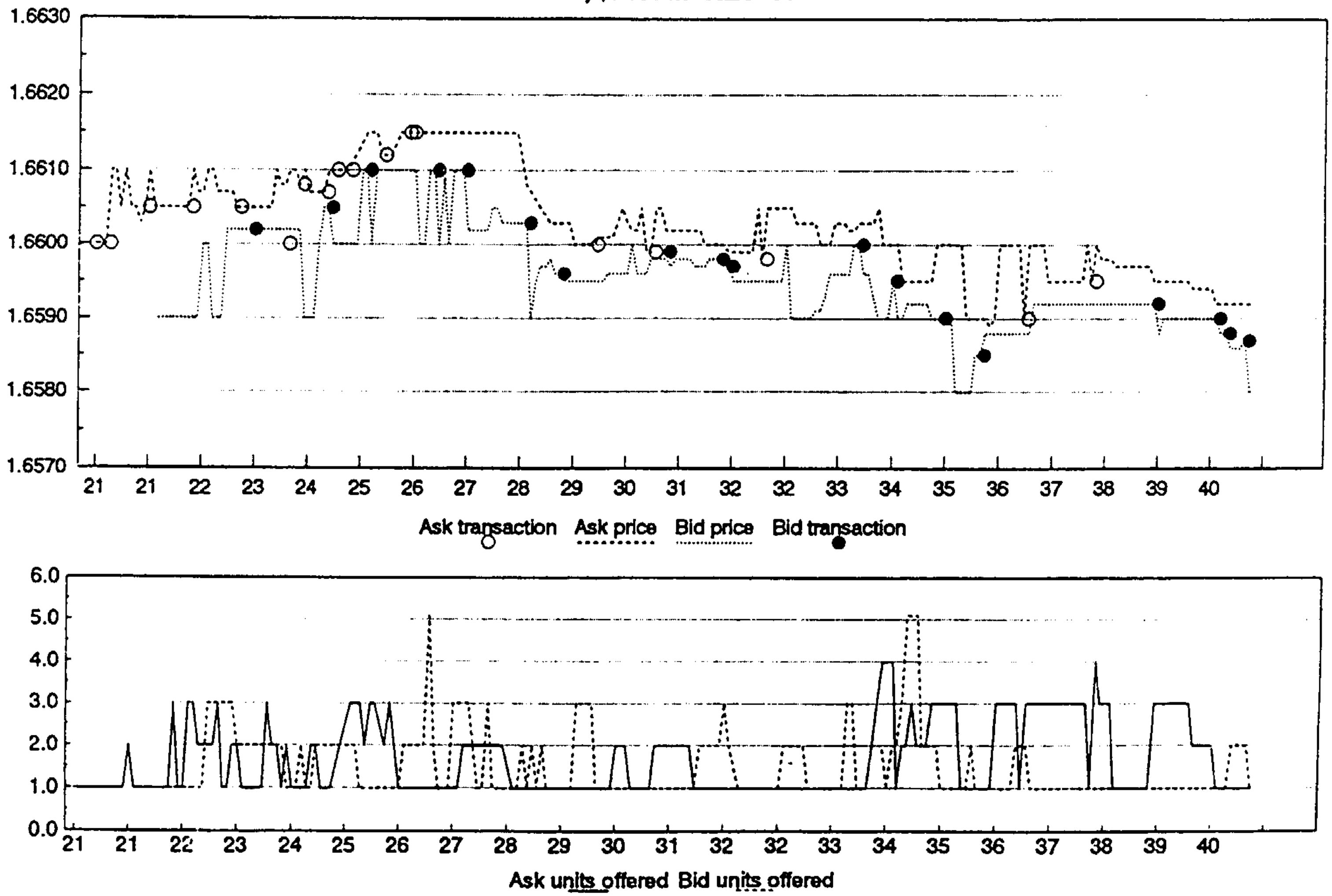
Note: scale is larger than on other plots





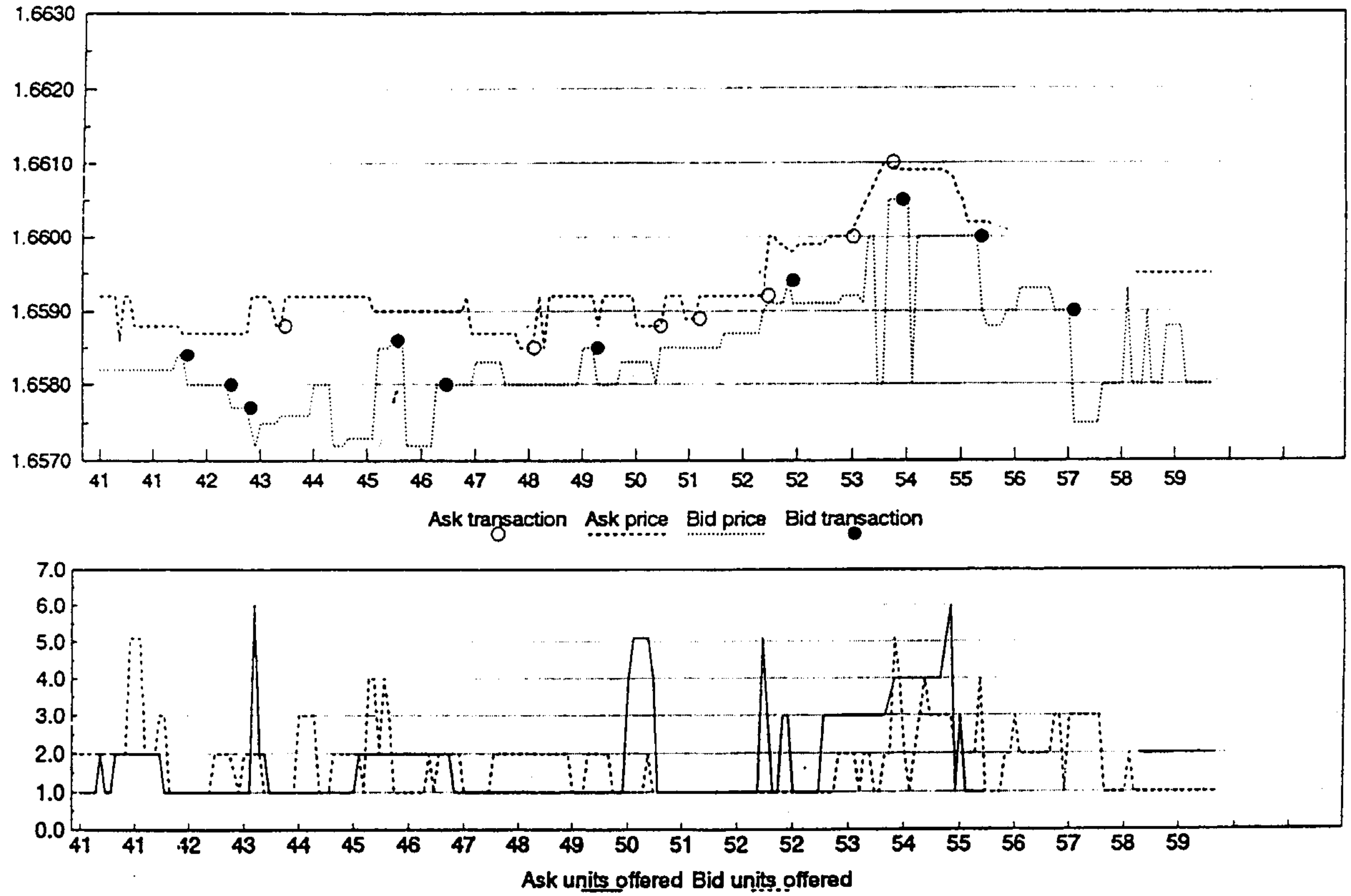
Reuters Dealing-2000-2 Data

DM/$: Hour 6:20-40



Reuters Dealing-2000-2 Data

DM/$: Hour 6:40-59



Reuters Dealing-2000-2 Data

DM/$: Hour 7:0-20