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# A Comparison of the Cost of Trading French Shares on the Paris Bourse and on SEAQ International

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**Abstract**

This paper analyses the cost of trading French shares on two exchanges, the Paris Bourse and London's SEAQ International. Using a large data set consisting of all quotes, limit orders and transactions for a two month period, it is shown that for small transactions the Paris Bourse has lower implicit transaction costs, measured by the realised or quoted bid-ask spread. The market in London, however, is much deeper and provides immediacy for much larger trades. Moreover, we find that the cost of trading is decreasing in trade size, rather than increasing over the range of trade sizes that we examine. This suggests that order processing costs are an important determinant of bid-ask spreads, since competing market microstructure theories (adverse selection, inventory control) predict bid-ask spreads increasing in trade size.

## 1. Introduction.

The growing importance of London as an international stock market where shares from other European countries are traded, constitutes a major change in the structure of Europe's financial markets. In recent years, London's SEAQ International has attracted considerable trading volume from the continental exchanges (see for example Worthington (1991)). This increased competition from London has induced the domestic exchanges to modernise and adapt their trading systems. An example is the move towards fully automated trading systems in Spain and Italy.

It seems natural to suppose that London has attracted large volume because trading costs are lower, particularly for large trade sizes. In this paper we use a large data set, a simultaneous record of all quotes, limit orders and transactions in both London and Paris, to compare the implicit cost of trading French shares on the Paris Bourse and on SEAQ International. The bid-ask spread is a major component of the total cost of trading, and we will provide a number of measures of the spread on both exchanges. We also briefly discuss published information on explicit costs of trading (such as commissions) in order to gauge the total cost of trading.

In the paper two different types of estimates of the bid-ask spread are presented. First, the average **quoted** spread is estimated from the Paris limit order book and market makers' quotes in London. Second, the average **realised** spread is estimated from actual transactions prices. Estimates of the quoted and realised spread are presented for different times of day and for different transaction sizes. The dependence of the spread on trade size is also of theoretical interest, because it can be used to assess the validity of market micro-structure theories that predict that the bid-ask spread will be increasing in trade size.

Both the quoted and the realised spread are not directly observable in our data set. On the Paris Bourse part of limit order can be hidden from the public information system, so that the limit order book seems less deep than it actually is. Uncorrected estimates would therefore overestimate the quoted spread in Paris. In London the problem is that there is some misreporting of transaction times, which causes a timing bias in our realised spread estimate. In order to circumvent these problems we also present model-based estimates of the average realised spread using transaction prices only. These estimators can be seen as refinements of Roll's (1984) estimator.

The setup of the paper is as follows. In section 2 we briefly discuss the major theories that explain the existence and the size of the bid-ask spread. In section 3, we describe the trading systems on the Paris Bourse and on SEAQ International. In section 4 we describe our data. The spread estimates are presented in sections 5, 6 and 7. In section 5 we compute the average quoted spread and in section 6 the average realised spread, both in Paris and in London. In section 7 we take a model-based approach to estimating the realised spread that uses transactions data only. Finally, we summarise the main conclusions in section 8.

## 2. Theories of the bid-ask spread.

In the literature on stock market micro-structure there are a number of theories that explain the bid-ask spread. Most theories view the spread as a compensation for the services of a market maker, who takes the other side of all transactions. In the literature, e.g. Stoll (1989), three cost components are distinguished: order processing cost (including dealer oligopoly profit), inventory control cost and adverse selection cost. In this section, these three components will be discussed in more detail.

The order processing cost component reflects the cost of being in the market and handling the transaction. To compensate for these costs, the market maker levies a fee on all transactions by differentiating between buy and sell prices. Much of the empirical literature, such as Madhavan and Smidt (1987) and Glosten and Harris (1987), assumes that this fee is a fixed amount per share. However, it seems more natural to suppose that order processing cost is largely fixed *per transaction*, so that expressed as cost per share it should be declining in trade size.

A second type of cost for the market maker is the cost of inventory management. For example, a purchase of shares will raise the market maker's inventory above a desired level. The market maker runs the risk of price fluctuations on his inventory holdings and if he is risk averse he will demand a compensation for this risk. This intuition is formalised in the model of Ho and Stoll (1981), who show that the inventory control cost is an increasing function of trade size and share price volatility.

The third type of cost for the market maker arises in the presence of asymmetric information between the market maker and his potential counterparties in trading. This theory was first proposed by "Bagehot" (1971) and formalised in the models of Glosten and Milgrom (1985) and Kyle (1985). A trader with superior private information about the underlying value of the shares will try to buy or sell a large number of shares to reap the profits of this knowledge. The market maker, who is obliged to trade at the quoted prices, incurs a loss on transactions with better informed counterparties. To compensate for this loss he will charge a fee on every transaction, so that expected losses on trades with informed traders are compensated with expected profits on transactions with uninformed "noise" traders. Because the informed parties would tend to trade a large quantity in order to maximise the profits from trading on superior information, the adverse selection effect is related to trade size: large transactions are more likely to be initiated by informed traders than small transactions, as in the model of Easley and O'Hara (1987). Therefore, the asymmetric information cost is an increasing function of trade size, and the market maker's quotes for large transactions will be less favourable than the quotes for small sizes.

These theories have been developed for markets with competitive designated market makers. Nevertheless, the theories are frequently applied to exchanges with different trading systems, such as the NYSE. The trading system on the Paris Bourse also differs considerably because there are no designated market makers. But we may regard the issuers of public limit orders as market makers because they provide liquidity to the market. Just like market makers they run the risk that their limit order will be executed against a market order placed by somebody with superior information. The inventory control theory is applicable to the extent that we can regard those who place market orders as demanders of immediacy, while those who place limit orders are making the market by absorbing inventories in return for a price concession. In practice, the distinction between the two groups is not sharp, as any trader can place both types of orders.

Summarising, processing costs cause a decreasing, whereas both asymmetric information and inventory control cause an increasing spread as a function of trade size. The aim of this paper is to compare the depth of the market in Paris and London and to estimate the form of the dependence of the spread on trade size from quote and transactions data. We shall not attempt to identify the relative importance of the three cost components in this paper. This decomposition is the focus of a companion paper (De Jong et al. (1993)), where we concentrate on the dynamic effects of trades on quotes and transaction prices.

## 3. Description of the markets in French equities.

In this section we describe the trading systems on the major exchanges where French equities are traded: the Bourse in Paris and SEAQ International in London. Because the trading systems are so different - Paris is a continuous auction market whereas London is a dealership market - we devote two separate sub-sections to this description.

### a. The trading system on the Paris Bourse.

The Paris Bourse uses a centralised electronic system for displaying and processing orders, the Cotation Assistée en Continu (CAC) system. This system, based on the Toronto Stock Exchange's CATS (Computer Assisted Trading System), was first implemented in Paris in 1986. Since then, trading in nearly all securities has been transferred from the floor of the exchange onto the CAC system. All the most actively traded French equities are traded on a monthly settlement basis in round lots of 5 to 100 shares set by the Société des Bourses Françaises (SBF) to reflect their unit price. The SBF itself acts as a clearing house for buyers and sellers, providing guarantees against counterparty default.

Every morning at 10 a.m. the trading day opens with a batch auction where all eligible orders are filled at a common market clearing price. Nowadays the batch auction is relatively unimportant, accounting for no more than 10 to 15% of trading volume. Its role is to establish an equilibrium price before continuous trading starts. Continuous trading takes place from 10 a.m. to 5 p.m.

In the continuous trading session there are two types of orders possible, limit orders and market orders. Limit orders specify the quantity to be bought or sold, a required price and a date for automatic withdrawal if not executed by then, unless the limit order is good till cancelled ("à révocation"). Limit orders cannot be issued at arbitrary prices because there is a minimum "tick" size of FF 0.1 for stock prices less than FF 500, and FF 1 for higher prices. More than one limit order may be issued at the same price. To these orders, strict time priority for execution applies.

Market orders only specify the quantity to be traded and are executed immediately "au prix du marché", i.e. at the best price available. If the total quantity of the limit orders at this best price do not suffice to fill the whole market order, the remaining part of the market order is transformed into a limit order at the transaction price (for a detailed description of this system see Biais et al. (1992)). Hence, market orders do not automatically walk up the limit order book, and do not always provide immediate execution of the whole order[2].

After the opening, traders linked up to the CAC system will see an onscreen display of the "market by price" as depicted in Figure 1.

*place figure 1 about here.*

For both the bid side and the ask side of the market, the five best limit order prices are displayed together with the quantity of shares available at that price and the number of individual orders involved. The difference between the best bid and ask price is known as the "fourchette". Traders can scroll down to further pages of the screen to view limit orders available beyond the five best prices. In addition, some information concerning the recent history of trading is given: time, price, quantity and buyer and seller identification codes for the five last transactions, the cumulative quantity and value of all transactions since the opening, and the price change from the previous day's close to the latest transaction.

In practice, the underlying limit order book tends to be somewhat deeper than suggested by the visible display of limit orders. This is because traders who are afraid that they might move the market by displaying a very large order may choose to display only part of their limit order onscreen. The remaining part, known as the "quantité caché" or undisclosed quantity, remains invisible onscreen but may be called

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2 A trader who wants to trade a certain quantity immediately can circumvent this mechanism by placing a *limit order* at a very unfavourable price. This limit order will then be executed against existing orders on the other side of the market that show a more favourable price.

upon to fill incoming orders as the visible limit orders become exhausted. Strict price priority applies also to the hidden orders. Röell (1992) suggests that due to the quantité caché the visible depth of the market is about two thirds of the actual depth when hidden quantities are included.

The member firms of the Bourse (the "Sociétés de Bourse") key orders directly into the CAC system via a local terminal. All market participants can contribute to liquidity by putting limit orders on display. In particular, the Sociétés de Bourse may act in dual capacity: as agency brokers, acting on behalf of clients, and as principals, trading on own account. Their capital adequacy is regulated and monitored by the Bourse.

There is some scope for negotiated deals if the limit order book is insufficiently deep. A financial intermediary can negotiate a deal directly with a client at a price lying within the current fourchette, provided that the deal is immediately reported to the CAC system as a "cross order". For trades at prices outside the fourchette, the member firm acting as a principal is obliged to fill all central market limit orders displaying a better price than the negotiated price within five minutes.

**b. SEAQ International.**

SEAQ International is the price collection and display system for foreign equity securities operated by London's Stock Exchange. For each foreign equity included in SEAQ International, the system provides an electronic display of bid and ask prices quoted by the market makers registered for that equity.

The French equities in our sample are designated as firm quote securities, which means that during the relevant mandatory quote period (9:30 to 16:00 London time, i.e. 10:30 to 17:00 Paris time in our sample) the registered market makers are obliged to display firm bid and ask prices for no less than the "minimum marketable quantity", also referred to as the Normal Market Size (NMS), a dealing size set by the exchange's Council at about the median transaction size. Market makers are obliged to buy and sell up to that quantity at no worse than their quoted prices. In addition, when a market maker displays a larger quantity of shares than the minimum marketable quantity, his prices must be firm for that quantity. Outside the mandatory quote period, market makers may continue to display prices and quantities under the same rules regarding firmness of prices.

SEAQ International market makers are not allowed to display prices on competing display systems which are better than those displayed on SEAQ International. Market making in French shares is fairly competitive, see Röell (1992): during our sample period, most French equities were covered by at least ten market makers, and usually many more.

## 4. Data description.

In this section we describe the data provided to us by the Paris and London exchanges. We have quote and transaction data from both exchanges for the same period in the summer of 1991.

### a. The Paris Bourse.

The Paris data set is a transcription of all changes in the trading screen information for all shares on the CAC system for 44 trading days in the summer of 1991, starting May 25 and ending July 25. We have available a complete record of the total limit order quantity at the five best prices on both the bid side and the ask side of the market and all transactions. This enables us to reconstruct at every point in time the visible limit order book for each security in the sample, up to the cumulative volume of the observed best limit orders. However, we do not observe the "quantité caché", so the actual limit order book might be deeper than the observed quantities suggest.

Concerning transactions, there is an indicator showing whether the transaction is a "cross" negotiated outside the CAC system. We also have available broker identification codes of the buying and selling parties, which allow us to identify series of small transactions that were initiated by the same person as part of one large transaction. The transaction price per share for such transactions is defined as the quantity weighted average of the price of the small transactions that together make up the larger one.

In this paper we shall concentrate on ten major French stocks, listed and described in Table 1. Panel A shows the number of transactions and the average price on the Paris Bourse in our sample. For most series there are between five and ten thousand transactions in the data set. Statistics on transaction size and value in Paris are presented in panel B, which shows that (excluding cross transactions) the median transaction value is between FF 50,000 and FF 150,000 (£5,000-£15,000 at the time). The distribution of transaction size is very skewed: the mean is about twice the median, indicating that a few large transactions account for a large share of total turnover. Panel C shows the statistics for the cross transactions that are negotiated off-exchange. The crosses are relatively large: their median value is about 2 to 5 times as large as the median value of regular transactions, and the mean value is up to 10 times the mean value of regular transactions. Although there are relatively few crosses (between 2 and 5 % of the total number of transactions) they account for a large share of total trading volume.

We now turn to the distribution of transactions by time of day. Figure 2 depicts the distribution of trades in ACCOR shares in Paris. In this figure the trading day is split up into seven hours, ranging from 10:00am to 17:00pm (the period of continuous trading) and the number of transactions in each interval for all days in the sample is counted.

*place figure 2 here*

There is a clear lunch break effect between 1pm and 2pm. More interestingly, most trading takes place in the hour after opening and the hour before closing. The graphs for the other series show very similar patterns. Hence, our data match the U-shaped trading pattern found by McInish and Wood (1990) for the Toronto Stock Exchange, by Niemeyer and Sandas (1992) for the Stockholm exchange and by Kleidon and Werner (1992) for the S&P 100 firms on the NYSE. In contrast, Schmidt and Iversen (1991) found an inverted U-shaped trading pattern with the trading sessions of the German MATIS.

**b. SEAQ International.**

The data from the London exchange cover May to July 1991. Table 1, panel D shows some statistics for the ten stocks under consideration. There are fewer transactions in London than in Paris, but the median size of the transactions is much larger. The NMS is generally valued at about FF 1 million (£100,000), a rather large transaction by Paris standards. The average value of transactions in London is about 10 times the average value of regular transactions in Paris, and still somewhat larger than the mean value of crosses in Paris.

Percentiles of the distribution of trade size in London and Paris are given in Table 2. The results indicate that there are many very large transactions in London compared with Paris. For example, the 99$^{th}$ percentile in Paris is in the order of magnitude of one NMS, whereas the 90$^{th}$ percentile in London already is about 5 times NMS.

## 5. The quoted spread for French equities.

In this section we provide an analysis of the cost of immediacy on the Paris Bourse and SEAQ International. The cost of an urgent transaction is determined by the available orders in the limit order book in Paris and by the market maker quotes in London. An important determinant of the cost of immediacy therefore is the quoted spread. For Paris, the average quoted spread is determined as the average difference between bid and ask prices in the limit order book for a certain size. In London, the quoted spread is the difference between the best bid and ask quotes of the market makers. Although prices are negotiable in London, one cannot always count on "within-the-touch" prices for an immediate transaction.

In order to compute the quoted spread in Paris it is necessary to construct the limit order book. We observe all new limit orders, as well as all transactions that fill limit orders and orders that are withdrawn, so that we can recursively build up the order book over the day. There are two problems in constructing the order book, however. First, there is the unobserved "quantité caché", which makes the book deeper than observed. Second, we observe only the limit orders at the five best prices, so that we do not have prices for larger order sizes. In constructing the book we impute the fifth best limit order price for all sizes beyond the range for which the bid and ask price are observed [3].

[3] An alternative procedure is to exclude those observations for which we do not observe the quoted bid and ask price up to the required size. That procedure introduces a selection bias in the spread measure because the five best limit orders add up to a large size only when the market is deep. Hence, that procedure underestimates the spread. Comparison of this alternative procedure with the procediure described in the main text showed that the selection bias is more serious than the bias caused by

Clearly this biases the average quoted spread downwards. On the other hand, ignoring the quantité caché biases the average upwards. The net effect of these data imperfections on the estimates of the quoted spread is indeterminate.

A first way to measure the average quoted spread is by a simple **calendar time average** of the observed spreads between bid and ask prices:

$$(1) \qquad S_C^m(z) = \sum_{i=1}^{N} (t_{i+1}-t_i)\Big(A[t_i,z]-B[t_i,z]\Big) \Big/ \sum_{i=1}^{N} (t_{i+1}-t_i)$$

where $t_i$ is the calendar time index (in seconds) of the $i^{th}$ change in the limit order book, $A[t_i,z]$ denotes the marginal ask price at time $t_i$ for an order of size z, $B[t_i,z]$ denotes the corresponding bid price, and N is the number of quote changes in the sample period. Thus, each quote is weighted in proportion to the calendar time for which it appears on the trading screens (that is, the time until the next quote change). This measure computes the quoted price for the marginal unit only. The *average* spread for a hypothetical transaction of size z is obtained by averaging the marginal spread over all smaller sizes:

$$(2) \qquad S_C(z) = \sum_{t=1}^{N} (t_{i+1}-t_i) \sum_{y=1}^{z} z^{-1}\Big(A[t_i,y]-B[t_i,y]\Big) \Big/ \sum_{t=1}^{N} (t_{i+1}-t_i)$$

For London, the average quoted spread or "market touch" can be derived directly from the market maker's quotes. The London quotes apply to all sizes smaller than or equal to NMS.

Table 3, panel A shows the average quoted spread in London and Paris for sizes up to NMS. The averages are taken over the period of continuous trading in Paris and the mandatory quote period in London. All quotes outside normal trading hours are ignored. There is no point in going beyond NMS because the data on the limit order book in Paris for larger sizes are very sparse and therefore spread estimates for large sizes are unreliable. Table 3, panel B reports the percentage of bid or ask quotes for a particular size that were imputed. The table reveals that the calendar time average of the spread, $S_C(z)$, in Paris is very small for small sizes, between 0.15-0.4%, and rises for larger sizes. For example,

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imputing the fifth best price for unobserved limit orders. See also Anderson and Tychon (1993) who report large selection biases for Belgian stocks.

at NMS the average quoted spread in Paris is between 0.4 and 1.2%. The quoted spread in London (the "touch") is considerably bigger than the quoted spread in Paris for all sizes below NMS. The quoted spread for NMS in Paris is only half of the quoted spread in London. Röell (1992), who had available a number of snapshots of the complete limit order book (including the quantité caché) concludes that the Paris quotes are narrower than the London quotes for order sizes of up to 2 times the NMS, but that for larger sizes the limit order book runs out quickly.

Figure 3 shows a breakup by time of day of the average quoted spread for ACCOR shares. For Paris, the average fourchette (the difference between best bid and ask prices at the smallest lot size) and the quoted spread for 0.1, 0.5 and 1 times NMS are shown. For London, the average "touch" is graphed. The graph shows hourly time intervals, except for the early morning hour which is split in two because the London mandatory quote period starts only at 10.30 am Paris time.

*place figure 3 about here.*

It is clear that the Paris market is very tight, the fourchette is only about 0.25% for the series plotted and doesn't change much over the day, although it is slightly higher in the first half hour, which falls outside the mandatory quote period in London. The quoted spread in London is much larger than the fourchette and also larger than the average quoted spread at NMS in Paris for all times of the day.

A obvious drawback of the above spread measure is that it is a calendar time average, hence periods in which there is hardly any trading are given the same weight as periods of equal length in which trading is heavy. A second estimator conditions on the actually observed trade pattern by taking a **transaction time average** of the difference between bid and ask prices:

$$(3) \qquad S_T(z) = \frac{1}{N} \sum_{i=1}^{N} \sum_{y=1}^{z} \Big( A[t_i, y] - B[t_i, y] \Big) / z$$

where $t_i$ denotes the calendar time index of transaction i. There are no large differences between the calendar time average, $S_C(z)$, and the transaction time average, $S_T(z)$, reported in Table 4. For Paris, the transaction time average quoted spread is slightly smaller than the calendar time average at small sizes, and about the same at NMS. For

London, the calendar time and transaction time average quoted spreads are also very similar. The timing of transactions therefore does not seem to be very sensitive to variations in the spread. This is also evident from a comparison of Figures 2 and 3: trading volume does not seem to be concentrated at times of day when the fourchette is particularly narrow. Trading volume is U-shaped over the day, while the fourchette does not display an inverted U-shape[4]. Therefore, the transaction time average of the quoted spread is rather similar to the calendar time average.

A further refinement of the quoted spread measure is obtained if we condition not only on the pattern of trades over the day, but also on the size of transactions. The results of Biais et al. (1992) suggest that indeed large transactions tend to take place at times when it is relatively cheap to trade large quantities. This is formalised in the third estimator, which averages the quoted spread over times that transactions in a particular size class occurred:

$$(4) \qquad S_Q(\underline{z},\bar{z}) = \sum_{i=1}^{N} I(\underline{z}<z_i\leq\bar{z}) \sum_{y=1}^{z_i}\Big(A[t_i,y]-B[t_i,y]\Big)/z_i \;\Big/\; \sum_{i=1}^{N} I(\underline{z}<z_i\leq\bar{z})$$

where I(.) is an indicator function that takes the value one if the trades size exceeds the lower bound $\underline{z}$ and is smaller than or equal to the upper bound, $\bar{z}$, and takes the value zero otherwise. Table 5 reports the quoted spread $S_Q$ in for several size classes. For Paris, the value of $S_Q$ is usually slightly smaller than the value of $S_T$, indicating that indeed the size of transactions is related to the quoted spread. Like $S_C$ and $S_T$, $S_Q$ is increasing in trade size, nearly doubling from the smallest to the largest size class. For London, only the "touch" was averaged by transaction size class, and these show no clear pattern. In London, therefore, trade size does not seems to depend on the "touch".

In summary, the results of this section show that the quoted spread in Paris is much smaller than the quoted spread in London for small transaction sizes below NMS. However, for larger transactions the quoted spread in Paris rises quickly as the limit order book runs out. Some care has to be taken with these results because the estimates of the quoted spread in Paris ignore the hidden quantities and are marred by the problem that we only have data on the five best limit orders.

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[4] Schmidt and Iversen (1991) did find a clear U shaped spread pattern that was just the opposite of the inverted U shaped trading pattern.

**Section 6. Realised spread.**

In this section we compute spread estimates that are based on transaction prices rather than on quoted prices and will therefore be referred to as measures of the realised spread. The limit order and quote data are used to construct a measure of the mid-price of the stock only. The estimator of the realised spread that we propose is twice the average absolute difference between the quoted mid-price and the transaction price:

$$(5) \qquad S_R(\underline{z},\bar{z}) = 2 \sum_{i=1}^{N} I(\underline{z}<z_i\leq\bar{z})\cdot|p[i]-m[i]| \; / \; \sum_{i=1}^{N} I(\underline{z}<z_i\leq\bar{z})$$

where as before I(.) is the indicator function, p[i] is the actual transaction price (average price paid per share) and m[i] is the mid-price at the time of the $i^{th}$ transaction, defined as the average of the best bid and ask quote (or best buy and sell limit orders) for the smallest possible order size.

For Paris, there are at least two important differences between the realised spread measure and the quoted spread measures of the previous section. The first is that the limit order book data are required only to construct the mid-price. This means that the realised spread estimate in Paris is not affected by the quantité caché and the availability of only the five best limit order prices. The second important difference is that the implicit assumption that the market is equally deep on both sides is dropped. One would expect that large trades are more likely to take place on the deeper side of the market. If so, the realised spread measure should be lower than the quoted spread measure for larger trade sizes. Figure 4 illustrates this point for the Paris situation, where the transaction price is equal to the (average) bid or ask price in the limit order book. The figure shows that the quoted spread at a given size will exceed the realised spread if the trade takes place on the deeper side of the market.

*place figure 4 about here*

In London transactions are routinely priced within the touch, and therefore the quoted spread will be an overestimate of the realised cost of trading.

The realised spread is the measure that is relevant for a patient trader, who can wait for the best moment to trade, but it is probably not a good indicator of the cost of immediacy. First of all, an impatient trader cannot choose the deeper side of the market. Moreover, in London transaction prices for larger deals are generally negotiated within the touch, and the same is true for Paris cross transactions. This means that the realised spread, which measures the average cost of actual transactions, understates the cost of a hypothetical urgent transaction, where the trader cannot rely on negotiating within the quote prices.

The estimates $S_R$ of the average realised spread are reported in Table 6. In calculating the estimates we excluded all transactions outside the continuous trading (Paris) or the mandatory quote period (London) because outside normal trading hours the mid-quote is not a reliable proxy for the market consensus valuation of the stock.

Table 6, panel A shows the average realised spread in Paris. All transactions within the continuous trading period were used, including "crosses". The table clearly shows that the realised spread in Paris does not increase with trade size. In contrast, in the previous section we have seen that the quoted spread increases with size. The dependence of the quoted and realised spread in Paris on trade size is illustrated in Figure 4, where a quoted spread estimate ($S_T$) and the realised spread estimate ($S_R$) for the ACCOR series are graphed.

Estimates of the average realised spread in London are reported in panel B. The most striking result here is that the realised spread in London seems to be *declining* in trade size. This effect was also observed by Breedon (1992), Tonks and Snell (1992) and Röell (1992). A comparison of Table 4 and Table 6 shows that in London the average realised spread for transactions smaller than NMS is generally larger than the quoted spread. This seems impossible: the rules of SEAQ International oblige market makers to stand firm at the best quoted price for transactions smaller than NMS. A likely explanation for this anomaly is a *timing bias*. Unlike in Paris, the reported time of transactions in London can be inaccurate and the market maker quotes are not updated very frequently so that they may well be stale. In the Appendix we show that this biases our realised spread measure upwards, because the market mid-price may have moved between the actual transaction time and the reported time. In Table 6, panel C we report bias-adjusted realised spreads for London.

The observation that realised spreads do not increase with trade size is important because it is not in line with the inventory control and adverse selection models of the spread discussed in section 2, or with the assumption that order processing cost is fixed per share. Constant processing costs per transaction, and therefore declining per share, could be an explanation for the empirical result that the cost *per share* is smaller for large trade sizes. We return to this issue in section 7 where we estimate a parametric model for the dependence of the realised spread on trade size.

Comparing the realised spread in London with the realised spread in Paris, it appears that the London realised spread is considerably higher than the Paris one, so Paris seems to be cheaper. There are a number of caveats. First, there are few transactions larger than NMS in Paris (indeed most of those are cross transactions) while in London roughly half the transactions exceed NMS. Second, the full cost of trading also includes taxes and other explicit transaction costs. We return to this point in the concluding section.

## 7. Model-based estimates of the realised bid-ask spread

The spread measures of the previous section relied on data from the limit order book or quotes to construct an estimate of the unobserved consensus value of the stock. The estimators proposed in this section do not require such a proxy, and are therefore less sensitive to the problems encountered in section 6. In particular, timing bias is not a problem. The price paid for this improvement is the need to make some parametric assumptions about the process that generates prices. We build some simple models to estimate the realised spread and to estimate the dependence of the spread on trade size.

The simplest model that we consider is based on the work of Stoll (1989) and George, Kaul and Nimalendran (1991). In their models it is assumed that the transaction price, $p_t$ is equal to the (unobserved) mid-price prior to the trade, $y_t$, plus or minus one-half times the total spread, S. We allow for an error term, $u_t$, in the price equation, that picks up various effects on the transactions price that are not captured by the mid-price and the transactions type, such as price discreteness and trade size. Thus, the price equation is

(6) $$p_t = y_t + (S/2)Q_t + u_t$$

where $Q_t$ indicates whether the transaction is initiated by the buyer (+1) or the seller (-1). The variable $Q_t$ will henceforth be referred to as the "sign" of the trade. The mid-price $y_t$ in this equation is not observed, so we cannot estimate this model directly. In order to obtain an equation in observables only, we first difference (6) and make assumptions on the dynamics of the mid-price.

If there is asymmetric information between market makers and other traders, the market maker will revise his mid-price after a trade has occurred. Moreover, for inventory control reasons he will also change his quotes because the trade changes his inventory. Let $(1-\pi)$ be the fraction of the spread attributable to asymmetric information and inventory control, and $\pi$ the fraction attributable to processing cost, then the revised mid-price immediately after the transaction is

(7) $$m_t = y_t + (1-\pi)(S/2)Q_t$$

Finally, between two trades public information on the stock's value may come in so that the new mid-price prior to the subsequent trade is a revision of $m_t$

(8) $$y_t = \beta_0 + m_{t-1} + e_t$$

where where $\beta_0$ is the average and $e_t$ is the unexpected mid-price return resulting from public information between the two transactions. Under these assumptions the transaction price returns can be expressed as

(9) $$\Delta p_t = \beta_0 + (S/2)Q_t - \pi(S/2)Q_{t-1} + e_t + \Delta u_t$$

This is an equation in observables ($\Delta p_t$ and $Q_t$) and random error terms only. It is a valid regression model under the additional assumption that $Q_t$ is exogenous, so that $Q_t$ and $(e_t, u_t)$ are uncorrelated at all lags[5].

[5] If the pricing error $u_t$ is due to rounding, $Q_t$ and $u_t$ might be correlated. In that case, an instrumental variables technique could be used to estimate (9). We ignore this point in the estimation.

Under this assumption, $\pi$ and S can be estimated consistently by least squares, where the coefficient of $Q_t$ is half the realised bid-ask spread.

If we furthermore assume that $(e_t, u_t)$ is a joint white noise process, the regression has a first order moving average error structure. Moreover, the innovations in the true price are probably heteroskedastic, as suggested by the results of Hausman, Lo and MacKinlay (1992). One of the reasons for the heteroskedasticity is the difference in the calendar time span between transactions. However, there may be other factors that cause a time-varying conditional variance. Instead of specifying the form of heteroskedasticity, we estimate by OLS, which under the stated assumptions gives consistent point estimates, and compute heteroskedasticity and autocorrelation consistent (HAC) standard errors using the method proposed by Newey and West (1987).

In the literature several spread estimators have been developed for cases where no data on sign or size of the transactions are available. Roll (1984) proposes an estimator of the spread based on the first order autocovariance of the returns, $\gamma_{\Delta p}=E(\Delta p_t \Delta p_{t-1})$. In the simple model (9), Roll's estimator is consistent only under some very restrictive assumptions: no serial correlation in expected returns; no error term in the price equation ($\sigma_u^2=0$); no serial correlation in the transaction type ($E[Q_t Q_{t-1}] = 0$); and no asymmetric information or inventory control effects ($\pi=1$). Under these assumptions, the first order autocovariance of the returns is equal to $-(S/2)^2$, and Roll's estimator of the spread is given by

$$(10) \qquad \hat{S} = 2\sqrt{-\gamma_{\Delta p}}$$

Roll's estimator is biased downward if there is positive serial correlation in the transaction sign $Q_t$ (i.e. if transactions at the bid tend to be followed by further transaction at the bid and similarly for the ask). Choi, Salandro and Shastri (1988) adjust to Roll's estimator for serial correlation in $Q_t$, retaining the assumptions that there are no pricing errors ($\sigma_u^2=0$), no serial correlation in mid-price returns and no asymmetric information or inventory control effects ($\pi=1$). Choi et al. (1988) assume also that $Q_t$ follows a first order Markov process. Under these assumptions, the first order autocovariance of the returns is

$$(11) \qquad \gamma_{\Delta p}(1) = -(S/2)^2(1-\gamma_Q)^2$$

and from this expression the CSS estimator follows directly

(12) $\hat{S} = 2\sqrt{-\gamma_{\Delta p}(1)}/(1-\gamma_Q)$

where $\gamma_Q$ is the first order autocovariance of the transaction sign. This estimator takes the form of a simple correction by a factor $1/(1-\gamma_Q)$ of Roll's estimator.

The details of the estimation procedures are as follows. In line with the previous sections, we exclude all transactions outside the mandatory quote period (London) and the period of continuous trading (Paris). We include all other transactions, including the crosses in Paris. We take logarithms of the transaction prices and multiply those by 100 to obtain estimates of the percentage spread. The estimation equation is thus specified in returns, but only within-day returns were used because overnight returns are unlikely to follow the same process as intra-day returns, see Hausman et al. (1992). The classification of the trade as buyer initiated or seller initiated is done by comparing the transaction price with the mid-price. If the transaction price exceeds the mid-price, the trade is classified as buyer initiated ($Q_t$=1), and if the transaction price is lower than the mid-price the trade is classified as seller initiated ($Q_t$=-1). If the transaction price is exactly at the mid-price, the trade is not classified and the value 0 is assigned to $Q_t$. This procedure is exact for the Paris transactions the were executed through the CAC system, but for the crosses and the London data there might be some incorrect classifications due to reporting lags.

The model-based estimates of the realised spread in London and Paris are given in Table 7. Like our previous results in section 6, the model based estimates suggest that the realised spread in London substantially exceeds the realised spread in Paris. Comparing the average realised spread $S_R$ in Table 5 with the regression-based estimated spread, the latter is smaller for all stocks, suggesting that the average of best bid and ask quotes is not a good approximation of the unobserved true mid-price. This discrepancy is particularly striking in the case of the London data. There, because the market maker quotes are updated relatively infrequently, our data on the quoted mid-price may be a particularly inappropriate basis for computing realised spreads.

In addition to the effect of the *sign* of the trade (buyer or seller initiated) the *size* of the trade may also be an important determinant of the price. The microstructure theories discussed in Section 1 predict that due to asymmetric information and inventory control the spread will be an increasing function of trade size. To estimate the effect of size we extend model (6) in the spirit of Glosten and Harris (1987) and Madhavan and Smidt (1992). The price equation is extended with a linear term in the size of the transaction. In section 5 we found some evidence for a fixed processing cost per transaction that would generate a decreasing processing cost for large trade sizes. This effect is captured by adding the inverse of trade size to the price equation. Together, we add two additional variables to (6) and obtain

$$(6') \qquad p_t = y_t + (S/2)Q_t + \alpha z_t + \gamma z_t^{-1} + u_t$$

where $z_t$ is the signed trade size. First differencing (6') we obtain the equivalent of regression equation (9) but now including current and lagged trade size and the inverse of size as regressors[6]:

$$(9') \qquad \Delta p_t = \beta_0 + (S/2)Q_t + \alpha z_t + \gamma z_t^{-1} + \text{lagged terms} + e_t + \Delta u_t$$

In order to reduce the influence of very large transactions (outliers) on the estimates, we "censor" large trade sizes. For Paris, we pick the threshold at 2 NMS, which is about the 99.5% quantile[7]. The estimates are presented in Table 8, panel A. In London many more trades would be censored at 2 NMS, between 10 and 25 percent. We present estimates with the 2 NMS threshold in Table 8, panel B, and with a threshold of 5 NMS, which corresponds to the 95% quantile, in Table 8, panel C.

Estimates of the trade size augmented model are given in Table 8. For Paris, the coefficients of the size and the inverted size are small but significant for most cases. The Wald test of joint significance of the size and inverted size parameters is larger than its 5% critical value (5.99) for all series except one. On the other hand, for London less evidence for a trade size effect on the realised spread is found.

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[6] We do not impose restrictions on the coefficients of the lagged regressors. We do not want to run the risk of imposing invalid restrictions and thus misspecifying the model. Not imposing such restrictions does not affect the consistency of the estimators of the parameters of interest (S, $\alpha$ and $\gamma$).

[7] Hausman et al. (1992) also censor trade size at the 99.5% quantile.

The size effect is jointly significant only for BSN (BN) and Axa-Midi (CS). Partly this may reflect the smaller sample size of the London series.

Hasbrouck (1991) uses a more extensive model to assess the dynamic effects of transactions. More specifically, in his model the price effect of a transaction can last for more periods than the one period assumed implicitly in equation (7). Our regression based spread estimator can be extended easily to include more complex dynamics by adding lagged regressors to the regression models (9) and (9'). The parameters of interest are the coefficient of the current sign, trade size and inverted size, whereas the coefficients of the lagged variables are merely nuisance parameters. The parameter estimates using four (rather than one) lags of trade sign show only minor differences with the reported estimates and the conclusions do not change.

## 8. Summary and conclusions.

In this paper we compare the cost of trading French shares in Paris and in London. The estimates of the average quoted spread, which reflect the cost of immediate trading, suggest that the Paris Bourse is cheaper than London's SEAQ International for small transactions, roughly up to the normal market size. For larger sizes, however, the Paris limit order book often does not contain enough limit orders and the average quoted spread rises steeply, hence the Paris market is not very deep. The London market with its competing market makers provides more liquidity at larger trade sizes. The quoted spread in London for small sizes is however relatively large.

The estimates of the realised spread show a slightly different picture. It appears that the few large transactions that are executed in Paris (often "crosses") have a fairly low spread, lower than the spread in London. Our regression-based estimates suggest that at trade sizes of twice NMS the realised spread is still considerably lower than in London. On the whole, we conclude that if the trader is patient and prepared to wait for counterparties, transaction cost for large sizes can be fairly low in Paris compared with SEAQ-International.

The full cost of trading on either exchange includes taxes and other levies as well. Information on such explicit transaction costs are presented in London Stock Exchange (1992a). The commissions and fees in London are on average 0.14% of the transaction value and in Paris about 0.5% (these percentages are for a large transaction of 1 million ECU, roughly FF 7 million). Thus explicit transaction costs are higher in Paris for large transactions. One reason is that in London many large deals are done on a "net" basis, i.e. commissions are included in the price.

A theoretically interesting result is that the realised spread is virtually flat in trade size. Hence, we do not confirm the predictions of the pure inventory control or adverse selection microstructure theory (that the spread should be an increasing function of trade size) except for the quoted spread (where the spread increases with trade size by construction). Our estimates of a simple model for transaction prices confirm this result and indicate mild support for the hypothesis that part of the order processing cost is fixed per transaction rather than per share.

**Appendix. Adjustment for bias due to misreported transaction times.**

As explained in the main text, the $S_R(z)$ estimates of the average realised spread in London for transaction sizes smaller than NMS are sometimes larger than the average quoted spread, $S_Q(z)$. This seems impossible, because the true realised spread has to be smaller than the quoted spread since market makers are obliged to provide the best quoted price for transactions smaller than NMS. This anomaly is probably explained by a timing bias due to misreported transaction times in London. In this appendix we propose a model for the impact of timing bias on estimates of the realised spread that can also be used to correct the $S_R$ estimates for this bias.

Let S(z) be the average realised spread (as a function of size) that we would want to estimate. Suppose that the transaction is reported late, say at time t+k. In general the midprice recorded at time t+k is different from the mid-price at time t, so that in fact we estimate

$$\text{(A.1)} \qquad S_R(z) = E|S(z) + x_t|$$

where $x_t$ denotes the change in the mid-price in the interval between the time that the transaction actually took place and when it was reported. Suppose that $x_t$ is normally distributed with mean 0 and variance $\sigma^2$. Then we can apply the expressions in Amemiya (1985, p. 367), who shows that for a normally distributed variable $y \sim N(\mu,\sigma^2)$, the conditional expectation of y, given y>0 is

$$\text{(A.2)} \qquad E(y|y>0) = \mu + \sigma\cdot\frac{\phi(\mu/\sigma)}{\Phi(\mu/\sigma)}$$

where $\phi$ and $\Phi$ are the standard normal density and the cumulative standard normal distribution, respectively. Using this result the expectation of the absolute value in (A.1) can be written as

$$\text{(A.3)} \qquad S_R(z) = S(z)(2\Phi(a)-1) + 2\sigma\phi(a), \qquad a \equiv S(z)/\sigma$$

Figure 5 shows that the realised spread measure $S_R(z)$ is always larger than the S(z) that we want to estimate. The estimates reported in Table 6B will therefore in general overstate the true spread if $\sigma$>0.

We now turn to a method to correct for timing bias. Fundamental to the correction is the assumption that the variance of the timing error, $\sigma^2$, is independent of the transaction size. Moreover, it is known that most small transactions are at the touch (London Stock Exchange (1992b)). Thus, for small transactions the quoted spread and the true realised spread should be the same: $S(z)=S_Q(z)$. In Table 5, panel B the average quoted spread by size class can be found. The first step in the correction procedure is to solve (A.3) for $\sigma$, given $S(z)=S_Q(z)$ in the smallest size class. The second step is to compute S(z) for all other size classes from (A.3), given the estimate of $\sigma$ obtained in the first step and the estimated values of $S_R(z)$ from Table 6, panel B.

There is one problem with the procedure outlined just before. If we take the smallest size class to be the class from 0 to 0.1 NMS, we estimate quite a large $\sigma$. In fact, the estimated $\sigma$ is so large that (A.3) sometimes does not have a solution. Therefore, we choose to base the estimate of $\sigma$ on the average quoted spread for all transactions up to 1 NMS. Because quotes are firm up to 1 NMS, the quoted spread is an upper bound for the realised spread for this size class. Therefore, the estimated $\sigma$ from solving (A.3) given $S(z)=S_Q(0,1)$ gives a lower bound for the true timing error. This estimate of $\sigma$ will therefore yield a conservative correction of the realised spread for other size classes.

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**Table 1 Descriptive statistics of transactions data**

A. General

| Firm | full name | average price | minimum lot size | NMS |
|---|---|---|---|---|
| AC | Accor | 771 | 50 | 2000 |
| AQ | Elf-Aquitaine | 358 | 100 | 5000 |
| BN | BSN | 889 | 10 | 2500 |
| CA | Carrefour | 1919 | 5 | 500 |
| CS | Axa-Midi | 989 | 5 | 1000 |
| EX | Generale des Eaux | 2518 | 10 | 500 |
| OR | l'Oreal | 584 | 10 | 2500 |
| RI | Pernod-Ricard | 1162 | 25 | 1000 |
| SE | Schneider | 685 | 25 | 2000 |
| UAP | Un. Ass. de Paris | 538 | 25 | 2000 |

Notes: price is average transaction price in FF; lot size is minimum transaction size in Paris; "NMS" is Normal Market Size in London (both as a number of shares).

B. Paris transactions (excluding crosses)

| | size | | value | | N |
|---|---|---|---|---|---|
| | median | mean | median | mean | |
| AC | 150 | 258 | 114 | 197 | 5255 |
| AQ | 500 | 860 | 179 | 303 | 9855 |
| BN | 70 | 205 | 62 | 182 | 10728 |
| CA | 50 | 87 | 90 | 164 | 9943 |
| CS | 60 | 127 | 62 | 120 | 6482 |
| EX | 50 | 102 | 129 | 247 | 9585 |
| OR | 110 | 248 | 64 | 145 | 6813 |
| RI | 75 | 113 | 84 | 131 | 3626 |
| SE | 100 | 200 | 68 | 134 | 4329 |
| UAP | 250 | 422 | 134 | 222 | 5206 |

C. Paris transactions (crosses only)

| | size | | value | | N |
|---|---|---|---|---|---|
| | median | mean | median | mean | |
| AC | 500 | 3339 | 384 | 2531 | 148 |
| AQ | 500 | 4558 | 183 | 1607 | 598 |
| BN | 300 | 1170 | 266 | 1039 | 378 |
| CA | 200 | 670 | 366 | 1268 | 307 |
| CS | 100 | 2391 | 89 | 2266 | 221 |
| EX | 150 | 867 | 366 | 2070 | 475 |
| OR | 200 | 1176 | 116 | 694 | 271 |
| RI | 300 | 717 | 327 | 838 | 123 |
| SE | 600 | 1314 | 388 | 876 | 183 |
| UAP | 100 | 1378 | 54 | 728 | 402 |

D. London transactions

| | size | | value | | N |
|---|---|---|---|---|---|
| | median | mean | median | mean | |
| AC | 1400 | 2653 | 1094 | 2049 | 393 |
| AQ | 4000 | 8330 | 1473 | 2966 | 1168 |
| BN | 1000 | 1671 | 862 | 1487 | 853 |
| CA | 500 | 1199 | 950 | 2293 | 771 |
| CS | 800 | 1947 | 758 | 1858 | 291 |
| EX | 450 | 1038 | 1106 | 2545 | 905 |
| OR | 1250 | 2878 | 732 | 1691 | 449 |
| RI | 525 | 1260 | 630 | 1479 | 210 |
| SE | 1625 | 2841 | 1100 | 1970 | 204 |
| UAP | 3000 | 4503 | 1532 | 2406 | 518 |

General notes to panels B, C and D:
Size is measured in number of shares;
Value is measured in units of FF 1000;
N is the number of transactions.

**Table 2 Percentiles of transaction size distribution**

A. Paris excluding crosses

| | 90 | 95 | 99 | 99.5 | 99.9 |
|---|---|---|---|---|---|
| AC | 0.25 | 0.45 | 1.00 | 1.0 | 1.3 |
| AQ | 0.38 | 0.48 | 1.00 | 1.0 | 3.2 |
| BN | 0.20 | 0.30 | 0.60 | 0.8 | 1.7 |
| CA | 0.30 | 0.40 | 1.00 | 1.5 | 3.0 |
| CS | 0.27 | 0.40 | 0.94 | 1.1 | 3.5 |
| EX | 0.40 | 0.60 | 1.16 | 2.0 | 3.7 |
| OR | 0.22 | 0.31 | 0.68 | 0.9 | 1.5 |
| RI | 0.23 | 0.33 | 0.85 | 1.0 | 1.5 |
| SE | 0.25 | 0.38 | 0.70 | 0.9 | 1.5 |
| UAP | 0.41 | 0.50 | 1.50 | 2.5 | 5.0 |

B. Paris crosses only

| | 90 | 95 | 99 | 99.5 | 99.9 |
|---|---|---|---|---|---|
| AC | 1.5 | 2.5 | 3.7 | 12.4 | 12.4 |
| AQ | 2.4 | 5.7 | 20.0 | 20.0 | 20.0 |
| BN | 1.6 | 2.0 | 2.8 | 4.0 | 4.0 |
| CA | 2.2 | 4.0 | 10.0 | 10.0 | 10.0 |
| CS | 3.3 | 4.0 | 5.5 | 10.0 | 10.0 |
| EX | 4.0 | 6.0 | 20.0 | 24.4 | 91.1 |
| OR | 1.7 | 2.0 | 2.9 | 4.0 | 4.0 |
| RI | 2.0 | 2.0 | 3.0 | 3.6 | 3.6 |
| SE | 1.5 | 2.0 | 4.0 | 5.0 | 5.0 |
| UAP | 2.5 | 5.0 | 5.5 | 6.6 | 8.8 |

C. Paris all transactions

| | 90 | 95 | 99 | 99.5 | 99.9 |
|---|---|---|---|---|---|
| AC | 0.25 | 0.50 | 1.0 | 1.4 | 2.5 |
| AQ | 0.40 | 0.60 | 2.0 | 3.0 | 16.2 |
| BN | 0.21 | 0.36 | 0.8 | 1.2 | 2.4 |
| CA | 0.40 | 0.60 | 1.6 | 2.1 | 5.0 |
| CS | 0.29 | 0.48 | 1.1 | 3.0 | 5.5 |
| EX | 0.46 | 0.80 | 2.0 | 4.0 | 12.0 |
| OR | 0.22 | 0.39 | 1.0 | 1.5 | 2.8 |
| RI | 0.25 | 0.43 | 1.2 | 1.8 | 3.0 |
| SE | 0.25 | 0.48 | 1.0 | 1.5 | 2.5 |
| UAP | 0.50 | 0.75 | 2.5 | 4.6 | 5.5 |

| D. London all transactions | | | | | |
|---|---|---|---|---|---|
| | 90 | 95 | 99 | 99.5 | 99.9 |
| AC | 2.5 | 4.4 | 12.4 | 15.0 | 20.0 |
| AQ | 3.0 | 4.6 | 15.7 | 22.0 | 50.0 |
| BN | 1.6 | 2.4 | 5.0 | 6.0 | 12.0 |
| CA | 5.0 | 8.0 | 30.0 | 40.0 | 51.0 |
| CS | 4.0 | 6.0 | 13.3 | 21.6 | 32.8 |
| EX | 4.2 | 7.5 | 18.0 | 26.7 | 72.8 |
| OR | 2.2 | 3.4 | 9.8 | 18.8 | 20.2 |
| RI | 3.3 | 5.1 | 8.8 | 8.8 | 9.1 |
| SE | 3.8 | 5.2 | 9.7 | 10.0 | 10.7 |
| UAP | 5.0 | 7.5 | 12.5 | 15.5 | 21.2 |

**Table 3 Calendar time average quoted spread ($S_C$)**

| | Paris | | | | London |
|---|---|---|---|---|---|
| | minimum | 0.1 | 0.5 | 1.0 | 0-1 |
| AC | 0.247 | 0.277 | 0.444 | 0.646 | 1.268 |
| AQ | 0.187 | 0.206 | 0.300 | 0.409 | 0.977 |
| BN | 0.176 | 0.218 | 0.359 | 0.519 | 0.852 |
| CA | 0.216 | 0.245 | 0.372 | 0.504 | 1.346 |
| CS | 0.363 | 0.427 | 0.655 | 0.898 | 2.309 |
| EX | 0.135 | 0.147 | 0.210 | 0.285 | 1.004 |
| OR | 0.308 | 0.383 | 0.672 | 0.980 | 1.646 |
| RI | 0.367 | 0.413 | 0.650 | 0.912 | 2.106 |
| SE | 0.370 | 0.452 | 0.838 | 1.200 | 2.061 |
| UAP | 0.422 | 0.467 | 0.685 | 0.972 | 1.712 |

**Table 4 Transaction time average quoted spread ($S_T$)**

A. Average percentage quoted spread

| | Paris | | | | London |
|---|---|---|---|---|---|
| | minimum | 0.1 | 0.5 | 1.0 | 0-1 |
| AC | 0.228 | 0.258 | 0.427 | 0.629 | 1.315 |
| AQ | 0.174 | 0.197 | 0.305 | 0.426 | 0.954 |
| BN | 0.174 | 0.219 | 0.368 | 0.531 | 0.852 |
| CA | 0.195 | 0.223 | 0.349 | 0.478 | 1.228 |
| CS | 0.336 | 0.405 | 0.655 | 0.913 | 2.208 |
| EX | 0.130 | 0.143 | 0.211 | 0.290 | 1.006 |
| OR | 0.293 | 0.369 | 0.673 | 0.987 | 1.624 |
| RI | 0.339 | 0.394 | 0.649 | 0.921 | 2.159 |
| SE | 0.334 | 0.414 | 0.782 | 1.150 | 2.025 |
| UAP | 0.390 | 0.436 | 0.665 | 0.959 | 1.685 |

B. percentage missing quotes in Paris

| | minimum | 0.1 | 0.5 | 1.0 |
|---|---|---|---|---|
| AC | 0 | 0 | 0 | 18 |
| AQ | 0 | 0 | 2 | 45 |
| BN | 0 | 0 | 2 | 22 |
| CA | 0 | 0 | 4 | 33 |
| CS | 0 | 0 | 6 | 50 |
| EX | 0 | 0 | 1 | 13 |
| OR | 0 | 0 | 7 | 50 |
| RI | 0 | 0 | 5 | 56 |
| SE | 0 | 0 | 11 | 66 |
| UAP | 0 | 0 | 0 | 17 |

**Table 5 Transaction time average of percentage quoted spread by size class ($S_Q$)**

A. Paris

| size: | ≤0.1 | 0.1-0.5 | 0.5-1.0 | >1.0 | all |
|---|---|---|---|---|---|
| AC | 0.237 | 0.271 | 0.472 | 0.523 | 0.252 |
| AQ | 0.179 | 0.218 | 0.324 | 0.363 | 0.201 |
| BN | 0.182 | 0.228 | 0.422 | 0.555 | 0.197 |
| CA | 0.209 | 0.234 | 0.336 | 0.375 | 0.225 |
| CS | 0.356 | 0.434 | 0.697 | 0.720 | 0.389 |
| EX | 0.134 | 0.154 | 0.225 | 0.263 | 0.148 |
| OR | 0.309 | 0.396 | 0.706 | 0.782 | 0.342 |
| RI | 0.359 | 0.404 | 0.662 | 0.778 | 0.378 |
| SE | 0.356 | 0.449 | 0.831 | 0.993 | 0.386 |
| UAP | 0.421 | 0.465 | 0.716 | 0.925 | 0.453 |
| Number of transactions per size class | | | | | |
| AC | 3704 | 1506 | 121 | 41 | 5331 |
| AQ | 5961 | 3824 | 477 | 117 | 10262 |
| BN | 8138 | 2731 | 152 | 10 | 11021 |
| CA | 5810 | 3670 | 545 | 149 | 10025 |
| CS | 4303 | 2179 | 138 | 40 | 6620 |
| EX | 5039 | 4126 | 611 | 158 | 9776 |
| OR | 4742 | 2173 | 101 | 5 | 7016 |
| RI | 2577 | 1061 | 68 | 24 | 3706 |
| SE | 3331 | 1063 | 77 | 21 | 4471 |
| UAP | 2714 | 2529 | 212 | 70 | 5455 |

B. London

| size: | ≤0.1 | 0.1-0.5 | 0.5-1.0 | 1.0-2.0 | 2.0-5.0 | >5.0 | all |
|---|---|---|---|---|---|---|---|
| AC | 1.325 | 1.346 | 1.336 | 1.241 | 1.301 | 1.345 | 1.315 |
| AQ | 0.995 | 0.953 | 0.961 | 0.960 | 0.897 | 0.972 | 0.954 |
| BN | 0.880 | 0.852 | 0.845 | 0.830 | 0.812 | 0.849 | 0.852 |
| CA | 1.260 | 1.245 | 1.276 | 1.219 | 1.160 | 1.183 | 1.228 |
| CS | 2.418 | 2.206 | 2.285 | 2.132 | 2.054 | 2.166 | 2.208 |
| EX | 0.957 | 0.974 | 1.061 | 1.008 | 0.996 | 1.075 | 1.006 |
| OR | 1.505 | 1.625 | 1.625 | 1.656 | 1.680 | 1.716 | 1.624 |
| RI | 2.208 | 2.130 | 2.253 | 2.201 | 2.095 | 1.909 | 2.159 |
| SE | 2.003 | 2.072 | 1.954 | 1.972 | 2.158 | 1.922 | 2.025 |
| UAP | 1.841 | 1.655 | 1.740 | 1.681 | 1.706 | 1.488 | 1.685 |
| Number of transactions per size class | | | | | | | |
| AC | 48 | 136 | 73 | 83 | 35 | 18 | 393 |
| AQ | 118 | 329 | 274 | 254 | 147 | 46 | 1168 |
| BN | 174 | 373 | 165 | 87 | 46 | 8 | 853 |
| CA | 66 | 192 | 163 | 158 | 125 | 67 | 771 |
| CS | 30 | 84 | 66 | 47 | 45 | 19 | 291 |
| EX | 88 | 267 | 158 | 194 | 131 | 67 | 905 |
| OR | 49 | 177 | 94 | 80 | 37 | 12 | 449 |
| RI | 33 | 71 | 39 | 31 | 24 | 12 | 210 |
| SE | 21 | 66 | 54 | 23 | 28 | 12 | 204 |
| UAP | 18 | 106 | 107 | 89 | 155 | 43 | 518 |

**Table 6 Average percentage realised spread $S_R$**

A. Paris

| size: | ≤0.1 | 0.1-0.5 | 0.5-1.0 | >1.0 | all |
|---|---|---|---|---|---|
| AC | 0.245 | 0.236 | 0.251 | 0.230 | 0.242 |
| AQ | 0.193 | 0.202 | 0.188 | 0.160 | 0.196 |
| BN | 0.187 | 0.188 | 0.201 | 0.181 | 0.187 |
| CA | 0.227 | 0.212 | 0.221 | 0.200 | 0.221 |
| CS | 0.372 | 0.378 | 0.429 | 0.327 | 0.375 |
| EX | 0.151 | 0.154 | 0.158 | 0.145 | 0.153 |
| OR | 0.325 | 0.315 | 0.305 | 0.171 | 0.322 |
| RI | 0.368 | 0.352 | 0.384 | 0.401 | 0.364 |
| SE | 0.362 | 0.359 | 0.311 | 0.178 | 0.361 |
| UAP | 0.458 | 0.416 | 0.434 | 0.381 | 0.438 |

Notes: Transactions only in continuous trading period (10-17). Crosses included in average.

B. London

| size: | ≤0.1 | 0.1-0.5 | 0.5-1.0 | 1.0-2.0 | 2.0-5.0 | >5.0 | all |
|---|---|---|---|---|---|---|---|
| AC | 1.357 | 1.164 | 1.055 | 1.286 | 1.382 | 0.688 | 1.191 |
| AQ | 1.759 | 1.237 | 1.337 | 1.028 | 1.298 | 2.046 | 1.307 |
| BN | 1.495 | 0.993 | 1.072 | 1.296 | 1.364 | 5.273 | 1.202 |
| CA | 1.720 | 1.521 | 1.137 | 1.158 | 1.226 | 1.390 | 1.323 |
| CS | 3.032 | 1.856 | 1.330 | 1.177 | 1.668 | 1.987 | 1.728 |
| EX | 1.452 | 1.105 | 1.067 | 1.035 | 1.128 | 1.478 | 1.148 |
| OR | 2.098 | 1.166 | 1.456 | 1.422 | 1.870 | 1.739 | 1.447 |
| RI | 2.146 | 1.192 | 0.980 | 1.783 | 1.410 | 1.101 | 1.409 |
| SE | 1.374 | 1.695 | 1.574 | 1.744 | 1.025 | 1.008 | 1.503 |
| UAP | 1.664 | 1.242 | 1.150 | 1.429 | 1.371 | 1.295 | 1.313 |

Notes: Transactions only in mandatory quote period (9.30-16).

C. London, bias corrected

| | $S_Q$ | $S_R$ | Realised, bias corrected | | | | |
|---|---|---|---|---|---|---|---|
| NMS | ≤1.0 | ≤1.0 | ≤1.0 | 1.0-2.0 | 2.0-5.0 | >5.0 | all |
| AC | 1.339 | 1.169 | 1.169 | 1.286 | 1.382 | 0.688 | 1.191 |
| AQ | 0.963 | 1.360 | 0.963 | 1.028 | 0.835 | 1.947 | 0.855 |
| BN | 0.857 | 1.134 | 0.857 | 1.115 | 1.211 | 5.273 | 0.972 |
| CA | 1.260 | 1.404 | 1.260 | 0.889 | 1.001 | 1.241 | 1.147 |
| CS | 2.270 | 1.859 | 1.859 | 1.177 | 1.668 | 1.987 | 1.728 |
| EX | 0.998 | 1.153 | 0.998 | 0.816 | 0.962 | 1.414 | 0.991 |
| OR | 1.607 | 1.394 | 1.394 | 1.422 | 1.870 | 1.739 | 1.447 |
| RI | 2.182 | 1.354 | 1.354 | 1.783 | 1.410 | 1.101 | 1.409 |
| SE | 2.016 | 1.601 | 1.601 | 1.744 | 1.025 | 1.008 | 1.503 |
| UAP | 1.709 | 1.232 | 1.232 | 1.429 | 1.371 | 1.295 | 1.313 |

Note: Transactions only in mandatory quote period (9.30-16)
Bias correction described in Appendix.

**Table 7 Model based estimates of realised spread**

model: $\Delta p_t = \beta_0 + \beta_1 Q_t + \beta_2 Q_{t-1} + \varepsilon_t$

A. Paris

| | Roll | CSS | $2\beta_1$ |
|---|---|---|---|
| AC | 0.178 | 0.259 | 0.214 |
| | | | (47.855) |
| AQ | 0.143 | 0.196 | 0.167 |
| | | | (65.196) |
| BN | 0.147 | 0.182 | 0.169 |
| | | | (86.701) |
| CA | 0.154 | 0.241 | 0.179 |
| | | | (56.733) |
| CS | 0.274 | 0.359 | 0.330 |
| | | | (48.947) |
| EX | 0.109 | 0.157 | 0.123 |
| | | | (58.959) |
| OR | 0.246 | 0.328 | 0.285 |
| | | | (59.805) |
| RI | 0.248 | 0.336 | 0.305 |
| | | | (35.139) |
| SE | 0.253 | 0.371 | 0.316 |
| | | | (41.965) |
| UAP | 0.349 | 0.521 | 0.404 |
| | | | (49.420) |

B. London

| | Roll | CSS | $2\beta_1$ |
|---|---|---|---|
| AC | 1.075 | 1.802 | 0.890 |
| | | | (10.214) |
| AQ | 1.136 | 2.040 | 1.290 |
| | | | (13.740) |
| BN | 0.679 | 1.354 | 0.781 |
| | | | (12.666) |
| CA | 1.003 | 1.991 | 0.809 |
| | | | (11.010) |
| CS | 2.152 | 3.997 | 1.131 |
| | | | (6.961) |
| EX | 0.954 | 1.717 | 0.771 |
| | | | (12.077) |
| OR | 0.849 | 1.401 | 0.992 |
| | | | (11.418) |
| RI | 0.748 | 1.284 | 0.819 |
| | | | (6.765) |
| SE | 2.071 | 4.186 | 1.901 |
| | | | (4.396) |
| UAP | 0.902 | 1.444 | 0.842 |
| | | | (11.575) |

Notes: Heteroskedasticity and autocorrelation consistent t-ratios below parameter estimates; Further notes see Table 3.

**Table 8 Model based estimates of realised spread**

model: $\Delta p_t = \beta_0 + \delta Q_t + \alpha z_t + \gamma / z_t + \text{lags} + \varepsilon_t$

A. Paris (size censored at 2 NMS)

| | $2\delta$ | $2\alpha$ | $2\gamma$ | Wald | N |
|---|---|---|---|---|---|
| AC | 0.181 | 0.059 | 2.399 | 18.513 | 5342 |
| | (23.338) | (2.870) | (4.279) | | |
| AQ | 0.145 | 0.014 | 3.979 | 52.172 | 10364 |
| | (36.234) | (1.745) | (6.944) | | |
| BN | 0.158 | 0.038 | 0.184 | 21.349 | 11012 |
| | (58.359) | (3.665) | (4.020) | | |
| CA | 0.172 | 0.012 | 0.107 | 8.364 | 10157 |
| | (44.577) | (0.527) | (2.878) | | |
| CS | 0.302 | 0.073 | 0.298 | 11.630 | 6608 |
| | (30.145) | (1.985) | (3.385) | | |
| EX | 0.115 | 0.017 | 0.168 | 15.473 | 9970 |
| | (41.387) | (1.163) | (3.931) | | |
| OR | 0.257 | 0.047 | 0.854 | 37.772 | 6996 |
| | (42.213) | (2.446) | (6.137) | | |
| RI | 0.283 | 0.008 | 0.965 | 4.947 | 3660 |
| | (20.015) | (0.226) | (2.077) | | |
| SE | 0.313 | -0.056 | 0.561 | 9.337 | 4426 |
| | (29.231) | (-2.053) | (1.270) | | |
| UAP | 0.348 | -0.000 | 3.764 | 77.760 | 5515 |
| | (30.332) | (-0.021) | (7.981) | | |

Notes: size censored at 2 NMS;

HAC t-ratios below parameter estimates;

Wald: $\chi^2(2)$ test of joint significance of $\alpha$ and $\gamma$;

N: number of observations.

**Estimated percentage realised spread**

| size: | 0.1 | 0.5 | 1.0 | 2.0 |
|---|---|---|---|---|
| AC | 0.199 | 0.213 | 0.241 | 0.299 |
| AQ | 0.155 | 0.154 | 0.160 | 0.173 |
| BN | 0.162 | 0.177 | 0.196 | 0.234 |
| CA | 0.173 | 0.178 | 0.184 | 0.196 |
| CS | 0.313 | 0.340 | 0.376 | 0.449 |
| EX | 0.117 | 0.123 | 0.132 | 0.148 |
| OR | 0.265 | 0.281 | 0.305 | 0.352 |
| RI | 0.293 | 0.289 | 0.292 | 0.299 |
| SE | 0.311 | 0.286 | 0.257 | 0.201 |
| UAP | 0.367 | 0.351 | 0.349 | 0.348 |

**Table 8 Model based estimates of realised spread**

model: $\Delta p_t = \beta_0 + \delta Q_t + \alpha z_t + \gamma / z_t + \text{lages} + \varepsilon_t$

B. London (size censored at 2 NMS)

| | $2\delta$ | $2\alpha$ | $2\gamma$ | Wald | nobs |
|---|---|---|---|---|---|
| AC | 1.021 | -0.145 | -8.390 | 4.130 | 298 |
| | (6.661) | (-1.222) | (-1.982) | | |
| AQ | 1.380 | -0.089 | -0.687 | 1.306 | 1072 |
| | (11.041) | (-1.115) | (-0.117) | | |
| BN | 0.618 | 0.170 | 14.232 | 32.066 | 765 |
| | (7.336) | (1.304) | (5.659) | | |
| CA | 0.841 | -0.169 | 2.283 | 4.036 | 676 |
| | (8.767) | (-1.447) | (1.351) | | |
| CS | 0.831 | 0.249 | 6.980 | 23.104 | 208 |
| | (2.601) | (1.065) | (4.684) | | |
| EX | 0.747 | 0.006 | 1.687 | 3.079 | 809 |
| | (9.606) | (0.062) | (1.742) | | |
| OR | 0.683 | 0.204 | 74.628 | 7.230 | 355 |
| | (5.161) | (1.802) | (2.588) | | |
| RI | 0.535 | 0.193 | 26.374 | 2.625 | 130 |
| | (2.321) | (1.121) | (1.572) | | |
| SE | 2.088 | -0.157 | -10.197 | 2.238 | 125 |
| | (3.494) | (-0.332) | (-1.352) | | |
| UAP | 0.782 | 0.042 | 0.947 | 0.905 | 426 |
| | (6.167) | (0.502) | (0.903) | | |

**Estimated percentage realised spread**

| size: | 0.1 | 0.5 | 1.0 | 2.0 |
|---|---|---|---|---|
| AC | 0.964 | 0.940 | 0.871 | 0.728 |
| AQ | 1.369 | 1.335 | 1.291 | 1.202 |
| BN | 0.692 | 0.715 | 0.794 | 0.960 |
| CA | 0.832 | 0.758 | 0.672 | 0.503 |
| CS | 0.926 | 0.970 | 1.087 | 1.332 |
| EX | 0.753 | 0.751 | 0.754 | 0.760 |
| OR | 1.002 | 0.845 | 0.917 | 1.106 |
| RI | 0.818 | 0.684 | 0.755 | 0.935 |
| SE | 2.022 | 2.000 | 1.927 | 1.772 |
| UAP | 0.790 | 0.803 | 0.824 | 0.865 |

**Table 8 Model based estimates of realised spread**

model: $\Delta p_t = \beta_0 + \delta Q_t + \alpha z_t + \gamma / z_t + \text{lags} + \varepsilon_t$

C. London (size censored at 5 NMS)

| | $2\delta$ | $2\alpha$ | $2\gamma$ | Wald | nobs |
|---|---|---|---|---|---|
| AC | 0.976 | -0.066 | -7.459 | 4.123 | 298 |
| | (8.018) | (-1.311) | (-1.817) | | |
| AQ | 1.283 | 0.002 | 3.167 | 0.241 | 1072 |
| | (11.391) | (0.048) | (0.486) | | |
| BN | 0.591 | 0.187 | 13.980 | 30.103 | 765 |
| | (6.777) | (1.569) | (5.450) | | |
| CA | 0.819 | -0.095 | 2.325 | 4.263 | 676 |
| | (9.655) | (-1.501) | (1.370) | | |
| CS | 0.793 | 0.188 | 6.996 | 27.599 | 208 |
| | (3.184) | (1.794) | (5.240) | | |
| EX | 0.737 | 0.037 | 1.724 | 3.261 | 809 |
| | (10.204) | (0.572) | (1.770) | | |
| OR | 0.735 | 0.113 | 70.061 | 9.312 | 355 |
| | (7.021) | (2.189) | (2.677) | | |
| RI | 0.680 | 0.036 | 21.844 | 1.943 | 130 |
| | (3.696) | (0.408) | (1.381) | | |
| SE | 2.163 | -0.166 | -13.606 | 3.896 | 125 |
| | (4.362) | (-1.081) | (-1.971) | | |
| UAP | 0.814 | 0.012 | 0.606 | 0.534 | 426 |
| | (8.692) | (0.346) | (0.719) | | |

**Estimated percentage realised spread**

| size: | 0.1 | 0.5 | 1.0 | 2.0 | 5.0 |
|---|---|---|---|---|---|
| AC | 0.932 | 0.935 | 0.906 | 0.841 | 0.644 |
| AQ | 1.289 | 1.285 | 1.286 | 1.288 | 1.294 |
| BN | 0.666 | 0.696 | 0.783 | 0.967 | 1.525 |
| CA | 0.818 | 0.774 | 0.726 | 0.631 | 0.347 |
| CS | 0.882 | 0.901 | 0.988 | 1.173 | 1.734 |
| EX | 0.747 | 0.757 | 0.775 | 0.811 | 0.921 |
| OR | 1.026 | 0.848 | 0.876 | 0.975 | 1.306 |
| RI | 0.902 | 0.741 | 0.738 | 0.763 | 0.865 |
| SE | 2.079 | 2.067 | 1.991 | 1.829 | 1.334 |
| UAP | 0.819 | 0.821 | 0.827 | 0.839 | 0.876 |

FIGURE 1

| ACCOR | 10:08:43 | 24- 5-1991 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| -----Bid----- | | | -----Ask----- | | | --Transactions--- | | |
| 1 | 200 | 763 | 770 | 800 | 3 | 400 | 765 | 10:08 |
| 1 | 500 | 762 | 774 | 100 | 1 | 50 | 765 | 10:08 |
| 1 | 400 | 761 | 775 | 200 | 1 | 50 | 770 | 10:06 |
| 4 | 450 | 760 | 778 | 1000 | 1 | 50 | 770 | 10:02 |
| 1 | 50 | 754 | 779 | 100 | 1 | 100 | 768 | 10:02 |

**Figure 1 Simplified trading screen of CAC system**

Limit orders: five best prices, total quantity at that price and number of individual orders involved.
Transactions: size, price and time of five latest trades

GAUSS Tue Apr 27 11:28:37 1993

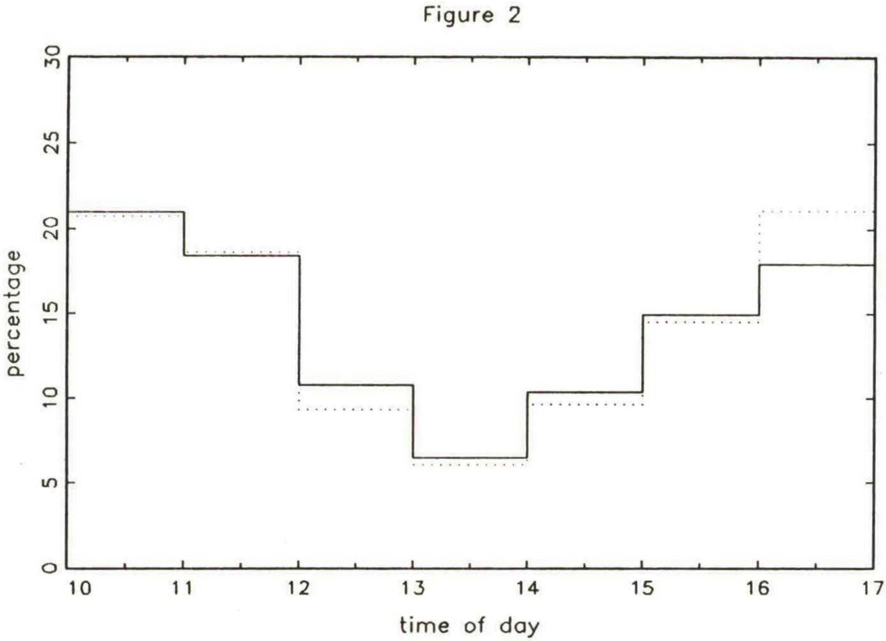


**Figure 2 Trading volume by time of day in Paris, Accor.**

Solid line: percentage of transactions in time interval.
Dotted line: percentage of shares traded in time interval.

GAUSS Tue Apr 27 11:30:47 1993

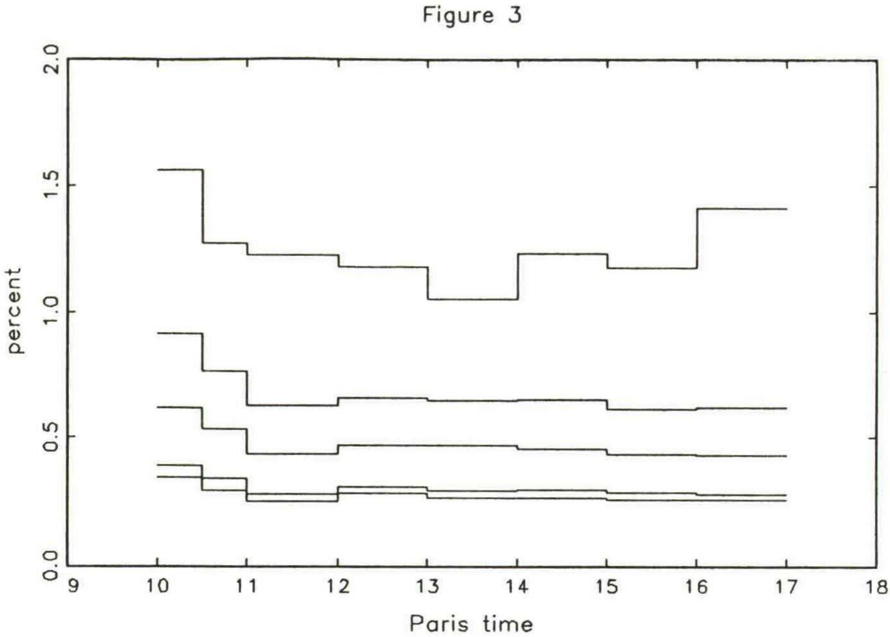


**Figure 3 Average quoted spread by time of day, Accor.**

Top line: average quoted spread ($S_C$) in London for NMS.

Bottom lines: average quoted spread ($S_C$) in Paris for smallest size, 0.1, 0.5 and 1.0 times NMS.

GAUSS Tue Apr 27 11:20:43 1993

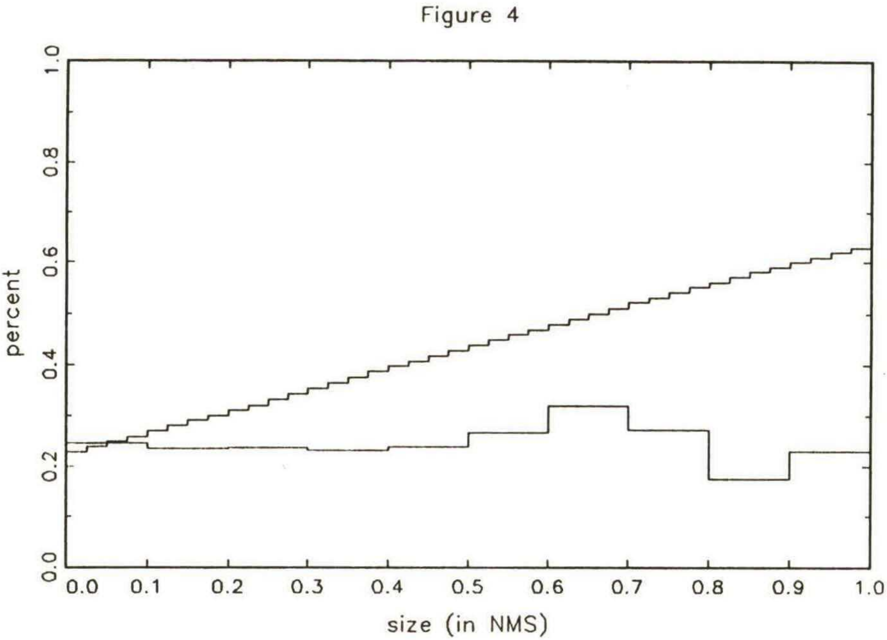


**Figure 4 Quoted and realised spread in Paris by transaction size, Accor.**

Top line: transaction time average of quoted spread $S_T(z)$;

Bottom line: average realised spread $S_R(z)$.

GAUSS Tue Apr 27 11:14:04 1993

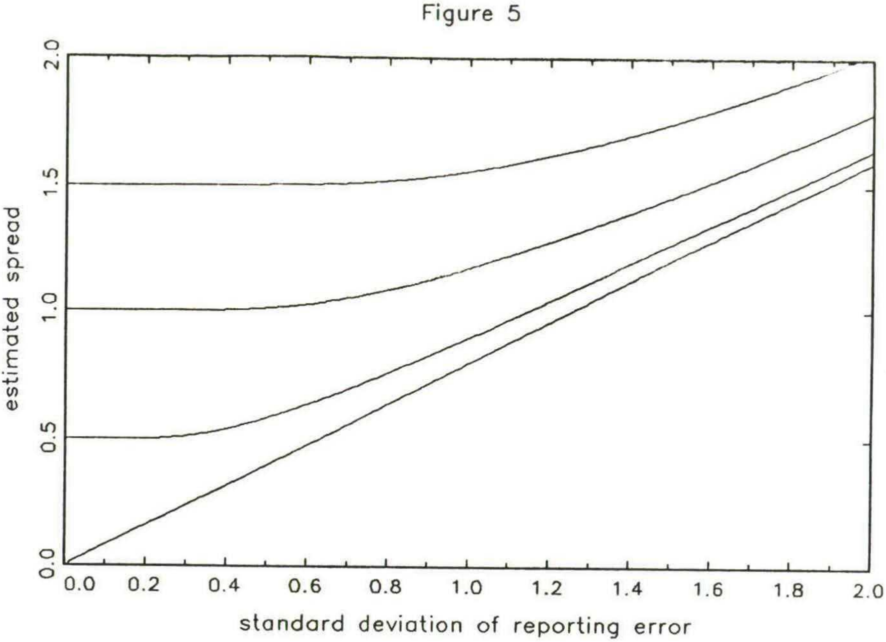


**Figure 5 Timing bias by standard deviation of reprting error.**

Estimated spread for true spread equal to 0, 0.5, 1 and 1.5.

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