TRADING & QUANTITATIVE RESEARCH REPORT

FOREX LIQUIDITY

Investigating the orderbook of the EUR/USD exchange rate

In collaboration with:

CENTURY
ANALYTICS

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INTRODUCTION & THEORY

In financial markets, the liquidity is the degree of ease at which a security can be bought or sold. If there are many buyers and sellers, and if the bid and ask prices quoted by these are close to each other – then the asset in question has a high liquidity. If the liquidity is low, a potential buyer or seller could have to execute at prices far off the present equilibrium or perhaps not at all be able to execute an order for the wanted quantity. The problems posed by low liquidity is relational to the volume an actor would like to buy and sell, which is why understanding the liquidity of a specific market is essential for the actor who wants scale up trading.

The main aim of this research is to answer the following questions regarding market liquidity:

1) How much is generally possible to buy and sell in the market?
2) What is the relative price of buying and selling different quantities?
3) What is the relative premium one is paying to execute the entire order directly, rather than piece by piece over time?
4) How does the answers to above questions change over time, for example over a trading day?

The answers come from an analysis of the liquidity of the forex market, specifically the EUR/USD exchange rate, by simulating trading in historical order book data. This is done using tick data for a 40-level order book, i.e. containing the 20 topmost levels of ask and bid quotes, respectively. Two different types of orders are tested, namely *Market Orders* and *Immediate or Cancel Orders* (IOC), both for the ask and bid side independently. These order types will be described further in the next section. Results from the analysis are presented as tables and graphs in the following sections.

Definitions / Order types

For a Market Order, the only input is the order size, i.e. how much one want to buy or sell. The order is executed directly for as large a portion as possible of the desired quantity, filling the order from the first to last level of the ask or bid side until either the order is completely filled or until the volume of the last level is taken. For a single Market Order, the output is the difference between the top of book price and the weighted average price of buying or selling for the executed order. By simulating trading of Market Orders in all time periods of the dataset and for all order sizes ranging between minimum and maximum quantity available, one is able to partwise answer question 1, 2 and 4.

An Immediate or Cancel Order (IOC) needs not only a specified quantity but also a specified maximum spread. The spread considered in this instance is the tolerance level of the buyer or seller, i.e. how much one is accepting to go beyond the top of book price. The IOC is executed directly in almost the same manner as the Market Order, filling the order from the first to last level of the ask or bid side until either the order is filled, until the volume of the last level is taken or until the average price for the bought/sold quantity is equal to the maximum acceptable price. If the IOC order is not filled in the first time period, a new IOC order is issued in the following time period with the remaining quantity to be filled as the new order size. For this project we also added a time limit on the IOC order which was 5 min. This means that if the order is not fulfilled within 5 min, we close the order. To perform these tests accurately the order book is simulated, and bought/sold quantities are kept track off. This simulation will be described further in the Method section. As from the Market Order, the main output from the IOC order is the difference in price between the executed price and the top of book price, but in addition to this also the time between initiation and completion. Together with the results from the Market Order tests, this gives the ability to answer question 2, 3 and 4 in further detail.

Data

The data set used in this research consists of historical order book data for the EUR/USD exchange rate, with price and volume quotes for the 20 topmost levels of the ask and bid. Each row in our data represents the current state of the order book for a given point in time, at the resolution of one tick per row. In the financial markets, the word tick can mean two different but closely related things. On one hand, it is the smallest possible change in the price of a security, and on the other it is the change in the price of a security between two consecutive trades. In this paper, and specifically in the notion of data resolution, "tick" is used in the last referred meaning. Tick size resolution data thus means that each row represents the point in time at which a trade was executed, i.e. that something changed from the last tick. The number of ticks per second varies for different securities and over time, but in the EUR/USD data used in this paper, the number of ticks per second is about 30.

The data for each level is the quoted price and volume, which means that there is no transactional data.

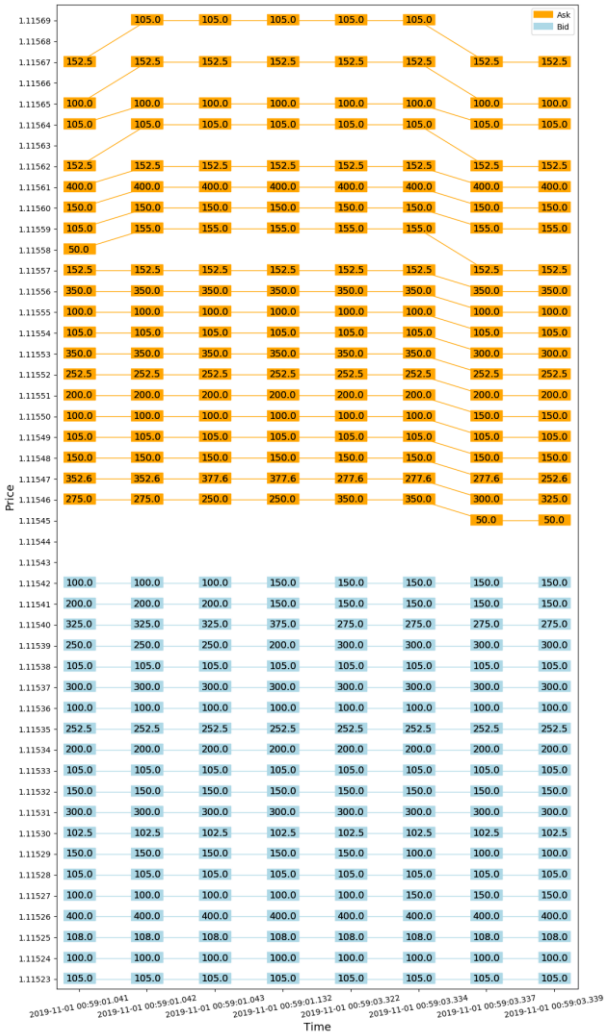

Figure 1. Orderbook for the first 8 timeslices. The price is shown as a function of time with 20 levels for the ask and the bid.

METHOD

In this section we describe the Python code that was written for this project. We discuss in more details the Market Order function, the Immediate or Cancel Order (IOC) function and we use plots to help visualize both functions.

Market Order

The market order function contains three inputs:

- Buy or sell.
- The amount of shares.
- The time tick/slice.

We can visualize the market order function by looking at Figure 2. In that time slice we chose to place an order with an amount of 1990. The levels get filled in order starting from the top of the book till we complete the full order with the quantities. The relative difference is then found by calculating the weighted average using the quantities and prices covered with the order. Then, the top of the book price gets subtracted from the weighted average to arrive at the relative difference which is the return of our function.

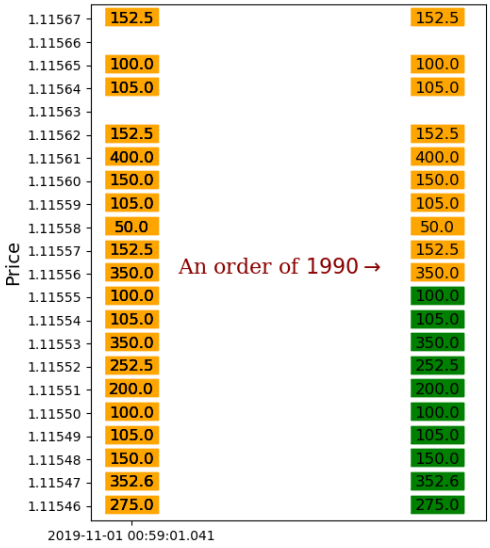

Figure 2. A visualization of the market order function for a specific tick with a specific order. The green levels are the levels filled with the order.

IOC (Simulation)

As described earlier, a detailed simulation of the order book is required to test the Immediate or Cancel orders over time, since the bought or sold quantities cannot be bought or sold twice. To explain in more detail, if the historical orderbook data state that a quantity of 100 is available for purchase for the price 1.5 at two consecutive points in time, then this means that the quantity either was not bought during the first period or that is was bought and replaced. Since it is not possible to tell which case is true from the data, a conservative approach is to assume the first, i.e. that the quantity was not bought during the first period. In simulation this means that if the quantity is bought by the IOC order in the first time period, then it should not be there in the second time period. Only if there is a positive difference in quantity between the second and first time period, i.e. that the second time period contains quantities that were not present in the first, does the quantity in the simulated order book increase.

Figure 3 shows an example of how the simulation works. The top part of the plot titled "Real" shows 5 random time slices. In this example we are just showing 11 Ask levels just for simplicity. In this example we place an order of 1000 shares at "Timeslice 3". The middle part of the plot shows how the computation done in order to simulate the order book that results from us placing that order. The order is subtracted from each time slice and as mentioned before one can see that the simulated order book increases only when the second time slice contains the quantity that is not present in the first time slice. The bottom part of the plot titled "Simulation" shows the resulting book after the order that was placed.

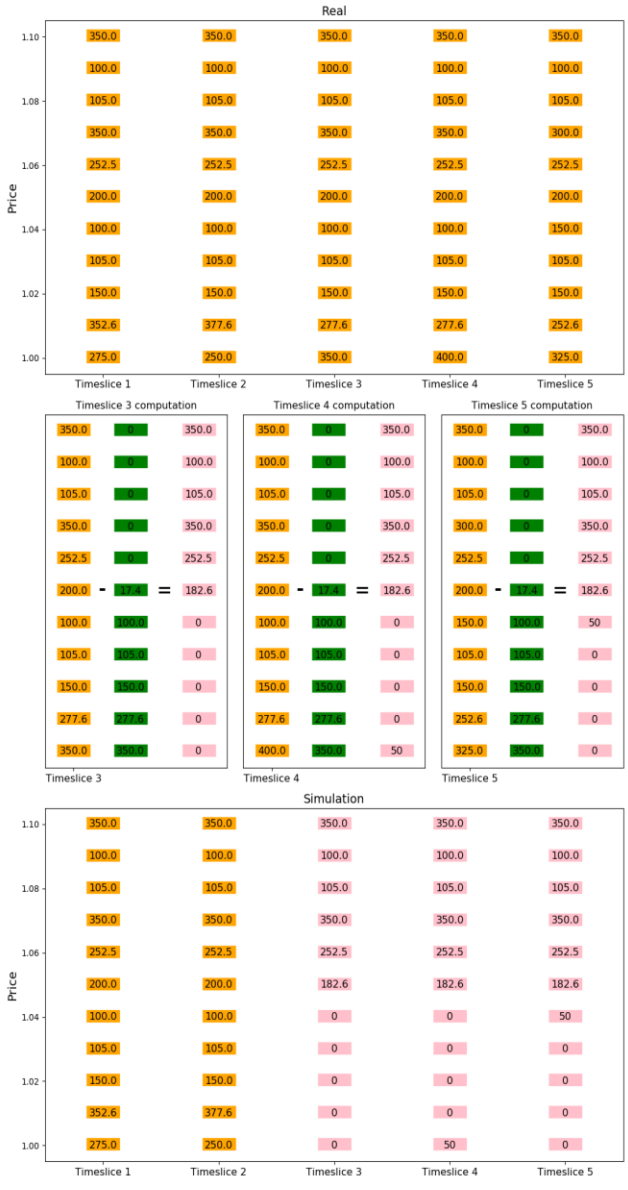

Figure 3. A visualization of the simulation for 5 timeslices with an order size of 1000 shares. The orange color indicate that we are looking at the Ask, the green represents the order placed and the pink color represents the simulated slice after the order.

RESULTS & DISCUSSION

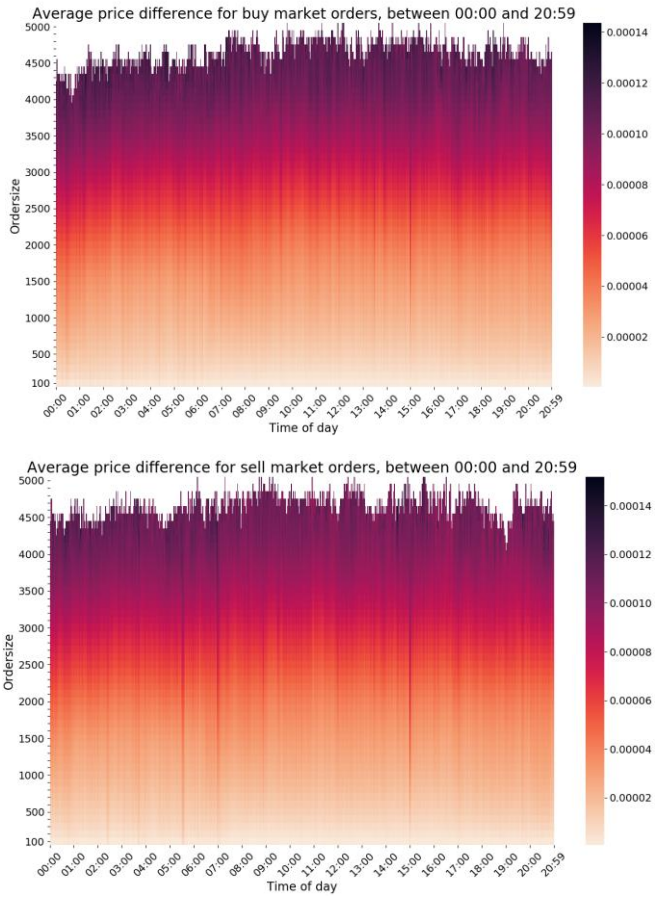

Figure 4 and 5. The figures show the average price difference compared to the top of book price, for order sizes between 100 and 5000 in steps of 100. The results in tick resolution are resampled into the average price difference for each minute of the day. The price difference is shown by the color bar to the right of the graph. The top figure shows the result for buy market orders and the bottom for sell market orders.

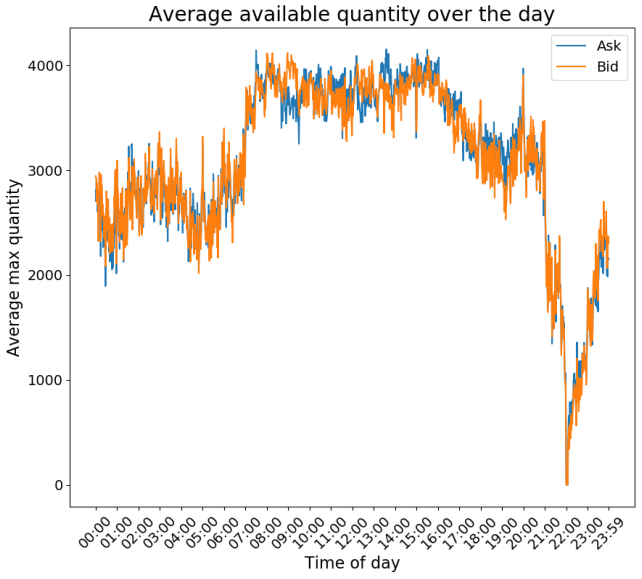

Figure 6. The figure shows the average available quantity for buying and selling. The results in tick resolution are resampled into the average quantity available for each minute of the day. Ask-quantities are the quantities that are available for buy orders and bid-quantities are the quantities that are available for sell orders.

Market orders

The resampled results from market orders are presented in a series of figures. Figure 4 (top-left) shows the average price differences from buy orders as a heatmap, where darker colors indicate a larger difference in accordance with the color bar in the right of the figure. The price difference mostly varies at the fifth decimal point, which is one tenth of a pip and constitutes percentage changes in the range of thousandths of a percent. For example, if a buy order of size 2500 at 12:00 results in a price difference of 6e-5, and the top of book price is 1.1160, the percentage price difference is 0.00538%. The figure shows the results up until 20:59, where the patterns seen are fairly constant, in contrast to the extreme results found around 22:00 which is discussed later on. The results for sell market orders follow a very similar pattern, as can be seen in Figure 5 at the middle of this page to the left.

From Figures 4 and 5 it looks like the average price difference increases with the order size at relatively constant pace. Since this cannot be deduced merely from these figures, the nature of the relationship between price difference and order size is shown and described further on the next page.

In Figure 6 (bottom-left) it is evident that the average available ask and bid quantities follow each other closely within the given data set. One can also see that the volumes are highest between European working hours, and drop sharply to reach 0 at 22:00. At 22:00 to 22:05 the market is closed, and thereafter volumes return to normal during the following one to two hours. Since higher tradeable volumes is a key factor of market liquidity, these results indicate that the EURUSD exchange rate is as most liquid during the European working hours and as least liquid around the break at 22:00.

As can be seen in Figure 7 (bottom-right), the average price differences around the 22:00 break far exceed the price differences seen throughout the rest of the day. Comparing the ranges of the average price differences in Figure 4 and Figure 7 shows that there is a difference in magnitude by a factor of 10, meaning that the prices around 22 on average are at least 10 times higher than what is at other times. The relatively higher price differences around the break correspond with the low available quantities at the time, further supporting that the market is much less liquid around 22:00.

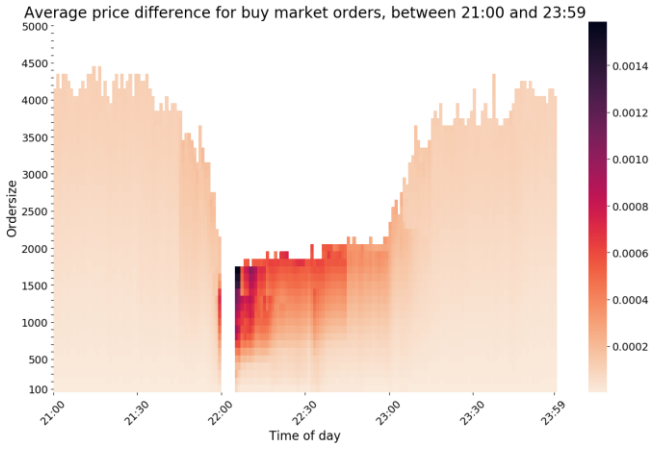

Figure 7. The figure shows the average price difference for buy market orders over the 22:00 break. In comparison with the average price differences in Figure 4, the range around 22 differs by a magnitude of 10.

RESULTS & DISCUSSION

Price vs. Order size

To better grasp the relationship between price and order size, the price difference is estimated as a function of order size and time of day via linear regression. Figure 8 (bottom) shows the average increase in price difference for an increase in order size, based on the resampled results for each minute of the day. The relationship breaks dramatically around 22:00, which is reasonable given the low to no volumes available for trading at that time. Not shown in the graph, the R^2 value for each pointwise linear regression is close to 1.0 up until the breaking point, meaning that the linear estimate explains the relationship with a very high precision up until that point. For the time around 22:00 the linear regressions show no explanatory power and it is therefore not included.

As can be seen in Figure 8, the coefficient of the linear regression mostly varies in the range 2.2e-8 to 3.0e-8, suggesting that for a given point of time, if the order size is increased by 1, the price difference increases by approximately 2.2e-8 to 3.0e-8. During the hours from mid night until the European working hours there seems to be a downwards facing trend in this relationship, meaning that it becomes relatively cheaper to buy larger quantities. From around 7:00 to 20:00 the relationship can be considered as relatively mean stationary, suggesting that the relationship stays quite stable. This gives further support to the previous notion that the EURUSD is as most liquid during the European working hours and offers an estimation of how much more a market participant can expect to pay for larger orders.

IOC orders

Due to computation intensity, the IOC orders are only tested for buy orders of two different order sizes, for one day of data and for a max spread of 0. By definition, the max spread of 0 means that no order results in a positive price difference, since the top of book price at order initiation is this case also constitutes the maximum weighted average price accepted in order execution. Figure 9 shows the average price differences, resampled into the average for each minute of the day. The results are too incoherent for any conclusions to be drawn, but it seems as if fewer orders result in price differences of 0 during the European working hour. This suggests that the gains from using an IOC order instead of a market order would be larger during these hours, although there is not enough data to allow conclusions of this kind. However, the IOC orders seem to be executed in greater share during the same period, as can be seen in Figure 10, showing the share of orders filled for each 30-minute period of the day.

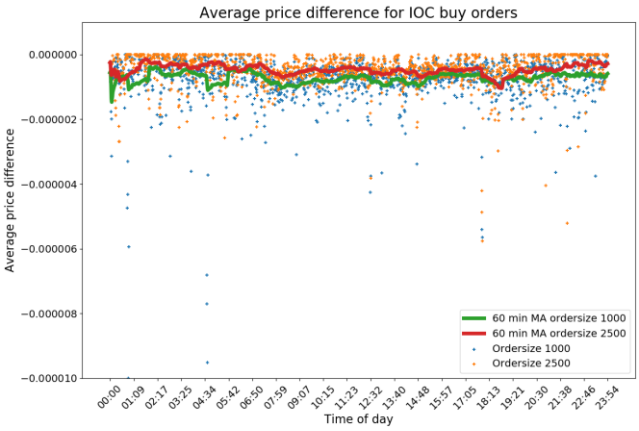

Figure 9. The figure shows the average price difference for IOC buy orders, for the order sizes 1000 and 2500, and for a max spread of 0.

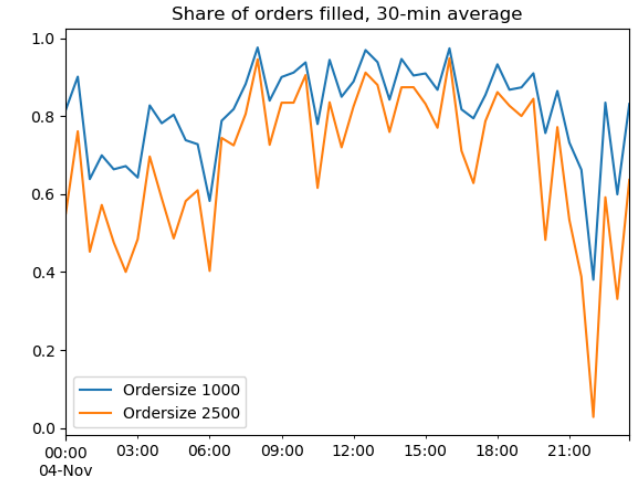

Figure 10.
The figure shows the average share of IOC orders that are filled for each 30-minute time slot of the trading day. The general trend of higher liquidity during the European working hours is further supported.

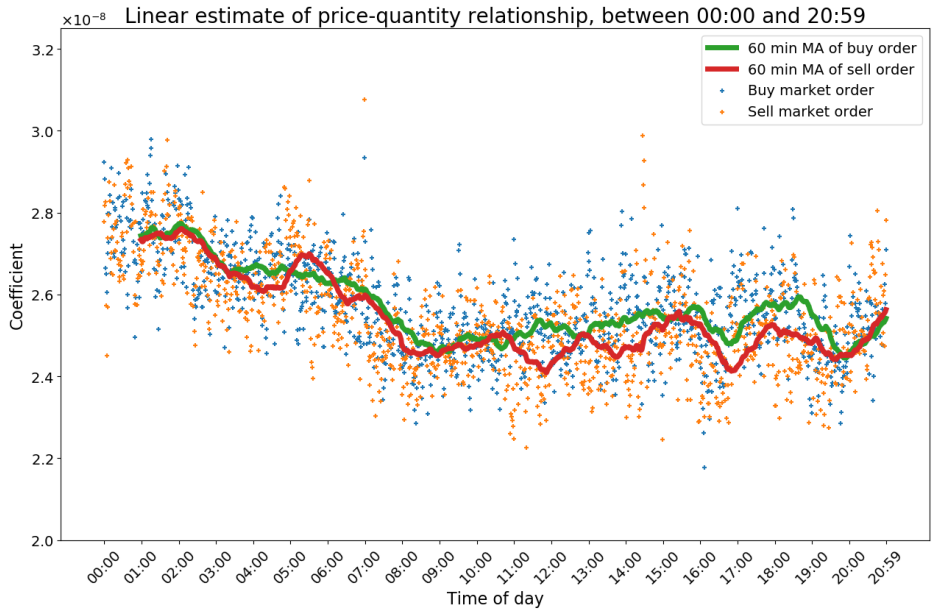

Figure 8.
The figure shows the linear estimates of the relationship between the price difference and the order size, based on the resampled results for the average price differences for each minute of the day, between 00:00 and 20:59.

Each blue and orange point represents the coefficient of the linear regression of price difference on quantity, for the resampled average results of each minute of the day. The red and green lines are the 60 minutes moving averages of the coefficents. Note that the values on the y-axis are displayed with a multiplicator on the top, meaning that each value on the axis should be multiplied by 10^{-8} to get the true value.

Although there is considerable variation in the relationship, one can distinguish a declining trend until approximately 7 or 8 o' clock in the morning, followed by a seemingly more stable mean. This complements the scenario posed by Figure 6, of the period during European working hours offering higher liquidity.

CONCLUSIONS

In this report, we have investigated the liquidity of the EUR/USD exchange rate through order-simulations using historical orderbook data. Our aim has been to answer four questions regarding market liquidity, which are presented in summation below:

1) How much is generally possible to buy and sell in the market?
The available quantities available for immediate order execution vary a lot throughout the trading day, which can be seen in Figure 6. During the European working hours, around 08:00 to 16:00, about 3500-4000 lots are available for immediate buying or selling. In comparison, about 2000-3000 lots are on average available for buying or selling during the night and early morning, between 23:00 and 07:00. Around the break 22:00 to 22:05 low volumes are available.

While these quantities represents what is available at any given time, it is reasonable to assume that this would only hold part true in live testing. Any order that take a significant share of the available ask or bid quantity is likely to affect the market, which could respond innumerous ways.

2) What is the relative price of buying and selling different quantities?
As can be expected for an immediately executed market order, the average price difference increases with the quantity bought/sold. Figure 4 and 5 shows that this relationship seems to be relatively stable during most of the trading day, between 00:00 and 21:00. Around 22:00, when the volumes are low, the trend breaks, and the average price difference is considerably higher, as can be seen in Figure 7.

The relationship between price and quantity is found to be linear with a very high coefficient of determination, except for the period around 22:00. Through linear regressions, this relationship is quantified and shown to be in the range of 2.2e-8 to 3.0e-8 for the hours 00:00 to 21:00, suggesting that an increase in order size of 100 on average would increase the price difference by around between 2.2e-6 and 3.0e-6. To put this in perspective, an increase in the price difference of 2.5e-6 is 2.5% of a pip, or a 0.000224% change in price relative to a top of book price of 1.1155.

3) What is the relative premium one is paying to execute the entire order directly, rather than piece by piece over time?
This question remains to be answered.

4) How does the answers to above questions change over time, for example over a trading day?
As mentioned in questions 1 and 2, there are considerable differences with regards to market liquidity during the trading day. During the European working hours, there are higher quantities available for buying and selling, and the relative cost of increasing the order size is lower than during the rest of the day. Before the break at 22:00 to 22:05, liquidity plummets with lower quantities available and higher costs of execution. The market is then over the course of the following one to two hours restored.

We must also keep in mind that the data that we are working with is only the market maker side. This means that we don't have any data on the actual transactions. In layman's terms, we are not considering the other traders that are involved in the market. This adds another branch that we can explore in the future. Adding the transaction side will get us closer to the simulating how the market really behaves.

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Other