Bid-ask spread components on the foreign exchange market: The case of the Moscow Interbank Currency Exchange

Masterproef voorgedragen tot het bekomen van de graad van

Master of Science in de Toegepaste Economische Wetenschappen: Handelsingenieur

Valerie Hemberg

onder leiding van

Prof. Dr. Michael Frömmel
PhD Student Frederick Van Gysegem
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Confidentiality clause

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Valerie Hemberg
Declaration of Confidentiality with Regard to the MICEX Data

Under the following guarantees of confidentiality, the dataset consisting of daily and intraday currency trades between 2000 and 2011 at the Moscow Interbank Currency Exchange was obtained:

- The data shall not be disclosed to any person.
- The data set shall be used exclusively in the course of this master thesis.
- All reasonable steps will be taken to ensure that no other person gains access to the dataset.
- Upon completion of the master thesis, the data will be destroyed.
Preface

This thesis is written in order to obtain my second master’s degree in Business Engineering with a major in Finance. The subject was chosen because it had so many different elements in it which could provide me with the necessary variation during the whole period I worked on it and because I have a general interest in financial topics. After more than a year of hard work, it still is interesting.

This thesis could not become what it is today without the help of some people. First of all, I would like to thank my promoter Frederick Van Gysegem who guided me through the whole process and always gave constructive feedback, also at times when things did not go the way I wanted them to go. I feel very lucky to have a promoter like that.

I would also like to thank my parents for their support in everything I do. I could not wish for any better parents. A special thank-you to my sister who carefully read the first version of my interim report. Only she can find more than 100 errors in 5 pages. I love you and know that I’m smiling right now.

Last but not least, I would also like to thank all my friends who gave me some great memories from the past 5 years. A special thank-you to my dear friend Emilie Mouton. Everybody should have a friend like you.
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List of Abbreviations and Symbols

Abbreviations:

ASC         Adverse selection component or adverse selection cost(s)
ATM         At-the-money
AV          B/a spread calculation method that uses the average transaction price of all buys and
            the average transaction price of all sells for every half-hour
b/a         Bid-ask
BIS         Bank for International Settlements
BSM         Black and Scholes (1973) and Merton (1973)
Buysell     Indicates whether the trade was a buy or a sell
C\(_0\)      B/a spread calculation method that uses the transaction prices that correspond with
            the last change in direction of two orders and where the time span between those
            orders is equal to zero
C\(_{0,5}\)   B/a spread calculation method that uses the transaction prices that correspond with
            the last change in direction of two orders and where the time span between those
            orders is the minimum time span that is larger than zero seconds for that half-hour
C\(_{5,10}\)  B/a spread calculation method that uses the transaction prices that correspond to the
            last change in direction of two orders and where the time span between those orders
            is the minimum time span that is larger than or equal to 5 seconds for that half-hour
C\(_D\)       The number of dealers that are active on a given day as a proxy for the competition in
            a certain half-hour
C\(_T\)       The number of dealers that are active on a given day weighted by the number of
            trades per half-hour as a proxy for the competition in a certain half-hour
C\(_V\)       The number of dealers that are active on a given day weighted by the traded volume
            per half-hour as a proxy for the competition in a certain half-hour
C\(_V\)       Measure for competition, with Y being the method used and where Y\={D,T,V}
CHF         Swiss franc
Close       The price at which the market closed
D2000-1     Dealing 2000-1
D2000-2     Dealing 2000-2
D3000       Dealing 3000
EBS         Electronic Broking Services
ECB European Central Bank
ER Exchange rate
EUR Euro
EWQS Equal-weighted average of the quoted spread
EWQS_x Equal-weighted average of the quoted spread, with X being the method used for calculating the b/a spread and where X=\{AV, MM, LV, WA, LC, C_{00}, C_{05}, C_{50}\}
Forex Foreign exchange
FX Foreign exchange
GDP Gross domestic product
GMT Greenwich Mean Time
HI Herfindahl index
High The highest price at which a transaction took place
I Informed
IHC Inventory holding component or inventory holding cost(s)
IHP Inventory-holding premium
IHP_{i} Inventory-holding premium charged to an informed trader
IHP_{u} Inventory-holding premium charged to an uninformed trader
IHP_{x,t} Inventory-holding premium based on \(T_{x}, \sigma_{x} \) and \(\sqrt{\tau_{z}}\)
Invcurvol The total price paid (in Russian Ruble) for ‘volcur’
ITM In-the-money
j Dealer j
JPY Japanese yen
LC B/a spread calculation method that uses the transaction prices that correspond to the last change in direction of two orders
Low The lowest price at which a transaction took place
LV B/a spread calculation method that uses the last transaction price of each buy and sell transaction for every half-hour
M Number of markets on which the stock is listed
MHI Modified Herfindahl index
MICEX Moscow Interbank Currency Exchange
MM B/a spread calculation method that uses the minimum transaction price of a customer sell and the maximum transaction price of a customer buy for each half-hour
n Hedge ratio
NASDAQ National Association of Securities Dealers Automated Quotations
ND Number of dealers
NOK Norwegian kroner
NS Number of shareholders in a certain stock
Numpart The number of parties active in a market on a given day
Numtrades The number of trades that took place on a given day
NYSE New York Stock Exchange
OPC Order processing cost(s)
Open The price at which the market opened
O-T-C Over-the-counter
OTM Out-of-the-money
$\text{p}_0$ Observed security price
$\text{p}_{t_0}$ Observed security price at time $t$
$r$ Risk-free interest rate
REWQS Relative equal-weighted quoted spread, which is the EWQS divided by the true exchange rate $T$
REWQS$_{x}$ Relative equal-weighted quoted spread, which is the EWQS$_{x}$ divided by the true exchange rate $T_x$
RSRP Relative bid-ask spread, which is the spread divided by the true exchange rate $T$
RSRP$_{x}$ Relative SRP$_{x}$, which is the SPR$_{x}$ divided by the true exchange rate $T_x$
RUB Russian Ruble
RVWES Relative volume-weighted effective spread, which is the VWES divided by the true exchange rate $T$
RVWES$_{x}$ Relative volume-weighted effective spread, which is the VWES$_{x}$ divided by the true exchange rate $T_x$
S True exchange rate
SP Stock price
SPR Bid-ask spread
SPR$_{x}$ Bid-ask spread, with $X$ being the method used for calculating the b/a spread and where $X=${AV, MM, LV, WA, LC, $C_0$, $C_{05}$, $C_{510}$}
$t$ Time until an offsetting order arrives
$t_1$ Method for calculating the time until an offsetting order arrives, where the difference between buy and sell orders is taken into account
$t_2$ Method for calculating the time until an offsetting order arrives, where the difference between buy and sell orders is not taken into account
Time until an offsetting order arrives calculated according to method \( Z \), where \( Z = \{1, 2\} \)

True exchange rate

True exchange rate, corresponding to the b/a spread calculated according to method \( X \), where \( X = \{AV, MM, LV, WA, LC, C_{01}, C_{05}, C_{510}\} \)

Clearing today

Clearing tomorrow

Total volume traded by all dealers

Time rate

The trading day on which the trade took place

The time at which the trade took place

Total volume traded by all dealers

Uninformed

US dollar

United States

Volume traded by a dealer

Volume traded by dealer \( j \)

The total volume traded

Volume-weighted average of the effective spreads

Volume-weighted average of the effective spreads, with \( X \) being the method used for calculating the b/a spread and where \( X = \{AV, MM, LV, WA, LC, C_{01}, C_{05}, C_{510}\} \)

B/a spread calculation method that uses the weighted average of the buy and sell prices for every half-hour

Weighted average price

Exercise price

Symbols:

Return volatility

Annualized return volatility corresponding to the b/a spread calculated according to method \( X \), where \( X = \{AV, MM, LV, WA, LC, C_{01}, C_{05}, C_{510}\} \)

Expected value

Inverse of

Cumulative unit normal density function

Change in value of

Absolute value of

Average value of
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1. Introduction

The foreign exchange market is by far the largest financial market in the world and plays a key role in today’s economy, therefore a proper functioning of this market is crucial. In order to better understand how this market works, Lyons (2006) introduced a microstructure approach to the foreign exchange market. This microstructure approach introduces characteristics of microstructure finance that until then were neglected. These are for instance the role of private information, but also the differences in market structures and the influence they have on price formation.

One of the key elements in the microstructure approach to the foreign exchange market is the bid-ask spread. The bid-ask spread is the difference between the quoted price at which the passive party will sell and the quoted price at which the passive party will buy. A good understanding of the determinants of the bid-ask spread is important for several reasons. Bid-ask spreads are considered to cover trading costs, so they provide information about the fairness of a dealer’s rents. Furthermore, they are also important in evaluating the merits of competing trading mechanisms. The bid-ask spread is typically considered a function of several cost components: the order processing component, the inventory holding component, the adverse selection component and competition. In early papers, the influence of these determinants of the bid-ask spread was investigated separately. Later one, one started to recognize that these components co-exist and that it even can be hard to disentangle the influence of these different determinants.

We contribute to literature by testing the bid-ask spread decomposition model of Bollen, Smith and Whaley (2004) on the foreign exchange market. Until now, the model has only been tested with data on the stock market i.e. Nasdaq stocks. For our investigation, we exploit a new dataset that contains trade data of the Moscow Interbank Currency Exchange Market. The model of Bollen et al. (2004) is a simple model that takes into account the effects of order processing costs, adverse selection costs, inventory holding costs and competition. In their model, the adverse selection component and the inventory holding cost are taken together and modeled as an at-the-money option with a stochastic time to expiration. They call this the inventory-holding premium and they argue it to be the compensation a dealer asks for holding a security in inventory.

We expect to see some differences in comparison with the results found by Bollen et al. (2004). These differences could be related to the type of market under study i.e. the foreign exchange market from a country in transition (i.e. Russia). However, inspired by the work of Lyons (2006) who
indicated a gap between theory and practice – and which has led to the microstructure approach to the foreign exchange market –, we will conduct a survey in order to get an idea of how the dealers active on different financial markets believe these determinants influence the bid-ask spread.

This thesis starts with a literature overview in sections 2 and 3 (i.e. part I). Section 2 explains in brief how the foreign exchange market works. This is necessary because our empirical research work uses data from the foreign exchange market. However, for readers familiar with the foreign exchange market, this section can be skipped. Section 3 summarizes the existing literature on the components of the b/a spread. This section is divided into a subsection that provides an overview of the existing theoretical models that explain the size of the b/a spread and a section that compares and discusses the empirical findings based on these theoretical models. With section 4 starts our empirical research work (i.e. part II). Section 4 explains the decomposition model of Bollen, Smith and Whaley (2004), which we will test with data from a foreign exchange market i.e. the Moscow Interbank Currency Exchange. Section 5 specifies and describes the data that we have used. This section also explains how we converted our data into variables that we could use in our decomposition model. In section 6 we present our empirical findings and some insights concerning these findings. Section 7 shows the intraday patterns that we have found in our dataset. Section 8 gives a summary of the survey we conducted in order to obtain a more complete view on the components of the b/a spread. This section contains an overview of the components that, according to traders, determine the size of the b/a spread in practice, but also to what degree they take into account the different b/a spread components suggested in our model.
2. The Foreign Exchange Market

The foreign exchange market, sometimes also referred to as the forex market\(^1\), is one of the most important financial markets in today’s economy. Currencies are bought and sold in this market. Next to being the largest financial market in the world, it is also a global market. This means that buyers and sellers can trade currencies at several places spread around the world, which allows for major currencies to be traded around the clock. This section is, for the most part, inspired by the work of Lyons (2006).\(^2\) First, we explain the institutional structure of the foreign exchange market. This is followed by an overview of the main characteristics of the FX market. Next, technological developments and instruments traded on the FX are discussed. We end this section by giving a brief overview of the different theoretical approaches to the foreign exchange market.

2.1. The institutional structure of the foreign exchange market

When explaining the institutional structure of the foreign exchange market, one should know the existing basic forms of market organization. Lyons (2006) points out that there are three institutional forms of market organization. These are:

(1) Auction markets
(2) Single dealer markets
(3) Multiple dealer markets

On an auction market a participant can choose to place market orders as well as limit orders. A market order is the purchase/sale of X units at the best available price (aka best price). Limit orders conversely are the purchase/sale of X units when the market reaches a certain price. Limit orders are collected in a limit order book and the most competitive limit orders make up the best available buy and sell price. In an auction market no dealers are present.

In a single dealer market there is only one dealer who is available to quote prices at which he is prepared to trade. Because he is the only one, his prices are consequently the best available buy and sell price. When a counterparty asks for a quote and decides to trade, the dealer is obligated to buy or sell at his quoted bid or ask price.

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\(^1\) Foreign exchange trading is also called currency trading and the foreign exchange is sometimes abbreviated to FX.

\(^2\) This means that, unless stated otherwise, Lyons (2006) is the reference work for this entire section.
Multiple dealer markets are markets where more than one dealer is active and these dealers experience competition from the other dealers. Multiple dealer markets can be centralized or decentralized. In a centralized multiple dealer market the bid and ask prices are brought together at a single location or on a single monitor (e.g. NASDAQ). In a decentralized multiple dealer market this is not the case. This means that the same transactions can be conducted against different prices than is the case when they are brought together at a single place or on a single monitor.

The structures in place are often hybrid structures composed of different combinations of these three basic institutional forms. The New York Stock Exchange (NYSE), for example, has a hybrid structure that combines an auction market with a single dealer market. The NYSE is characterized by a specialist system. For each stock on the NYSE there is one and only one specialist that makes a market in that stock. This specialist keeps track of a limit order book. Suppose that an investor wants to buy $X$ units of a certain stock. He will place a market order with the specialist who will then look at the limit order book for the best available ask price. This corresponds with an auction market. However he can also choose to trade for his own account when he decides to sell to the investor at an even lower ask price. This corresponds with a single dealer market. Note that when he takes the other side of the transaction, his bid or ask price will be between the best available bid and ask price deducted from his limit order book. The limit order book prevents the specialist from exercising monopoly power and is also the reason why pure single dealer markets are almost never found.

The foreign exchange market is a decentralized multiple-dealer market. There is no monitor that shows all prices available in the market, nor is there a single place where all dealers come together to trade. The institutional structure is thus completely different than, for example, the above-mentioned structure of the NYSE. This decentralization is the result of the fact that customers are spread all over the world and banks want to be located near to their customers, but also because an exchange rate is always a ratio between two countries.

2.2. The main characteristics of the foreign exchange market

The foreign exchange market has three characteristics that gives it its own distinct character in comparison with other financial markets. Following Lyons (2006), these are:

(1) High transaction volume
The transaction volume on the foreign exchange market is gigantic. Every three years the Bank for International Settlements (BIS) conducts a study on the size and the evolution of the market. Table 1, coming from the most recent study on the FX market of the BIS, gives an overview of the daily turnover in this market. The data speak for themselves as they are daily data and expressed in billions of US dollars. Between 2007 and 2010 the foreign exchange market grew by almost 20%, this can be explained by a growth in trading of other financial institutions (cf. further down).

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total turnover foreign exchange instruments</td>
<td>1,527</td>
<td>1,239</td>
<td>1,934</td>
<td>3,324</td>
<td>3,981</td>
</tr>
<tr>
<td>Turnover at April 2010 exchange rates²</td>
<td>1,705</td>
<td>1,505</td>
<td>2,040</td>
<td>3,370</td>
<td>3,981</td>
</tr>
</tbody>
</table>

¹Adjusted for local and cross-border inter-dealer double-counting. ²Non-US dollar legs of foreign currency transactions were converted into original currency amounts at average exchange rates for April of each survey year and then reconverted into US dollar amounts at average April 2010 exchange rates.

Source: BIS (2010)

Table 1: Global foreign exchange market turnover

Lyons (1996) gives an explanation for this high transaction volume on the foreign exchange market. According to him the existence of hot potato processes on the foreign exchange market helps clarify this high volume turnover. Hot potato trading is explained by means of an example. Suppose a customer places a large order of 50 million USD with his bank. The bank, through its interbank dealers, wants to get rid of this 50 million USD, so an interbank dealer who works at this bank (person A) will sell 10 million USD to 5 other dealers who each work at other banks. This is done through direct trading. In the assumption that none of these 5 dealers is interested in the position but accept to trade because of the compensation they receive in the form of the bid-ask spread³, each of these 5 dealers contacts 4 other dealers in their network and sells them 2.5 million USD each. The interbank volume that has been traded is now 100 million USD. This will continue to grow because the interbank dealers who just bought 2.5 million USD will sell this to other dealers again. Basically, the customer trade is passed on from dealer to dealer like a hot potato because the dealers do not want to hold an open position. These undesired open positions are frequent on the foreign

³ The bid-ask spread as a compensation for a trade will be explained later on in this paper.
exchange market and a consequence of the presence of risk-averse dealers (Lyons, 1997). This is one way of explaining hot potato trading. Another way in which the concept has been explained, is the way in which person A (receiving the customer order of 50 million USD) calculates his share of this amount that he will hold after distributing the position among himself and nine other interbank dealers of other banks. This means that he will divide this 50 million USD by 10, sells 5 million USD on to 9 other interbank dealers and keeps 5 million USD. Now every dealer, himself included, holds 5 million USD. The other 9 dealers will now do the same: they will each share this 5 million USD with 9 other dealers. Although this explanation is a little bit different from the first, the trade is still passed on from one dealer to another and results in an increased interdealer share which, in turn, results in a high trading turnover on the foreign exchange market. Lyons (1996) did mention that this passing-on does not go on infinitely. Eventually dealers will hold some of the supply.

Considering the **parties involved**, the foreign exchange market can be divided into two segments according to Lyons (2006): the customer market and the interbank market. In the customer market transactions take place with customers. In the interbank market, transactions happen between dealers directly or through brokers.

Customers can be non-financial companies like importing and exporting companies that need foreign currencies for their international operations, but these can also be financial companies, central banks, financial managers, etc. In general, customers place the largest single trades and use the currencies for their operational activities. They place their orders with sales teams of banks, also called corporate traders. For banks it is important to have a good sales team because this determines the number of orders they receive. The number of orders received, in turn, determines the banks’ trading profits. About 75% of dealers’ gross profits come from their customers. Their volumes, however, do not make up even half of the total volume traded (cf. further down). Furthermore, customer orders are also important because they contain important private information. Lyons (2006) considers information private if not everyone has access to or can obtain that information, unlike with public information. Consequently, disposing over private information leads to better predictions of future prices. Lyons (2006) further identifies two types of private information. The first type of private information provides the dealer with information about the value of something other than future exchange rates. The second type of private information allows the dealer to better predict future exchange rates. An example of the first type of private information is when a central bank places an order with a dealer. The dealer can deduct information about future interest rates.

---

4 Customers are presented with a larger b/a spread (cf. further down).
from this order (Peiers, 1997). Another example of the first type of private information is when a dealer observes the aggregate orders placed with him by his customers. By doing so, he receives information about the trade balance before numbers are published officially. One can generalize this by saying that customer order flow\(^5\) allows to obtain information about exchange rate fundamentals, in this case the trade balance (Lyons, 1997). An example of the second type of private information is a dealer who knows his own inventory position and who can estimate inventory positions of other dealers better than the public. This information allows him to better forecast future prices (Lyons, 2006). This second type of private information is more relevant in our work here.

Dealers work for banks and quote bid and ask prices when asked for by customers or other dealers. Dealers typically specialize in one currency pair. For instance, one dealer will only trade dollars for euros and the other way around. The trend of increasing mergers and acquisitions in the banking sector has led to an increased market share in the foreign exchange turnover of the main banking institutions. Evidence of this concentration in the banking industry can be found in table 2.

<table>
<thead>
<tr>
<th>Concentration in the banking industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of banks accounting for 75% of foreign exchange turnover^1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Switzerland</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Denmark</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Sweden</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>France</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Canada</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Germany</td>
<td>9</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Australia</td>
<td>9</td>
<td>10</td>
<td>8</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>United States</td>
<td>20</td>
<td>13</td>
<td>11</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Japan</td>
<td>19</td>
<td>17</td>
<td>11</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>24</td>
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<td>16</td>
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<td>Singapore</td>
<td>23</td>
<td>18</td>
<td>11</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Hong Kong SAR</td>
<td>26</td>
<td>14</td>
<td>11</td>
<td>12</td>
<td>14</td>
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<tr>
<td>Korea</td>
<td>21</td>
<td>14</td>
<td>12</td>
<td>12</td>
<td>16</td>
</tr>
</tbody>
</table>

^1 Spot transactions, outright forwards and FX swaps. Source: BIS (2010)

Table 2: Concentration in the banking industry

---

^5 Order flow consists of signed transactions. A positive sign is given when the initiator of a trade buys, a negative sign when the initiator of a trade sells.
In the interbank market, transactions do not only take place bilaterally between dealers, but dealers can also contract brokers to do this. Brokers will never quote their own prices but they will, by contrast, collect the quotes of different dealers and in turn communicate these to dealers. The prices communicated are the best bid and ask price. The advantage of working with a broker is that dealers remain anonymous. Only when a dealer agrees to buy or sell at the price communicated by a broker, will the broker reveal the identity of the dealer from whom the best bid or ask price was coming. Brokers will never trade for their own account and, in return for their services, they ask a commission fee. Because of the fact that brokers arrange matches between dealers, this leads to a certain degree of concentration.

These different parties lead, in turn, to different types of trades according to Lyons (2006). These different types of trades can be seen in figure 1. A distinction is made between direct interdealer trades, brokered interdealer trades and customer-dealer trades. The inner ring is the most liquid ring and is recognized by spreads that are narrower than in the outer two rings. Going from the inner to the outer ring the spread increases. Note that – according to Lyons (2006) – the spread given to a customer depends on the volume he trades. This will be lower for customers who trade high
volumes. Direct interdealer trading usually takes place for trades of standard size (i.e. 10 million USD), whereas brokered interdealer trading usually happens for larger trade sizes.

Table 3 gives the distribution of the foreign exchange turnover according to counterparty. Other financial institutions include hedge funds, pension funds, central banks, etc. The increase in the foreign exchange market turnover mainly comes from the increased trading activity of the other financial institutions. Furthermore, in 2010 for the first time their trading activity exceeded trades between reporting dealers. The decreased share of the interdealer transactions is explained by the increased concentration caused by mergers and acquisitions in the banking industry and the use of electronic broking platforms (cf. subsection 2.3.) (BIS, 2010).

<table>
<thead>
<tr>
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<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1,527</td>
<td>100</td>
<td>1,239</td>
<td>64</td>
<td>1,934</td>
<td>100</td>
<td>3,324</td>
<td>100</td>
<td>3,981</td>
<td>100</td>
</tr>
<tr>
<td>With reporting dealers</td>
<td>961</td>
<td>63</td>
<td>719</td>
<td>37</td>
<td>1,018</td>
<td>53</td>
<td>1,392</td>
<td>42</td>
<td>1,548</td>
<td>39</td>
</tr>
<tr>
<td>With other financial institutions</td>
<td>299</td>
<td>20</td>
<td>346</td>
<td>18</td>
<td>634</td>
<td>33</td>
<td>1,339</td>
<td>40</td>
<td>1,900</td>
<td>48</td>
</tr>
<tr>
<td>With non-financial institutions</td>
<td>266</td>
<td>17</td>
<td>174</td>
<td>9</td>
<td>276</td>
<td>14</td>
<td>593</td>
<td>18</td>
<td>533</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 3: Global foreign exchange market turnover by counterparty

The last characteristic in line is transparency. Transparency is the degree to which one has a clear view of the different transactions that take place between the participants in a market. Transparency in the foreign exchange market is important because it allows dealers to determine the ‘correct’ exchange rates. When transparency is low, it is very difficult to gather information that is necessary to arrive at these exchange rates and will thus not be reflected in the exchange rates. Transparency is related to how much one can see of the order flow. When a market is highly transparent, participants can see the trades that take place and will adjust their expectations and actions accordingly. However, the foreign exchange market is characterized by low transparency. The reason for this is twofold. First, there is no legislation that obligates disclosure of transactions on the foreign exchange market in contrast with, for example, equity markets and bond markets. Second, the institutional structure contributes to the low transparency. The foreign exchange market is a...
decentralized multiple-dealer market (cf. subsection 2.1.). This structure makes it very hard to have an overview all the transactions that take place and consequently also leads to low transparency. Furthermore, this decentralization of the foreign exchange market makes it very hard to regulate this market. In addition to this, Osler (2009) makes a distinction between pre-trade transparency and post-trade transparency on the foreign exchange market. Before trades take place only the best bid and ask quotes are available i.e. pre-trade transparency, whereas post-trade transparency refers to the listing of transaction prices at which trades took place. The size of the trades are not revealed. Consequently, both the pre- and the post-trade transparency are low.

2.3. Technological developments on the foreign exchange market

Having discussed the three main characteristics of the foreign exchange market, it is also interesting to know how technological developments have influenced the evolution of the foreign exchange market. In 1987, Reuters launched Dealing 2000-1 (D2000-1). D2000-1 is a system that made it possible for dealers to trade through chat messages instead of making trades over the phone or through an intercom system when dealing bilaterally. In 1992, Reuters introduced Dealing 2000-2 (D2000-2), which meant the arrival of electronic brokers. D2000-1 and D2000-2 together form Dealing 2000 (or D2000). A year later Electronic Broking Services (EBS) was launched on the market, which is more or less the same as D2000-2. Furthermore, the advent of the Internet allowed customers to place their orders online in the late nineties. Today electronic brokers use the newest version of the trading system by Reuters, that is D3000. The electronic broker systems fulfill the same function as the traditional voice brokers that work over the phone or through an intercom system, only now it is electronic.

These developments – however D2000-1 to a lesser degree – changed the market structure and had an impact on the liquidity of the market and on the possibilities of gathering information. Rime (2003) argues that it has an impact on transaction costs, because matching orders happen more efficiently i.e. search costs decrease for customers asking for quotes, commission fees of electronic brokers decrease, etc. This more efficient matching also means less hot potato trading, which means a lower share of interbank transactions (cf. subsection 2.1.). As dealers know better where the market price is at and matching happens more efficiently, dealers will be less inclined to share risk by passing on a trade like a hot potato. Furthermore the advent of electronic brokers – despite the fact that they perform the same function as voice brokers – led not only to a higher degree of

---

6 This subsection is based on Rime (2003), except when mentioned otherwise.
concentration on the foreign exchange market, but it also led to higher transparency: prices and signs of all transactions that take place through electronic brokers are now aggregated and visible.

This higher transparency, however, is a double-edged sword. Suppose a customer, for instance the central bank, goes to a bank and places a large order. It will now be much more difficult for the dealer from this bank to transfer the order to other dealers without the market becoming aware of it and conclude that this order may contain important information. Perfect transparency is also not wished for in the foreign exchange market. However, the fact that dealers still use electronic brokers indicates that dealers are able to live with this higher transparency.

The arrival of electronic brokers does not mean the disappearance of voice brokers or the end of bilateral transactions. It is mainly the markets in major currencies that work with these electronic broker systems. Furthermore, in times of stress, dealers seem to appreciate the existence of an alternative trading channel.

At the end of the nineties, customers started trading with each other directly on non-bank sites on the Internet. These non-bank sites marked a key change in the bank-customer relationship: increased competition for the customer order flow, which is an important source of information (cf. subsection 2.1.). Banks reacted to this by creating websites (e.g. FXConnect, Currenex, FXall) for their customers. On these sites banks offer quotes when requested for by customers. Administration is easier for both parties. These sites are multibank sites, because different banks can provide prices on them (Rime, 2003). Lyons (2002) puts forward three possible scenarios for the future of bilateral transactions between customers which we will not discuss in depth. He believes the most likely scenario is the maintenance of the current structure in which banks fight for customers’ orders by offering competitive prices in comparison with those on non-bank sites.

2.4. Instruments traded on the foreign exchange market

It is relevant to know that when one talks about the foreign exchange market in its broadest sense, this not only includes the spot markets in major currencies like the US dollar, the Japanese yen, the euro, but it also contains markets in other instruments like forwards, options and swaps (i.e. currency and foreign exchange swaps7) in a lot of different currency pairs alongside these major currencies.

7 The main difference between these two instruments is that in a foreign exchange swap an exchange takes place of the principal amount of two currencies which is some time later reversed, whereas in a currency swap
Despite the strong growth of the foreign exchange market in financial derivatives, the spot market is still considered as the essence of the foreign exchange market. This can be seen when reviewing the literature on the microstructure of the foreign exchange market. This literature is mainly focused on the spot market. Also, table 4 that gives an overview of the distribution of transaction volume according to instrument, shows this clearly. Table 5 gives an overview of the distribution of transaction volume according to currency and gives the reader an idea of the currencies that are traded the most. To make it clear, when we talk about the foreign exchange market, we mean the spot foreign exchange market unless mentioned otherwise.

Foreign exchange market turnover by instrument

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Spot transactions</td>
<td>568</td>
<td>386</td>
<td>631</td>
<td>1,005</td>
<td>1,490</td>
</tr>
<tr>
<td>Outright forwards</td>
<td>128</td>
<td>130</td>
<td>209</td>
<td>362</td>
<td>475</td>
</tr>
<tr>
<td>Foreign exchange swaps</td>
<td>734</td>
<td>656</td>
<td>954</td>
<td>1,714</td>
<td>1,765</td>
</tr>
<tr>
<td>Currency swaps</td>
<td>10</td>
<td>7</td>
<td>21</td>
<td>31</td>
<td>43</td>
</tr>
<tr>
<td>Options and other products</td>
<td>87</td>
<td>60</td>
<td>119</td>
<td>212</td>
<td>207</td>
</tr>
<tr>
<td>Total turnover foreign exchange instruments</td>
<td>1,527</td>
<td>1,239</td>
<td>1,934</td>
<td>3,324</td>
<td>3,981</td>
</tr>
</tbody>
</table>

Memo:
- Turnover at April 2010 exchange rates
- Estimated gaps in reporting
- Exchange-traded derivatives

Table 4: Foreign exchange market turnover by instrument

*Adjusted for local and cross-border inter-dealer double-counting. *Previously classified as part of the ‘Traditional FX market’. *The category “other FX products” covers highly leveraged transactions and/or trades whose notional amount is variable and where a decomposition into individual plain vanilla components was impractical or impossible. *Non-US dollar legs of foreign currency transactions were converted into original currency amounts at average exchange rates for April of each survey year and then reconverted into US dollar amounts at average April 2010 exchange rates. *Sources: FOW TRADEdata; Futures Industry Association; various futures and options exchanges. Reported monthly data were converted into daily averages of 20.5 days in 1998, 19.5 days in 2001, 20.5 in 2004, 20 in 2007 and 20 in 2010. Source: BIS 2010 (summary tables)

interest payments are exchanged over a certain period of time and typically at maturity the principals are exchanged.
## Currency distribution of global foreign exchange market turnover

Percentage shares of average daily turnover in April

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>US dollar</td>
<td>86.8</td>
<td>89.9</td>
<td>88.0</td>
<td>85.6</td>
<td>84.9</td>
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<tr>
<td>Euro</td>
<td>...</td>
<td>37.9</td>
<td>37.4</td>
<td>37.0</td>
<td>39.1</td>
</tr>
<tr>
<td>Deutsche mark</td>
<td>30.5</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>French franc</td>
<td>5.0</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>ECU and other EMS currencies</td>
<td>16.8</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Slovak koruna¹</td>
<td>...</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>...</td>
</tr>
<tr>
<td>Japanese yen</td>
<td>21.7</td>
<td>23.5</td>
<td>20.8</td>
<td>17.2</td>
<td>19.0</td>
</tr>
<tr>
<td>Pound sterling</td>
<td>11.0</td>
<td>13.0</td>
<td>16.5</td>
<td>14.9</td>
<td>12.9</td>
</tr>
<tr>
<td>Australian dollar</td>
<td>3.0</td>
<td>4.3</td>
<td>6.0</td>
<td>6.6</td>
<td>7.6</td>
</tr>
<tr>
<td>Swiss franc</td>
<td>7.1</td>
<td>6.0</td>
<td>6.0</td>
<td>6.8</td>
<td>6.4</td>
</tr>
<tr>
<td>Canadian dollar</td>
<td>3.5</td>
<td>4.5</td>
<td>4.2</td>
<td>4.3</td>
<td>5.3</td>
</tr>
<tr>
<td>Hong Kong dollar³,⁴</td>
<td>1.0</td>
<td>2.2</td>
<td>1.8</td>
<td>2.7</td>
<td>2.4</td>
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<tr>
<td>Swedish krona⁵</td>
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<td>2.5</td>
<td>2.2</td>
<td>2.7</td>
<td>2.2</td>
</tr>
<tr>
<td>New Zealand dollar³,⁴</td>
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<td>0.6</td>
<td>1.1</td>
<td>1.9</td>
<td>1.6</td>
</tr>
<tr>
<td>Korean won³,⁴</td>
<td>0.2</td>
<td>0.8</td>
<td>1.1</td>
<td>1.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Singapore dollar³</td>
<td>1.1</td>
<td>1.1</td>
<td>0.9</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>Norwegian krone³</td>
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<td>1.5</td>
<td>1.4</td>
<td>2.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Mexican peso³</td>
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<td>0.8</td>
<td>1.1</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Indian rupee³,⁴</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Russian Rouble³</td>
<td>0.3</td>
<td>0.3</td>
<td>0.6</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Chinese renminbi⁴</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Polish zloty¹</td>
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<td>0.5</td>
<td>0.4</td>
<td>0.8</td>
<td>0.8</td>
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<tr>
<td>Turkish new lira²</td>
<td>...</td>
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<td>0.1</td>
<td>0.2</td>
<td>0.7</td>
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<tr>
<td>South African rand³,⁴</td>
<td>0.4</td>
<td>0.9</td>
<td>0.7</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Brazilian real³,⁴</td>
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<td>0.4</td>
<td>0.7</td>
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<tr>
<td>Danish krone³</td>
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<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>New Taiwan dollar³</td>
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<tr>
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<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Czech koruna³</td>
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<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Because two currencies are involved in each transaction, the sum of the percentage shares of individual currencies totals 200% instead of 100%. Adjusted for local and cross-border inter-dealer double-counting (i.e. “net-net” basis). ²Data previous to 2007 cover local home currency trading only. ³For 1998, the data cover local home currency trading only. ⁴Included as main currency from 2010. For more details on the set of new currencies covered by the 2010 survey, see the statistical notes in Section IV of BIS (2010). ⁵For 1998, the data cover local home currency trading only. Included as main currency from 2007. Source: BIS 2010

### Table 5: Currency distribution of global foreign exchange market turnover

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<th>Currency</th>
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<tbody>
<tr>
<td>Philippine peso</td>
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<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Chilean peso</td>
<td>0.1</td>
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<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Indonesian rupiah</td>
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<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Israeli new shekel</td>
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<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
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<td>Colombian peso</td>
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<td>0.0</td>
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<td>0.1</td>
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<td>0.1</td>
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<tr>
<td>Other currencies</td>
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<td>6.6</td>
<td>7.6</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>All currencies</strong></td>
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<td><strong>200.0</strong></td>
<td><strong>200.0</strong></td>
<td><strong>200.0</strong></td>
<td><strong>200.0</strong></td>
</tr>
</tbody>
</table>

2.5. **Theoretical approaches to the foreign exchange market**

Before moving on to the next section that deals with the components of the bid-ask spread, we will first elaborate some more on the different theoretical approaches to the foreign exchange market in order to be able to position the next section within the right theoretical context.

It was Lyons (2006) who noted that the discipline of exchange rate economics was not sufficient to explain exchange rate behavior on the FX market. Exchange rate economics is concerned with macroeconomic determinants (e.g. GDP⁸, inflation) and how these macroeconomic determinants can be modeled to explain exchange rates. Lyons (2006) pointed out the importance of and the need for a microstructure approach to the foreign exchange market which was until then lacking. This lack of a microstructure approach to the foreign exchange market was because the field of microstructure in finance conventionally had the equity market as a focal point. The development of a microstructure approach to the foreign exchange market came after Lyons had sat next to a spot trader for several days on the spot foreign exchange market and watched him work.⁹ In a chronological fashion, Lyons (2006) distinguishes between three theoretical perspectives on the foreign exchange market:

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⁸ Gross domestic product or GDP is the total value of all goods and services within a country (Levi, 2009).
⁹ This observation of the existence of a gap between theory and practice by Lyons, led us to carry out a survey (cf. section 8).
(1) Goods market perspective  
(2) Asset market perspective  
(3) Microstructure perspective

The goods market perspective on the foreign exchange is the one where buying and selling of goods is the driver of the demand for or the supply of currencies and, in turn, determines exchange rate behavior. Suppose a country increases its import activities, then there will be an increased demand for foreign currencies. This is the original perspective that held until the start of the 1970s. In this perspective one could, for instance, expect that a country with a trade deficit on its trade balance will have a depreciated currency.\(^{10}\) However empirical testing of this perspective did not give the results hoped for. The suggested macroeconomic determinant, i.e. the trade balance, did not explain the exchange rate dynamics. As mentioned earlier, only a small fraction of the total traded volume on the foreign exchange market is the result of buying and selling goods (cf. subsection 2.2.), so these poor results cannot come totally unexpected.

From the seventies onwards the asset market perspective made its appearance. This perspective has its roots in the goods market perspective. Not only buying and selling of goods but also buying and selling of assets is considered a driver of the demand for and the supply of currencies and thus, in turn, also determines exchange rate dynamics. The logic behind it is exactly the same: a country in which they buy more foreign assets, will have a higher demand for foreign currencies. The profits or losses on these assets will furthermore depend on the exchange rate movements of the foreign currency needed to buy these assets. The models in this perspective are somewhat more complex. This cannot be said for the goods market perspective. Again however, empirical testing of these models did not give the results hoped for. These models again are based on macroeconomic determinants.\(^{11}\)

Lyons (2006) reasons that these two perspectives – because they do not give significant empirical results – should be augmented with elements from microstructure finance. This has led to the microstructure perspective on the foreign exchange market. Each perspective consequently expands the previous perspective. A well-known definition of market microstructure is the one from Maureen

\(^{10}\) A deficit on the trade balance means that the supply of the domestic currency increases on the foreign exchange market because demand for foreign currencies increases. This should logically lead to a depreciation of the domestic currency.  
\(^{11}\) What Lyons (2006) also stresses, is that these macroeconomic models do not take the total traded volume into consideration. However, as this is a distinct characteristic of the foreign exchange market, at least some consideration should be given in these models to this factor.
O’Hara (1995). Paraphrasing O’Hara (1995), market microstructure comes down to the study of how prices of assets are formed by trying to discover the underlying formation process whilst taking into account trading rules. Three characteristics of microstructure finance also arise in the microstructure perspective on the foreign exchange market:

- Some information is private.
- Different market players each have their own way of affecting rates.
- Different institutional structures and, as a result, different trading mechanisms that affect exchange rates.

The first characteristic is key and will pop up several times in the next section. Since dealers at banks receive customer buy or sell orders that are not disclosed to dealers working for other banks, this renders information to dealers that is private (cf. subsection 2.2.). The reason why different market players affect rates in their own way is, for instance, because they can interpret the same information in their own way\textsuperscript{12} or because of the inherent nature of the market player: a speculator will display different market behavior than a market-maker. Why differences in institutional structures affect rates differently should be clear by now (cf. subsection 2.1.).

Looking at these three characteristics, it is clear that the microstructure perspective introduces some very important elements. Two of these elements are the order flow and the bid-ask spread. These elements will not be found in macroeconomic models.

Order flow are signed transactions and should not be confused with volume. We consider a simple example to explain the concept. Suppose a dealer receives a sell order for 5 million USD from one of his clients. From the client’s perspective – who sells 5 million USD to the bank and who is the initiator of the trade - the order flow is -5 million USD. However, the volume traded is 5 million USD and is unsigned. If it had been a buy order, then order flow would have gotten a positive sign. Signing happens from the perspective of the initiator of the trade. When there are no dealers, then the limit order book is used and the market orders that arrive to clear the limit orders are considered to come from the initiating side. In this case, market orders determine the sign of the order flow. In the microstructure approach, order flow is used to explain exchange rates. In the literature this relationship is referred to as ‘the order flow model’. The reason for the substantial role that order flow plays, can be explained as follows: non-dealers watch, analyze and learn about fundamentals.

\footnote{\textsuperscript{12} This was also mentioned by one of our respondents in our survey (cf. section 8).}
When these non-dealers start trading on the foreign exchange market, dealers are provided with customer order flow. These dealers, in turn, will try to discover and learn about fundamentals by observing their order flow. Depending on how they interpret this order flow, they will determine where to set the exchange rate. Important about this customer order flow, is that this provides a dealer with private information (cf. subsection 2.2.).

The second key element in the microstructure approach, and the subject under study here, is the bid-ask spread or b/a spread. Several reasons can be cited to explain the attention that b/a spreads receive. First of all, b/a spreads get a lot of attention from a scientific public because datasets usually consist of bid and ask prices and consequently b/a spreads are easily measurable.\(^\text{13}\) This cannot be said for instance from the just discussed customer order flow, because this is private information to dealers. Second, from a practical point of view, b/a spreads are important because they are considered to cover trading costs. So, they provide information about the fairness of dealer’s rents. Finally, the characteristic that different trading mechanisms affect prices in different ways (cf. above) has not been considered to be part of models based on rational expectations i.e. the models used in the goods market perspective and the asset market perspective. Actually, in these models, the assumption has been made that trading mechanisms do not affect prices. However this assumption no longer holds in the microstructure perspective and thus the question arises on how they affect prices and how they influence the b/a spread. Despite the fact that the b/a spread receives a lot of attention and is a key element in the microstructure perspective, Lyons (2006) does stresses that b/a spread determination is only one subfield in microstructure literature. In microstructure literature many models exist and a lot of these models do not even mention the b/a spread.

As the purpose of this paper is to see whether or not certain determinants\(^\text{14}\) have a significant influence on the size of the b/a spread, we can now put our work in a correct theoretical framework.

\(^{13}\) This is especially the case for equity markets and bond markets where trades must be disclosed.

\(^{14}\) These components can be found in section 3 and are the inventory holding component, the order costs, the adverse selection component and competition.
3. The components of the bid-ask spread

The bid-ask spread or b/a spread\(^\text{15}\) is the difference between the stated bid and ask price. This difference can also be explained using the active and passive party. The party that requests the quotes and decides whether or not they will sell at the bid price or buy at the ask price, is called the active party or the initiator of the trade. The party that quotes these prices is called the passive party. The active party has the freedom to choose when to place a market order and/or a limit order as the passive party is ready and waiting to provide liquidity. Consequently the passive party is the one who determines the size of the b/a spread as he quotes bid and ask prices on request, whereas the active party is the one for whom the spread is a given (Levi, 2009).

The b/a spread is expressed in so called pips. A pip is one unit of the fourth decimal point. Suppose the bid and ask price for EUR/USD are 1.2323 and 1.2325 respectively, then the spread is two pips (Levi, 2009).

According to Logue (1975), a distinction can be made in the research work on the behavior of a market-maker.\(^\text{16}\) On the one hand, there are studies that focus on the determinants of the b/a spread (see Demsetz (1968), Bagehot (1971), Tinic (1972), etc.). On the other hand, there are studies that focus on how the market-maker determines his equilibrium price defined as the mid-point price between the bid and the ask price according to his inventory (see Smidt (1971), Barnea (1974), etc.). This suggests that the market-maker will change the level of his bid and ask prices by changing the equilibrium price, however he may keep the size of the b/a spread the same. Logue (1975) focuses on mid-point price behavior, so his conclusions will not be mentioned here. However the distinction that he makes is a very important and fundamental one.

As it is the goal of this paper to apply a b/a spread decomposition model, we will exclusively focus on the first strand of literature by giving an overview of the studies that examine the determinants of the b/a spread. We make a distinction between theoretical models, which we will discuss in a

\(^{15}\) We will use the terms bid-ask spread, b/a spread and spread interchangeably.

\(^{16}\) A market-maker is someone who buys and sells securities for his own account or for his customers (Flood, 1991). Lyons (2006) remarks that, in the literature, ‘dealer’ and ‘market-maker’ often are used interchangeably. However, if you want to make a distinction between these two terms, then dealer is the appropriate term for markets that have a dealership structure. The term market-maker is more appropriate in case of a hybrid auction-dealership market structure. So, for the FX exchange market, the term dealer is more correct. This is also the term we will use.
chronological fashion, and the empirical research work done based on these models. This enhances the existing literature on the b/a spread, as this has not been done before.

### 3.1. Theoretical models

#### 3.1.1. The b/a spread as a compensation for liquidity services

Demsetz (1968) was the first to explore the determinants of the b/a spread. According to Demsetz the b/a spread is the compensation a dealer asks for predictable immediacy. Suppose investors want to buy a certain security, then they will call upon a dealer who is available to take the opposite position of the transaction. The fact that the dealer asks compensation for the immediacy he offers in the form of the b/a spread can be explained by the dealer’s willingness to distance himself from his optimal and desired portfolio that he would normally hold when he does not provide this service. Demsetz also formulated this immediacy otherwise as the willingness to keep an inventory and wait for buy and sell orders to arrive. Demsetz looked for the determinants that influenced this cost of immediacy and consequently influenced the size of the b/a spread. In his model he suggests the time rate of transactions, the volume traded and the price of the security as determinants of this cost of immediacy. Demsetz also argues that competitive forces have an impact on the size of the b/a spread. The fiercer the competition, the narrower the b/a spread becomes. However, in general, changes in the size of the b/a spread indicate changes in the cost for immediacy.

Tinic (1972) modified and refined the work of Demsetz (1968). There is a difference in the terms used as Tinic does not talk about the cost of immediacy but of the liquidity cost that is represented by the b/a spread. Tinic argues that the determinants formulated by Demsetz are insufficient to explain the b/a spread. The cost of liquidity services is, to a large extent, determined by inventory costs and policies.\(^7\) These inventory costs are, in turn, divided into three categories: factors affecting the purchase/sale of a single issue and the costs of uncertainty, factors affecting the overall cost structure of a dealer and factors that erode or enhance the profit margin. In this latter category we find, for instance, competition. In essence, the model of Tinic is more extensive as he includes more determinants in his model.

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\(^7\) Basically, policies regulate the actions of dealers and can prevent them from setting too wide spreads. For example, Tinic (1972) argues that it is not unreasonable to expect monopolistic pricing policies in the NYSE when there are no external competitive pressures.
In the work of Tinic and West (1972) the b/a spread is also seen as the liquidity cost and again some determinants of the b/a spread are formulated. However, these determinants could already be found in the work of Demsetz (1968) and Tinic (1972) and, consequently, their work does not introduces any new determinants.

The above-mentioned research works can be taken together and assembled under the common denominator that Barnea and Logue (1975) have formulated as ‘The Liquidity Theory’. This theory states that the b/a spread is the cost for providing liquidity services. This can be seen as a summary of the first few works on the determinants of the b/a spread.

3.1.2. The b/a spread as a compensation for the lack of special information

Bagehot (1971) looked at the b/a spread from a different perspective. Instead of arguing that the b/a spread is the cost of liquidity services offered, Bagehot argues that a dealer who is on hand to trade is faced with three different types of dealers:

1. Dealers who have special information at their disposal
2. Dealers who trade because of liquidity reasons
3. Dealers who believe they have special information at their disposal, however they do not know that this information is already reflected in the prices

According to Bagehot, dealers who have special information – the first group - will try to exploit this information by trading with a dealer who is available to trade at any moment. Consequently, the latter will lose money against dealers who have special information. However, he will try to recover this loss by winning against the liquidity-motivated traders – the second group. These liquidity-motivated dealers trade because they want to smoothen their consumption or want to adjust their portfolios to a more desirable risk-return profile. The way in which he wants to recover this loss is by setting a b/a spread. However the size of the spread set by a dealer who is available to trade has an impact on both groups. If he sets this b/a spread very wide, it is unlikely that dealers with special information will trade because their chances of making a profit diminish. Especially if the information they have only indicates a small deviation from the equilibrium price. One might think that the wider the b/a spread, the greater the profits of the dealer will be. Nothing is further from the truth, as the second group will also be less motivated to trade with the dealer when there is a wide b/a spread. The third group, despite the fact that they think they have special information, actually increase the size of the second group. They allow the dealer to make the b/a spread narrower.
Barnea and Logue (1975) characterized this new perspective that was introduced by Bagehot (1971) as an adversary theory of ‘The Liquidity Theory’ and called it the ‘B-T Theory’. This theory states that the b/a spread is the compensation for the money dealers lose against inside information dealers, recovered against liquidity-motivated dealers by setting a b/a spread.

Copeland and Galai (1983) have formally analyzed the idea of Bagehot (1971) and constructed a theoretical model in which an equilibrium b/a spread was determined by making a comparative assessment of the money lost to traders with special information against the profits they make by trading with liquidity traders.

3.1.3. Stoll’s multiperspective approach

The work of Stoll (1978a) is very important in the literature on the determinants of the b/a spread. Stoll acknowledged there was some research (see Demsetz (1968), Tinic (1972), Benston and Hagerman (1974)\textsuperscript{18}, etc.), that tried to determine the factors underlying the b/a spread, had been done but they lacked an explicit theoretical basis. In response to this, Stoll developed a more rigorous and a more explicit model of the determinants of the b/a spread.

Stoll (1978a) follows Demsetz’s (1968) reasoning that the b/a spread is the compensation for providing immediacy, but Stoll extends the work of Demsetz by arguing that this compensation consists in three kinds of transaction costs:

1. Order costs
2. Holding costs
3. Information costs

The order costs are the costs of arranging trades from beginning to end and comprise, for instance, the costs of the infrastructure (space rent, computer, etc.), communication costs, clearing costs, costs of record keeping, etc. Most works, like Stoll (1978a) and Glosten & Harris (1988), consider these order costs as a fixed cost per transaction, which results in decreasing costs per unit of volume when volume increases. This cost are also known as the order processing cost (or the OPC).

\textsuperscript{18} Benston and Hagerman (1974) further discuss the determinants suggested by Demsetz (1968) and also conduct empirical tests to see whether these determinants have a significant influence on the b/a spread.
However, the term used to indicate the order processing cost is not always clear. O’Hara and Oldfield (1987), for instance, talk about transaction costs. Order processing costs are assumed to be included in these transaction costs. Yao (1998a), for his part, includes ‘fixed’ transaction costs in his model. It is not clear here either what he means by these ‘fixed’ costs, but he does say that these contain the order costs. Glosten and Harris (1988) also speak of fixed transaction costs, but they do state that it consists, for instance, of trade clearing costs and, consequently, can be seen as order costs.

Stoll (2003) argues that it is likely that the b/a spread will be wider in a market where there are no professional dealers, because this lack of professional dealers bring with it higher order costs.

According to Stoll (1978a), the **holding costs** are the costs a dealer bears for moving away from his desired portfolio and for being available to trade when other dealers want to buy or sell a security. Almost literally it is the cost for holding an inventory of certain securities the dealer would otherwise not hold if he only holds his optimal portfolio. Basically, this view corresponds with the work of Demsetz (1968) (cf. subsection 3.1.1.). The holding costs are also known as the inventory holding component (or the IHC) of the b/a spread.

The IHC is a dual concept according to Stoll (1978a). First, the dealer faces opportunity costs by choosing to hold certain securities. The money that the dealer has used to buy the securities could have been used for something else that could have been more profitable. Second, the price can change when holding the security in inventory. The price of the security in inventory can decrease in value, but it can also increase in value and thus change in a more desirable direction for the dealer. It should be noted that when you have a security that has more or less a stable value over time, this will lead to lower inventory holding costs. If the dealer has a security in portfolio that has a high price volatility, then the shorter the odds of that security’s value moving in an undesired direction, and the higher the holding costs will be.

The IHC is also closely related with the liquidity of the market of the security. Demsetz (1968) already argued that the higher the transaction rate in a certain security, the easier it is to offset your current inventory position with an offsetting trade. In very liquid markets, transactions follow one another closely or, to use the terms of Demsetz (1968), the ‘time rate’ is high i.e. the frequency at which orders arrive is high, which means that you will find a dealer who is willing to take an offsetting position more quickly. Our work here is focused on the foreign exchange market, which is generally

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19 To be more applicable to the foreign exchange market, security can be replaced by currency.
said to be a very liquid market. However, there are some differences in liquidity depending on the currency pairs exchanged. The markets in major currencies are far more liquid than the markets in minor currencies.

Theoretical examinations of the IHC were done by Garman (1976)\textsuperscript{20}, Stoll (1978a) and Amihud and Mendelson (1980). These latter authors, for instance, constructed a formula that describes the behavior of the b/a spread as a function of the inventory position. When the b/a spread comes close to a certain desired inventory position, the spread will be minimal and the other way around.

There are also other theoretical works that justify an IHC, however it is examined in the context of what influence the inventory has on prices independent of what happens to the b/a spread. Our focus is not on how the equilibrium price is determined, but one should be aware that this component also exists in this context. Ho and Stoll (1981) argue that when a dealer has a large inventory of a certain stock, he will lower both bid and ask price to encourage potential buyers. The size of the b/a spread, however, remains the same and is, in their work, influenced by two other factors: transaction rate and transaction size, which, of course, can be linked to liquidity.

The information costs suggested by Stoll (1978a) are the costs a dealer incurs as a consequence of trading with a counterparty that has superior information.\textsuperscript{21} A dealer does not know who has superior information, so he will protect himself by widening the b/a spread. These counterparties who have superior information are also called information traders and the component is also known as the adverse selection component (or the ASC). This cost corresponds with the new perspective introduced by Bagehot (1971) (cf. subsection 3.1.2.).

Other papers also justified the existence of an ASC that has an influence on the b/a spread. Copeland and Galai (1983) formulated a model in which the b/a spread widens when the share of informed traders increases (cf. subsection 3.1.2.). In Glosten and Milgrom’s model (1985), the b/a spread not only becomes larger when the number of informed traders increases, but also when the quality of the private information improves (or when the elasticity of the liquidity traders increases). These authors come to the theoretical conclusion that there is an ASC that has an influence on the b/a spread. However, one should note that these authors do not say this is the only determinant of the b/a spread.

\textsuperscript{20} Garman (1976) has constructed an inventory control model that looks at the arrival rate of orders. If this arrival rate is very uncertain, then dealers are forced to hold a more unbalanced portfolio.

\textsuperscript{21} The different authors use different terms like superior information or special information. It is information that can be exploited because it is private.
Some other theoretical studies, like Kyle (1985), Easley and O’Hara (1987), Admati and Pfleiderer (1988a) or Hasbrouck (1991a) also justify the existence of an ASC, however in their work they examine it in the context of the influence it has on the equilibrium price. As mentioned in the beginning of this chapter, our work does not focus on how the equilibrium price is determined, but it is interesting to know that they also take the ASC into account in their work.

Concerning the ASC, Hasbrouck (1991a, 1991b) made some interesting remarks. First, he in fact mentioned that, in past models, the information asymmetry component has been modeled as a determinant both of price and of the b/a spread (Hasbrouck, 1991a). Second, he argues that although b/a spreads can be observed easily, there is a huge drawback if one wants to know the influence of the ASC component on the b/a spread (Hasbrouck, 1991a). He explains this by referring to the work of Glosten (1989). Glosten, in his work, showed that for a certain trade size, the b/a spread differs according to the degree of competition. A monopolistic dealer, for instance, will set a wider b/a spread. Furthermore, Hasbrouck (1991b) argued that the stated b/a spread is conditional on a certain trade size. Hasbrouck (1991b) argues that the impact of the ASC on the b/a spread, in general, is not considered for trades of different sizes. Consequently, Hasbrouck (1991a) recognizes that there are other factors, in addition to the ASC, that can affect the size of the b/a spread, e.g. competition, clearing fee and trade size. He argues that it is not easy to separate the effect of the ASC from the other components. Third, another drawback mentioned by Hasbrouck (1991b), is that the b/a spread measures the information asymmetry in an absolute way. It can be interesting to know what the size of this is relative to the total information that acts on the value of a security. Hasbrouck (1991b) thus makes a plea for an absolute and relative measure of informational trades. Hasbrouck (1991b) did introduce a relative measure for trade informativeness, but this was fitted within a model that investigated stock price formation.

Other examples of studies that consider the ASC as a determinant of the b/a spread are those of Benston and Hagerman (1974), Branch and Freed (1977), Chiang and Venkatesh (1988), McInish and Wood (1992) and Foster and Viswanathan (1993). An in-depth study of these works shows that there are several methods possible for modeling the ASC component, one method more complex than the

22 This is also true for the price.

23 In both Hasbrouck (1991a) and Hasbrouck (1991b), the impact of information on price is investigated and not on the b/a spread.
other.\textsuperscript{24} For example, Branch and Freed (1977) use the number of different securities that a dealer trades as a proxy for the ASC.

In the context of the adverse selection component, Lyons (1996)\textsuperscript{25} conducted some interesting research work. Lyons (1996) wanted to know whether or not high trading intensity on the foreign exchange market conveyed more information asymmetry in its trades. Dealers can be faced with customers (dealer and non-dealer) that have special information about a security’s true price which they will try to exploit to make a profit from this information (cf. subsection 3.1.2.). For example a dealer – who is the only one who has a view on his non-dealer customer order flow – can exploit the information that the non-dealer customer order flow contains on the interdealer market because it is private information. In his research work, Lyons (1996) makes a distinction between, on the one hand, the hot potato perspective and, on the other hand, the event uncertainty perspective. In this second perspective, which he adopted from the work of Easley and O’Hara (1992), both the presence of transactions and absence of transactions contain information. According to Easley and O’Hara (1992), when transactions take place, they provide info on the direction of the information, whereas the absence of transactions would have us believe that probably no information event has occurred. Conclusively the trade intensity tells something about information event uncertainty. Uncertainty increases when no transactions take place. Uncertainty decreases when transactions take place. So, when trading intensity increases, the trades should contain more information. In the hot potato perspective, when trading intensity increases, the trades contain less information. For that we refer to the work of Admati and Pfleiderer (1988a). Admati and Pfleiderer (1988a) are the first ones to make a distinction between discretionary and nondiscretionary liquidity traders. In contrast to nondiscretionary traders who have no freedom in choosing the timing of their trade, discretionary traders are able to time their transactions. Admati and Pfleiderer (1988a) do assume that they are restricted to a certain time period in choosing this timing, for example the trades must take place before the trading day ends. Furthermore, discretionary traders will prefer to trade when there is a lot of trading activity in a certain security because then their trades do not have a lot of influence on the security’s price. Because these liquidity traders have the incentive to group their transactions, trades are less informative when trading intensity is high. Lyons (1996), in his research work, came to the finding that transactions were less informative when time between trades is small, which fits the hot potato perspective.

\textsuperscript{24} The same holds true for the other components mentioned. In our work here, we do not give an overview of all the possible modeling methods of the different components, as there are too many methods and this would lead us too far astray.

\textsuperscript{25} Lyons (1996) was already mentioned in the section on the foreign exchange market. He argued that hot potato trading helped increase volume turnover in the foreign exchange market.
Despite the interesting research work of Lyons (1996) in which he introduces and describes different and contradictory perspectives concerning the ASC, other works can provide yet another perspective on how the ASC could possibly influence the b/a spread. For example, McInish and Wood (1992) argue that those periods during which there are more exceptionally small or large trades contain more information.26 For this argument they base themselves on Hasbrouck (1988) who, in turn, argued that exceptionally large trade orders contain more information. Nevertheless, McInish and Wood (1992) also contrasted this, citing Amihud and Mendelson (1980), who argue that unusually large trades may capture dealers moving away from their desired inventory position, which can be linked with the IHC.

Admati and Pfleiderer (1988a) argue that informed traders will trade when there is a lot of activity by liquidity traders and the reason for this, as argued by Admati and Pfleiderer (1988a), can be linked to the influence of the IHC on the b/a spread: if informed dealers trade when liquidity traders are actively trading, inventory costs will be low, which will lead to smaller b/a spreads and, consequently, lower transaction costs for these information-motivated traders. And, of course, it also gives them an opportunity to hide their trades that contain information better.

Because Stoll (1978a) introduces an IHC as well as an ASC, it can be argued that the Liquidity Theory and the B-T Theory of Barnea and Logue (1975) are not necessarily incompatible. In fact, they can even co-exist and have an influence at the same time (Stoll, 2003) (cf. above). However, Stoll (2003) also pointed out that there is a difference between these determinants. The inventory effect occurs because of public information that becomes available after the trade is made, whereas the adverse selection effect occurs because there is private information available before the trade happens and which will become public after the trade.

Furthermore, the two aforementioned theories – the B-T Theory and the Liquidity Theory – suggested by Barnea and Logue (1975), actually correspond with two dominant channels that are referred to in the theory on the determinants of the b/a spread. The first channel emphasizes the inventory holding costs and the models in this channel are called inventory control models. The

26 They found a statistically significant relationship between the b/a spread and measure that captured unusually large trades, which suggested that these exceptionally large trades contain private information.
second channel focuses on the relation between private information and the size of the b/a spread and the models in this channel are called asymmetric information models.  

Later works in which models are constructed that include both components – the IHC and the ASC – as determinants of the b/a spread and even other determinants too like order costs, competition, etc. show that these two dominant channels (the inventory control models and the asymmetric information models) are not necessarily antithetical. However, Yao (1998a) does argue that trying to separate these two components into empirical studies is not that easy. Examples of such theoretical studies can be found in Stoll (1978a) and Madhavan and Smidt (1991). Note that this difference is not always very clear. For example, according to Lyons (1996) these models are considered to belong to the inventory holding branch. Furthermore, the theoretical model on which our empirical work is based, namely the work of Bollen, Smith and Whaley (2004), also incorporates several components: the IHC, the ASC, the OPC and competition.

3.1.4. Competition as a determinant of the b/a spread

Besides the above-mentioned components, another component used in several theoretical models as a determinant of the b/a spread is competition.

The early works (see Demsetz (1968), Tinic (1972), Tinic and West (1972), etc.) on the determinants of the b/a spread already highlighted the influence that competition can have on the b/a spread. Competitive forces make the b/a spread smaller. This was already mentioned when discussing Demsetz’ (1968) work. Copeland and Galai (1982) furthermore argue that when there is perfect competition a dealer is not able to make a profit as his expected costs will equal his expected profits. However, a monopolist will be able to make a profit.

27 In the literature, b/a spread decomposition models are sometimes also categorized in another way i.e. not according to components but according to the method used. Categories belonging to the latter are: the covariance-based models and trade indicator models. The first group of models are based on serial covariance, while the second group of models are based on trade indicators that take into account whether the trade is executed near the bid quote or the ask quote that pre-exists before a transaction (McGroarty, ap Gwilym and Thomas, 2007). For example the theoretical decomposition models of Glosten and Harris (1988) and Huang and Stoll (1997) can be classified as trade indicator models according to McGroarty, ap Gwilym and Thomas (2007). The work of Stoll (1989) can be classified as a covariance based model according to Naranjo and Nimalendran (2000). Note, however, that there are also trade indicator models like the one of Madhavan, Richardson and Roomans (1997), that do not explain the composition of the b/a spread but do explain what the drivers of asset prices are. Examples of each category of models can be found in the work of Naranjo and Nimalendran (2000). Note that these are not necessarily b/a spread decomposition models and, strikingly, they classify the Huang and Stoll (1997) model as a covariance-based model.

28 The works that study the influence of determinants of price later on also include both components, e.g. Hasbrouck (1991b).
Competition can come in many forms (cf. subsection 3.2.1.). A global bilateral distinction can be made. There can be competition within a market. For example, dealers on the same market that quote bid and ask prices not only face competition from other dealers like them, but they also compete with dealers that submit limit orders. This form of competition has been recognized in many theoretical works (i.e. Demsetz (1968), Tinic (1972), Garman (1976), Stoll (1978a), Amihud and Mendelson (1980), Ho and Stoll (1981), Copeland and Galai (1982), etc.). In addition to competition within markets, there is also competition between markets. Suppose that the b/a spreads on the currency exchange in London are very wide for the currency pair EUR/USD, then this will probably be an invitation for traders to go somewhere else where they can trade euros for US dollars.

Non-competitive pricing can also determine the size of the b/a spread. For instance, dealers can adopt rules (for example, a minimum tick size\textsuperscript{29}) to increase the size of the b/a spreads or there can be agreements between market-makers to increase spreads.

### 3.2. Overview of empirical research

This section provides the reader with an overview of the empirical research work done on b/a spread decomposition models. We focus on the differences between the existing empirical papers, and how these differences affect the size of the b/a spreads and/or the determinants of the spreads. These differences are categorized as follows:

1. Earlier empirical studies vs. later empirical studies
2. Equity market vs. foreign exchange market
3. Customer market data vs. interbank market data
4. Pre-EMU regime vs. post-EMU regime
5. Dealer perspective vs. market perspective
6. Minor currencies vs. major currencies
7. Long inter-transaction time vs. short inter-transaction time

\textsuperscript{29} The tick size is the smallest incremental price change.
3.2.1. Earlier empirical studies vs. later empirical studies

The earliest empirical studies on the determinants of the b/a spread were those from the first theoretical thinkers about the b/a spread and its components. This led to the fact that the earliest empirical research studies done on the determinants of the b/a spread were based on less formal theoretical models than the later empirical research studies.

For example, Demsetz (1968) was the first to write about the determinants of the b/a spread and he was also the first to test whether the determinants he suggested had a significant influence on the size of the b/a spread. For this he used data of 200 securities that were listed on the NYSE. According to Demsetz (1968), the b/a spread is the compensation for providing immediacy (cf. subsection 3.1.1.). In his empirical research work he models this compensation for immediacy by means of two factors: the transaction rate i.e. how actively a security is traded, and the price of the stock. To measure the transaction rate, Demsetz (1968) uses not only the number of transactions per day i.e. the time rate, but he also uses the number of shareholders. Demsetz (1968) also argued that competition will have an impact on the size of the b/a spread, i.e. fierce competition will make sure that the b/a spread will remain close to the cost of providing immediacy and will inhibit the market-maker from asking monopolist rents. According to Demsetz (1968) there are different types of competition: the number of competing markets, the degree of competition for the specialist’s job, the number of limit orders placed by people other than market-makers, traders that circumvent the specialist and, finally, other specialists. In his empirical model Demsetz (1968) took the number of markets on which the security was listed in order to model the influence of competition. Important to recognize is that Demsetz (1968) suggests that there are different ways in which the cost of immediacy and competition can be modeled. This becomes even clearer when looking at the different forms of the regressions he tests in search of the best fitting regression. By different forms we mean that in one regression the b/a spread is linearly related to the time rate while, in another, he uses the logarithmic form of the time rate. Demsetz’ best fitting regressions are:

\[
\text{Spread} = a_0 + a_1 SP + a_2 \ln(TR) + a_3 M \tag{1}
\]

\[
\text{Spread} = a_0 + a_1 SP + a_2 \ln(NS) + a_3 M \tag{2}
\]

---

Demsetz (1968) assumes that the b/a spread will increase as price increases. This to keep the transaction cost per unit of price equal and to prevent arbitrage.

As the number of shareholders in a certain security increases, the interest in the security they hold will increase. As a consequence the transaction rate will increase.
Where $SP$ represents the stock price, $TR$ is the time rate, $NS$ is the number of shareholders in a certain stock and $M$ is the number of markets on which the stock is listed. Demsetz (1968) tested these coefficients for significance and found that they were all significant at the 5% significance level, with the exception of $M$. All coefficients take the expected signs: the price coefficient has a positive sign, all the other coefficients have a negative sign as they are expected to decrease the b/a spread.

Looking at the empirical research work of Demsetz (1968), it becomes clear by what we mean with our argument that earlier empirical works were based on less formal theoretical models. One could criticize Demsetz’s work by arguing that he just takes several factors and looks to see what fits best. The same holds true for the empirical work of Tinic (1972) and Tinic and West (1972). Note that Demsetz (1968) found that competition had no significant influence on the b/a spread. Tinic (1972), however, did find a statistical significant influence of competition in his empirical results. This led to the empirical research work of Tinic and West (1972) who focused on checking whether or not competition has a significant influence on the b/a spread.

The works of Demsetz (1968) and Tinic (1972) can be classified as inventory-based models (cf. subsection 3.1.3.), while other earlier empirical studies can be classified as information models. As the theory around the subject evolved over time, authors began to recognize, that both inventory and private information affect the b/a spread and this, in turn, led to empirical research work that validates both components. When testing later theoretical works that took into account both an IHC and an ASC, disentangling both components in empirical work proved to be a huge challenge, as argued by Yao (1998b). Besides the fact that later empirical works are based on more formal theoretical models, this makes it more difficult to compare the earlier empirical works with later works. Hasbrouck (1988) however pointed out that dynamic analyses could be used to disentangle the two effects. Conversely, Madhavan and Smidt (1991, 1993) constructed theoretical models that disentangle the two components from the start.

### 3.2.2. Equity market vs. foreign exchange market

There are several differences between the empirical works on the equity market and the foreign exchange market. First, extending theoretical models focused on the equity market to the foreign exchange market can be challenging because of the differences between these two markets. Second,
b/a spreads in general are wider on the equity market because this market is not as liquid as the foreign exchange market. Third, there is a difference in the percentage share of the b/a spread that is attributable to each of the different components.

In earlier empirical studies, the common focus was on the application of a decomposition model to the equity market. Trading processes sometimes show similarities over different markets, but there are also differences in the trading processes over different markets which can impact the empirical work as an application of a theoretical model (cf. subsection 2.1). In some of the empirical studies that focus on the equity market, data coming from the NYSE is used. This is, for example, the case in the work of Glosten and Harris (1988). However, there is an important difference between the NYSE and the electronic, inter-dealer currency market as used in Mcgroarty, ap Gwilym and Thomas (2007) for instance. That is, in the latter there are no specialists, while these play a key role on the NYSE. One must be careful, therefore, not to take the equity market and the NYSE for one and the same.

Two other major stock markets (the London Stock Exchange and the NASDAQ) are, just like the foreign exchange market, organized as multiple dealership markets. These markets also have electronic brokers. First of all, these differences in market structures, for instance, between the NYSE and the foreign exchange market, may have as a result that the model used on the NYSE cannot be be used on the FX market. However, similarities between the NASDAQ or the London Stock Exchange and the foreign exchange market may, then again, mean that the model from the equity market may well be extended to the foreign exchange market.

To illustrate this, Mcgroarty et al. (2007) applied the model of Huang and Stoll (1997) and used data from the electronic, inter-dealer spot foreign exchange market. This model was tested by Huang and Stoll (1997) themselves, but they used data of the 20 stocks in the Major Market Index. These are actively traded stocks. However as the model of Huang and Stoll (1997) was more suited to work with data from the NYSE, simply applying the model to the foreign exchange market led to results in the work of Mcgroarty et al. (2007) that were difficult to interpret in a meaningful way. The influence of the IHC on the b/a spread was sometimes more than 100%, what then was compensated by a negative percentage value of the ASC. Mcgroarty et al. (2007) decided to adapt the model of Huang and Stoll (1997), so that it would be better suited to the structure of the electronic, inter-dealer foreign exchange market.\(^\text{34}\) In this modified trade indicator model the components behave as

\(^{34}\) The electronic, inter-dealer foreign exchange market is order-driven whereas the model of Huang and Stoll (1997) was based on a quote-driven market. Quote-driven and order-driven markets work differently. Based on the work of Bloomfield (2005), Mcgroarty, ap Gwilym and Thomas (2007) adapted the trade-indicator model to take into account this difference and to obtain plausible results.
expected (for instance, the IHC was not larger than 100%) and the three components (the ASC, the IHC and the OPC) were all significant and exceeded the 95% critical value.

Another example, for instance, is the theoretical model of Madhavan and Smidt (1991). This model considers a trading process to be found in a typical single dealer market, for example the NYSE. Lyons (1995) was the first to apply this model to the foreign exchange market by using data obtained from a single dealer whose trades were mostly direct with other dealers. Most of his trades were incoming, so he provided quotes on request. This is very similar to the trading processes on the NYSE, what meant that Lyons (1995) could apply the Madhavan and Smidt (1991) model easily. However, trying to use data from electronic brokers with different trading styles will lead to less desirable results. This was the case when the Madhavan and Smidt model (1991) was applied by Bjønnes and Rime (2005) to data from the foreign exchange market. They found that a lot of variables did not have the proper sign and were insignificant. There was no significant ASC nor a significant IHC. Despite the fact that the Madhavan and Smidt model was both used by Lyons (1995) and Bjønnes and Rime (2005) for data on the foreign exchange market, the latter showed that the model may not be as useful on the foreign exchange market because of differences in trading styles.

A last example is Yao (1998b) who applied the decomposition model of Glosten and Harris (1988), but he added two extensions to the model to enable a better fit with the data they obtained from an DEM/USD dealer that worked for a NYC commercial bank.

Another difference between the foreign exchange market and equity market is that b/a spreads in the foreign exchange market are generally smaller than in equity markets. This indicates higher liquidity of the foreign exchange market in general. The liquidity of a market is determined by how fast one can trade large volumes of a certain security with a minimal impact on the price of that security or – in the case of the foreign exchange market – how fast one can trade large volumes of a currency pair with a minimal impact on the exchange rate. Huang and Stoll (1997), who use data from the NYSE, find that the b/a spread is, on average, 25 basis points wide while Payne (2003) finds an average b/a spread of 1 basis point for the inter-dealer foreign exchange market. Note that higher liquidity also means lower inventory and order-processing costs (Bjønnes and Rime, 2005).

Bjønnes and Rime (2005) came also to the conclusion that the proportion of the b/a spread that can be explained by the ASC and IHC combined is larger on the foreign exchange market than on the equity market. This can be seen in table 6. Bjønnes and Rime’s (2005) empirical work showed that
the proportion that can be explained by both components together ranges from 76% to 82% for the DEM/USD dealers. They use the model proposed by Huang and Stoll (1997). Huang and Stoll (1997), however, also tested their model, but used data from the NYSE. In their work only 11% of the b/a spread could be attributed to the ASC or IHC. However, they explain this low value because the stocks under consideration are stocks that are actively traded. In actively traded stocks there is a relatively lower presence of informed traders. Important to know is that Bjønnes and Rime (2005) as well as Huang and Stoll (1997) used the exact same regression. However, in a next step in which they try to separate the influence of the IHC and the ASC, Bjønnes and Rime (2005) no longer find statistically significant results for the IHC. Furthermore, the contribution of the IHC and OPC are rather small it seems relative to the ASC, again in stark contrast with the results in Huang and Stoll’s (1997) work on the NYSE. So the ASC attributes the most to the b/a spread on the foreign exchange market according to Bjønnes and Rime (2005). This is not a strange result as they argue that b/a spreads in general are smaller on the foreign exchange market that, in turn, is a consequence of the higher liquidity and lower inventory and order-processing costs. According to Payne (2003), who uses data from the inter-dealer spot FX market, 60% of the spread is attributable to the ASC. Payne based his work on Hasbrouck (1991a, 1991b).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Market</strong></td>
<td>Stock market: NYSE</td>
<td>Foreign exchange market: DEM/USD</td>
</tr>
<tr>
<td><strong>Data</strong></td>
<td>Average of different stocks</td>
<td>Dealer 2</td>
</tr>
<tr>
<td><strong>ASC and IHC</strong></td>
<td>11.35 %</td>
<td>76%</td>
</tr>
</tbody>
</table>

ASC and IHC measure the percentage of the effective spread that is attributable to the ASC and the IHC. Bjønnes and Rime (2005) use data from 4 dealers working for a Scandinavian bank. For dealer 1, trading in NOK/DEM accounts for 68.6% of his total trading volume. So he is not taken into account here. For dealers 2, 3 and 4, their trading in DEM/USD is 100%, 91.6% and 65% respectively. The results of Bjønnes and Rime (2005) are all significant at the 1% level. The results of Huang and Stoll (1997) show the average of 19 different stocks with individual values ranging from 1.9% (ATT) to 22.3% (3M). The average value has a standard error equal to 0.0024. The result is also significant at a 1% level.

Source: Huang and Stoll (1997), Bjønnes and Rime (2005)

Table 6: Differences in the proportion of the spread that can be attributed to the ASC or IHC

From now on, our focus is explicitly on the spot foreign exchange market and on the differences within this market that affect the outcomes.
3.2.3. Customer market data vs. Interbank market data

The spot foreign exchange market has a two-tier structure (cf. subsection 2.2). The first tier is the customer market, the second tier is the interbank market. Yao (1998b) works with data that contains customer trades as well as trades from the interbank segment from a dealer on the DEM/USD market. Bjønnes and Rime’s (2005) empirical work also includes data from the first tier, but the proportion of the customer trades is lower than in the data of Yao (1998b). Conversely, the data used by Lyons (1995) or McGroarty et al. (2007) is strictly from the second tier. Comparison of their studies shows that b/a spreads are not uniform across the spot foreign exchange market. The b/a spreads that contain data of the customer market are generally wider than b/a spreads that come strictly from the interbank market segment. This can be seen in table 7. Yao (1998a, 1998b) and Bjønnes and Rime (2005) contend that customer trades are important because – besides conveying private information – they also find that they account for the lion’s share of total trading profits which could explain the larger spreads (cf. subsection 2.2.).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM/USD</td>
<td>0.0000082</td>
<td>0.000316</td>
</tr>
</tbody>
</table>


Table 7: Comparison of the average spread between a strictly inter-dealer market and a market that also contains customer data

3.2.4. Dealer perspective vs. market perspective

Whether one has data from the customer market segment and/or the interbank segment is closely related to from whom or where one has obtained one’s data.

When considering the empirical research work done on the interbank market segment of the foreign exchange market, there is a difference between, on the one hand, data obtained from one or more dealers, for example Lyons (1995), Bjønnes and Rime (2005), Yao (1998a, 1998b) and, on the other hand, data obtained from the (electronic) inter-dealer market, like from D2000-2 or EBS, for example McGroarty et al. (2007). The advantage of obtaining data from one or more dealers is that one can observe the inventories of these dealers and one can even study the strategic trading behavior of the
dealer when the counterparty’s identity is known (see Yao (1998b) or Bjønnes and Rime (2005)). This data normally contains the customer order flow from each dealer. However, this is, for example, not the case in Lyons (1995). Despite the fact that Lyons (1995) obtains his data from a dealer, this data does not include customer trade data. The advantage of data obtained from electronic brokers is that one has a wider view on the foreign exchange market.

Looking at the results of, for instance, Bjønnes and Rime (2005) and, for instance, McGroarty et al. (2007), one can see that in Bjønnes and Rime’s (2005) work, the ASC accounts for 80% of the b/a spread, in contrast with the work of McGroarty, ap Gwilym and Thomas (2007) where the share of the ASC as a determinant of the b/a spread is much less compared to the share of the IHC and the OPC component. The ASC explains – for all currency pairs – less than 50% of the b/a spread. This difference can be explained by the different perspective assumed in the two studies and they do not necessarily contradict each other because of this. This point is also argued by Bjønnes and Rime (2005). Individual dealers will try to extract private information from their customer order flow. However, they will exploit this information by mixing limit orders with market orders, which could explain why the ASC is smaller on the electronic inter-dealer market than in the case when an individual dealer is observed. Put simply, the ASC is more obscured in the electronic inter-dealer spot FX market.

This conclusion of Bjønnes and Rime (2005) should be contrasted with the work of Yao (1998b). Yao’s (1998b) empirical study contained data from only one but nevertheless a very important DEM/USD dealer. He came to the conclusion that the IHC, the ASC and the OPC account for 70%, 23% and 7% respectively of the b/a spread. His finding of 23% for the ASC contrasts with the 80% found by Bjønnes and Rime (2005). One can wonder then if the explanation given above by Bjønnes and Rime (2005) is incorrect and whether another explanation could be possible. One suggestion could be that this difference is attributable to the different decomposition model used. Bjønnes and Rime (2005) used the decomposition model of Huang and Stoll (1997), whereas Yao (1998b) used the decomposition model of Glosten and Harris (1988). Another possible explanation could be, that it is because Yao’s (1998b) data contained a higher share of customer trades in the total traded volume of the dealer i.e. the dealer mainly performs liquidity services for his customers.

3.2.5. Pre-EMU regime vs. post-EMU regime

A peculiar difference was noticed by McGroarty et al. (2007) in the share of the three components of the b/a spread suggested by Stoll (1978a) before and after the introduction of the euro. One assumes
that the euro is the linear successor of the Deutsche Mark. This difference can be seen in table 8. For all currency pairs the proportion of the ASC declines and the proportion of the IHC increases. With one exception, the proportion of the IHC is larger than the proportion of the ASC. This is the same for the OPC, where the IHC is bigger than the OPC except in one case. The decline of the ASC could – according to McGroarty et al. (2007) – be the result of foreign exchange limit-order traders who were, after the introduction of the euro, less able to predict future price moves of exchange rates. They state that is reasonable to believe that when the euro was introduced and with it the advent of the European Central Bank (ECB), traders were not able to predict the future actions of the ECB. This applies to exchange rates involving the euro. However, for all currency pairs, there was a reduction in the traders’ ability to interpret and predict the order flow.

Pre- and post-EMU breakdown of the b/a spread by its sub-components

<table>
<thead>
<tr>
<th></th>
<th>USD/JPY</th>
<th>USD/CHF</th>
<th>EUR/USD</th>
<th>EUR/JPY</th>
<th>EUR/CHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASC</td>
<td>29%</td>
<td>7%</td>
<td>29%</td>
<td>17%</td>
<td>25%</td>
</tr>
<tr>
<td>IHC</td>
<td>43%</td>
<td>61%</td>
<td>56%</td>
<td>70%</td>
<td>38%</td>
</tr>
<tr>
<td>OPC</td>
<td>28%</td>
<td>32%</td>
<td>15%</td>
<td>13%</td>
<td>37%</td>
</tr>
</tbody>
</table>

In this table one can find the breakdown of the b/a spread into its components for the above-mentioned spot exchange rates computed with the adapted trade indicator model of McGroarty et al. (2007). The currency code EUR refers to the Deutsche Mark in 1998 (pre-EMU), and to the euro in 1999 (post-EMU).

Source: McGroarty et al. (2007).

Table 8: Pre- and post-EMU breakdown of the b/a spread by its sub-components

3.2.6. Minor currencies vs. major currencies

The major currency markets are considered to be very liquid markets while, for smaller currencies, markets are less liquid. Liquidity has, according to Kyle (1985), three characteristics from which tightness (aside from depth and resiliency)35 in our context is interesting as it highlights the difference between the transaction price (whether one trades at the bid or ask price) and the midpoint price. In the major currency markets, the b/a spreads are reported to be narrow. This can be seen for example in table 8, where the b/a spread for the less liquid currency pair NOK/DEM is noticeably wider than for the more liquid currency pair DEM/USD.

35 Kyle (1985) defines depth as the size the order flow needs to be in order to change prices by a certain amount. Resiliency refers to how long it takes before prices have recovered from a shock.
Looking at the amount of empirical work done on the foreign exchange market, compared to that done on the equity market, we see that most of it has been done on liquid foreign exchange markets. There are some exceptions, like the work of Bjønnes and Rime (2005) and Frömmel and Van Gysegem (2011). In our work here, we also use data of less liquid currency pairs (cf. subsection 5).

Looking at the relative proportions of the three elements, Bjønnes and Rime (2005) noticed that for the more liquid currency pair DEM/USD a larger share of the size of the b/a spread could be attributed to the ASC and the IHC. This can be seen in table 10. For the less liquid currency pair NOK/DEM a larger share is attributed to the fixed component, namely the OPC. Bjønnes and Rime (2005) argued that this might be related to the fact that, first of all, the NOK/DEM market is less competitive, for example the NOK/DEM dealer in table 10 has a market share of 40% in the NOK/DEM currency market and, second, the fixed costs are distributed over fewer trades. Bjønnes and Rime (2005) applied the Huang and Stoll (1997) model. Lyons (1995) also used the model of Huang and Stoll (1997), but came to a different conclusion. His result can also be found in table 10. The values in table 10 are all significant at the 1% level.
### Differences between the share attributed to the ASC or IHC in the b/a spread for major and minor currencies

<table>
<thead>
<tr>
<th>Currency</th>
<th>NOK/DEM</th>
<th>DEM/USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dealer</td>
<td>Dealer 1</td>
<td>Dealer 2</td>
</tr>
<tr>
<td>ASC and IHC</td>
<td>50%</td>
<td>76%</td>
</tr>
</tbody>
</table>

ASC and IHC measure the percentage of the effective spread that can be attributed to the ASC or the IHC. Bjønnes and Rime (2005) use data from 4 dealers working for a Scandinavian bank. For dealer 1, trading in NOK/DEM accounts for 68.6% of his total trading volume. For dealers 2, 3 and 4, trading in DEM/USD, the percentages are 100%, 91.6% and 65% respectively. Lyons only considers one dealer in his study. The values are all significant at the 1% level.  

Source: Bjønnes and Rime (2005), Lyons (1995)

| 3.2.7. Long inter-transaction time vs. short inter-transaction time |

Lyons (1996) reported that trades are only informative when the inter-transaction time is long. Bjønnes and Rime (2005) tested this on the foreign exchange market. They defined inter-transaction time short if there was less than one minute between two trades for the major currency pair DEM/USD. For the less liquid currency pair NOK/DEM, they defined the inter-transaction time as short if there were less than five minutes between two trades. Bjønnes and Rime (2005) came to the conclusion that the proportion of the b/a spread that could be explained by the ASC remained the same, however the effective b/a spread did widen if inter-transaction time was longer (cf. above). This larger b/a spread can be explained by private information that is more informative, consistent with what Lyons (1996) postulated.

To conclude this section, note that despite the fact these differences were noticed in between empirical studies, one cannot say whether or not these differences are statistically significant. Furthermore, the explanation given here for these differences comes from the authors themselves. However, these explanations should be interpreted carefully as other empirical studies give contradicting results.  

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36 Note that this section does not make a distinction between relative and absolute spread measures (cf. subsection 5.3.1.1.) because we wanted to focus on the FX market and the empirical works discussed here made use of absolute spread measures. A distinction between absolute and relative spread measures can be found in the empirical works that use data from the equity market. To have an idea of these empirical works and the spread measure used, please refer to Bollen et al. (2004) who provide a table with an overview of whether these works use an absolute or relative spread measure.
PART II: EMPIRICAL INVESTIGATION
4. Empirical model

Our study of the b/a spread uses the structural model composed by Bollen, Smith and Whaley (2004). We will refer to it as the BSW model. This model takes into account the effects of the order-processing costs, adverse selection costs, inventory holding costs and competition. In their model, the adverse selection component and the inventory holding costs are taken together and modeled as an option with a stochastic time to expiration. The BSW model was empirically tested by Bollen et al. (2004) on the stock market and their formal modal uses terms accordingly. The terms we will use here are already adapted to the foreign exchange market context.

4.1. The IHC

Suppose for example that a customer places a sell order for a certain currency with a dealer. This means that the dealer who will buy that currency, will have a long position in that currency. Moreover, assume that the holding period in general is short before the position is unwound. For instance the dealer holds the currency only several minutes in inventory. This makes it reasonable to presume that the risk-free rate equals zero. Because of this long position, the dealer faces inventory-holding risk (cf. subsection 3.1.3.) and, to protect himself, the dealer will include a risk premium in his b/a spread to cover the expected IHC.

Suppose now that a viable hedging instrument exists, that the dealer can buy, and which allows him to minimize this holding risk. An example could be to go short on a futures foreign currency contract. The dealer will, in that case, hold a hedged portfolio that consists of the foreign currency and the hedging instrument. Bollen et al. (2004) argue that when the dealer operates within a Markowitz (1952) mean-variance framework, it is normal that the dealer will try to minimize the variance of value changes in his portfolio. Furthermore, if there are no transaction costs associated with the hedging instrument, then the dealer will determine his optimal number of hedging instruments per unit of foreign currency n as follows:

\[
\text{Min } E[(\Delta(ER) + n\Delta(\text{hedging instrument}))^2]
\]

37 A transaction on the foreign exchange market is an exchange of one currency for another. Analogous to the stock market – where a stock is bought and sold - we will refer here to the currency that is bought and sold on the foreign exchange market as the foreign currency, irrespective of the currency used to buy or sell the foreign currency.

38 A futures foreign currency contract is an agreement to buy or sell a foreign currency at a future time at a predetermined price, and this for a standardized quantity (Hull, 1989).
Where:

\[ \Delta(ER) = \text{Change in the exchange rate}^{39} \]

\[ \Delta(\text{hedging instrument}) = \text{Change in the price of the hedging instrument} \]

\[ n = \text{Hedge ratio} \]

The optimal number of hedging instruments or the hedge ratio \( n \) can be calculated by setting the first-order condition equal to zero and then solving for \( n \).

Unfortunately there is no viable hedging instrument. Looking again at the example of our futures foreign currency contract, the liquidity in the futures foreign currency market is lower than in the spot foreign exchange market and trading costs are higher. A dealer will not hedge if there is a chance that these costs will make his revenues in the spot market undone. Since no appropriate hedging instrument exists, the dealer will demand compensation under the form of an inventory-holding premium (IHP). This IHP is determined in such a way that when the market moves in the undesired direction the dealer minimizes his risk of loss. This can be expressed as follows and is called the lower semi-variance:\(^{40}\):

\[
\text{Min } E[(\Delta(ER) + IHP|\Delta(ER) < 0)^2]
\]

(4)

Which leads to the minimum IHP when setting the first-order condition to zero:

\[
IHP = -E(\Delta(ER)|\Delta(ER) < 0)Pr(\Delta(ER) < 0)
\]

(5)

The minimum IHP, in Eq. (5), is equal to the expected loss in value of the foreign currency that you have in inventory multiplied by the probability of the exchange rate making this adverse movement.

The expression given by the right-hand side of Eq. (5) matches the value of an at-the-money (ATM) option\(^{41}\) with time to expiration equal to the time you keep the foreign currency in stock. An ATM

---

39 The currency bought or sold – the foreign currency - is in the denominator. Thus the exchange rate expresses how much of a domestic currency needs to be paid or received for one unit of foreign currency.

40 Markowitz (1959) made a plea for the concept of semi-variance as a risk measure. This was in the context of choosing an optimal portfolio. He defended this concept by arguing that variance takes into account all extreme points in both directions, whereas semi-variance only considers one direction. Always assuming only one direction is undesirable.

41 An option gives a buyer the right to sell or buy a certain number of assets at a predetermined price i.e. the strike price. The buyer of an option is long the option, whereas the seller is short the option (Hull, 1989).
option sets the strike price equal to the underlying value of the asset when the option is written. So elaborating on our example, as the dealer is long the foreign currency he would buy a put option which offers protection against a falling exchange rate. Yet no viable hedging instrument exists, so one cannot seek refuge in currency options. Nevertheless option valuation can be used as a measure for the IHP. Consequently, the valuation framework after Black and Scholes (1973) and Merton (1973) (the BSM valuation framework) is used. According to this framework, the value of a put option looks like this:

\[
\text{Put option} = XN\left( - \frac{\ln\left(\frac{T}{X}\right)}{\sigma \sqrt{t}} + 0.5 \sigma \sqrt{t} \right) - TN\left( - \frac{\ln\left(\frac{T}{X}\right)}{\sigma \sqrt{t}} - 0.5 \sigma \sqrt{t} \right)
\]

Hence:

\[
IHP = XN\left( - \frac{\ln\left(\frac{T}{X}\right)}{\sigma \sqrt{t}} + 0.5 \sigma \sqrt{t} \right) - TN\left( - \frac{\ln\left(\frac{T}{X}\right)}{\sigma \sqrt{t}} - 0.5 \sigma \sqrt{t} \right)
\]

Where:

- \(T\) = True exchange rate
- \(X\) = Exercise price
- \(\sigma\) = Return volatility
- \(t\) = Time until an offsetting order arrives
- \(N(\cdot)\) = Cumulative unit normal density function

Because it is an ATM option, Eq. (7) can be simplified as follows:

\[
IHP = T \left[ 2N\left(0.5\sigma \sqrt{t}\right) - 1 \right]
\]

---

42 If only because it is highly unlikely that these hedging instruments will match the hedging needs. For example, as regards the expiration date, it is unlikely that you will find an option that has an expiration date that equals the time you have the foreign currency in stock. This could also be argued for the futures foreign currency contract.

43 Under the assumption that the domestic interest rate and the foreign interest rate equal zero.

44 For a call option, this formula is as follows: \(\text{Call option} = TN\left( \frac{\ln\left(\frac{T}{X}\right)}{\sigma \sqrt{t}} + 0.5 \sigma \sqrt{t} \right) - XN\left( \frac{\ln\left(\frac{T}{X}\right)}{\sigma \sqrt{t}} - 0.5 \sigma \sqrt{t} \right)\)

45 The true exchange rate is, unless stated otherwise, assumed to equal the midpoint price between the bid and ask price (cf. further down).

46 For an ATM option, the following holds: \(X=T\).
Eq. (8) is the same for an ATM put option and for an ATM call option (for proof see appendix A\textsuperscript{47}). However, a dealer does not know when an offsetting trade will occur, so Eq. (8) needs to be replaced by its stochastic equivalent:

\[
I\bar{H}P = T \left[ 2N(0.5\sigma\sqrt{t}) - 1 \right]
\] (9)

The greatest difficulty lies in estimating the time until an offsetting trade occurs. This could be done by using an arrival rate distribution, e.g. a Poisson distribution. However, in the BSW model, they provide proof that, for an ATM option, the expected IHP is linear in $\sqrt{t}$. Thus the expected IHP becomes:

\[
E(I\bar{H}P) = T \left[ 2N \left( 0.5\sigma E(\sqrt{t}) \right) - 1 \right]
\] (10)

With trade data available, $E(\sqrt{t})$ can be easily estimated. Looking at Eq. (10) one can conclude that the expected IHP is a function of the true exchange rate, the return volatility and the time until an offsetting order occurs. This latter can also be called the trading frequency of the foreign currency. Fixing the true exchange rate at a predetermined level, for instance €30.00\textsuperscript{48}, we can show how the value of the expected IHP changes as a function of the return volatility and the time until an offsetting order occurs (see figure 2). When the time between two offsetting trades is as high as 20 minutes and the return volatility equals 1, the expected IHP equals €0.1707.

\textsuperscript{47} This proof was not provided by Bollen et al. (2004).
\textsuperscript{48} This means that one pays €30 to buy one unit of a foreign currency.
Figure 2: The expected IHP as a function of return volatility and trading frequency, modeled in Eq. (10).

The true exchange rate is equal to €30. The return volatility can assume a value between 0 or 100% while the trading frequency, expressed in minutes, covers a range from 0 to 20.

Bollen et al. (2004), however, also argue that the expected IHP may be overstated. We will try to explain this in a few steps. Suppose this time the customer places a buy order (instead of a sell order) with a dealer.\(^49\) This means that the expected IHP will equal the value of an ATM call option. Consider the call option in place, which means that when the underlying price of the foreign currency increases the dealer is protected against these increases. However, when the price of the foreign currency decreases below the strike price, the dealer will not exercise his option as he is not losing money. In this case it is beneficial if he buys the foreign currency in the spot foreign exchange market. So the dealer gains when the price decreases and is protected against price increases.

However, if the foreign currency price falls and the market is highly competitive, this speculative gain is shared between more competitors as it is very attractive. In other words: the gains are limited. This is shown is figure 3. This can be modeled in such a way so that the expected IHP will equal the value of an ATM call option minus the value of an out-of-the-money (OTM) put option.\(^50\) If there was perfect competition in the foreign exchange market, the gains would even fall to zero and the strike prices of both the call option and the put option would be equal. This would also imply that the expected IHP has zero value. However this is not a realistic scenario as there is no perfect competition.

\(^{49}\) Under the assumption that the market-maker’s inventory position is equal to 0.

\(^{50}\) This is an option strategy, called an option collar.
It seems logical to work with the expected IHP as the value of an ATM call option minus the value of an OTM put option. However a dealer will only opt to sell an OTM put option when the market is characterized by fierce competition, because then there is little chance that the put option will go in-the-money for the party that is long the option. So not much is lost by working with the expected IHP as the value of an ATM call option. Figure 4 shows the difference between the expected IHP as an ATM call option (see figure 2) and the expected IHP as an ATM call less an OTM put option (see figure 3). Fact is – as figure 4 illustrates - that the differences between the two modeling methods only matter when the time between trades is high and when the return volatility is high. For the foreign exchange market, this is very unlikely (cf. further down). Not only do we express the time between trades for our dataset in seconds, but the mean return volatility almost never exceeds 10% (cf. further down). For these reasons, it is reasonable to use only the ATM option to estimate the expected IHP.

Figure 3: The expected IHP modeled as an ATM call option less an OTM put option, as a function of return volatility and trading frequency. The true exchange rate is equal to €30. The return volatility can assume a value between 0 or 100% while the trading frequency, expressed in minutes, covers a range from 0 to 20.
Figure 4: The difference between the expected IHP as an ATM call and the expected IHP as an ATM call less an OTM put. The expected IHP is a function of the return volatility and trading frequency. The true exchange rate equals €30. The return volatility can assume a value between 0 or 100% while the trading frequency, expressed in minutes, covers a range from 0 to 20.

4.2. The ASC

The just discussed expected IHP actually incorporates both the inventory-holding cost and the adverse selection cost from the dealer’s perspective. A dealer will demand different expected inventory-holding premiums depending on whether or not he deals with informed or uninformed customers. Suppose, as in our last example, that a trader buys at the ask price of the dealer so that the dealer is short the foreign currency. The dealer is now faced with one of two situations:

- **The trader is uninformed.** Presumably the true price of the currency will be between the bid and ask price quoted by the dealer. As a consequence the expected IHP equals the value of a slightly OTM call option with the strike price equal to the ask price. Here the expected IHP is denoted as $IHP_U$, where $U$ stands for uninformed.

- **The trader is informed.** This means that the true price is greater than the ask price. The expected IHP now equals an in-the-money (ITM) call option. Here the expected IHP is denoted as $IHP_I$, where $I$ stands for informed.
The value of $IHP_U$ or $IHP_I$ is, in both cases, equal to:

$$IHP_i = TN \left( \frac{\ln(\frac{S}{X})}{\sigma \sqrt{t}} + 0.5\sigma \sqrt{t} \right) - XN \left( \frac{\ln(\frac{X}{S})}{\sigma \sqrt{t}} - 0.5\sigma \sqrt{t} \right) \quad (11)$$

Where $i = U$ or $I$.

The dealer does not know which traders are informed. This means that he will ask an IHP, of each trader that comes to him, that is equal to the weighted sum of the IHC and the ASC.

$$IHP = (1 - p_i)IHP_U + p_i IHP_I \quad (12)$$

Where:

$$1 - p_i = \text{Probability that the trade is uninformed}$$

$$p_i = \text{Probability that the trade is informed}$$

When the time before an offsetting trade occurs tends to zero, the value of $IHP_U$ tends to zero and the value of $IHP_I$ equals the value of the ITM option. This means that – unlike one can see in figure 2 - the IHP never equals zero, as the expected IHP also represents compensation for the ASC.

The expected IHP, as written in Eq. (12), can be rewritten as follows:

$$IHP = IHP_U + p_i (IHP_I - IHP_U) \quad (13)$$

Eq. (13) shows that the ASC can be seen as an expected incremental cost on top of the compensation for the IHC. The expected cost for this informed trade is multiplied by the probability of an informed trade. This structure will be useful when one wants to estimate the probability of informed trades.

In our regressions in the empirical part of this paper (cf. section 6.2.) we will include the expected IHP as an ATM option, because we do not know the probability of a trader being informed and because informed and uninformed traders have ITM and OTM options respectively.
4.3. The OPC and competition

In the model of Bollen et al. (2004) the OPC is seen as a fixed cost. So when the traded volume increases, this would mean that the cost per unit of volume decreases. It is thus reasonable to represent the OPC as the inverse of the traded volume. As the traded volume increases, the OPC will decrease proportionally.

Concerning competition, Bollen et al. (2004) make use of the modified Herfindahl index (MHI) to model this determinant. As the name suggests, it is an adapted version of the Herfindahl index (HI):

\[ HI = \sum_{j=1}^{ND} \left( \frac{V_j}{Total\ V} \right)^2 \]  

(14)

Where:

- \( ND \) = Number of dealers
- \( j \) = Dealer \( j \)
- \( V_j \) = Total volume traded by dealer \( j \)
- \( Total\ V \) = Total volume traded by all dealers

The advantage of this measure of competition is that the distribution of trading volume between dealers has been taken into account (Tinic, 1972). The value that the HI can take goes from \( \frac{1}{NM} \) to 1. The first represents perfect competition, the second represents a monopoly situation.

The modified version created by Bollen et al. (2004) looks like this:

\[ MHI = \frac{HI - \frac{1}{NM}}{1 - \frac{1}{NM}} \]  

(15)

The difference between the original Herfindahl index and the modified Herfindahl index lies in the range of values the latter can take. The MHI ranges from 0 to 1, where 0 means perfect competition and 1 means there is only one dealer. It fits the model better as one can interpret that, when there is perfect competition, dealers will not be able to charge some rent whereas, in a monopoly market, the dealers will be able to charge a premium which will be equal to the corresponding coefficient.
4.4. Model specification

Based on the above information, Bollen et al. (2004) specify the regression model as follows, where \( i \) represents the number of the trade:\(^{51}\)

\[
SPR_i = a_0 + a_1 \text{inv}(TV_i) + a_2 \text{MHI}_i + a_3 \text{IHP}_i + \epsilon_i
\]

They also make some predictions about the signs that the coefficients are expected to have:

- Coefficient \( a_1 \) is expected to have a positive sign. Coefficient \( a_1 \) can assume a large value, but when there is a lot of competition in the market this will tend to zero, meaning that when competition is fierce dealers may not be able to recoup these order processing costs.
- Coefficient \( a_2 \) is expected to have a positive sign. In a market where there are few dealers and the volumes being traded are not distributed uniformly across these dealers, thus when the market approaches a monopoly situation, the MHI value will approach 1. In such an environment, it is reasonable to assume that the spread will increase as the MHI value increases.
- Coefficient \( a_3 \) is expected to have a positive sign. Basically, when your inventory holding costs increase, one expects the spread to increase as dealers will recover the IHP from the customer. This coefficient should tend to one as the estimate of the time between offsetting trades increases in accuracy.

How can we now interpret the intercept \( a_0 \)? When competition is fierce and trading activity in the foreign currency is high, the three determinants on the right-hand side of Eq. (16) will assume a value that approaches or is equal to zero. In such a situation the spread will be as narrow as it can be and thus will equal the tick size. The tick size can be defined as the smallest incremental price movement of a security that is allowed.

The above-specified model can be divided by the true exchange rate. In this case we get a model that makes use of relative spreads and that no longer has an intercept anymore:

\[
\frac{SPR_i}{T_i} = a_0 \left( \frac{1}{T_i} \right) + a_1 \left( \frac{\text{inv}(TV)_i}{T_i} \right) + a_2 \left( \frac{\text{MHI}_i}{T_i} \right) + a_3 \left( \frac{\text{IHP}_i}{T} \right) + \gamma_i
\]

\(^{51}\) In our regression results, \( i \) represents the number of the half-hour.
According to Bollen et al. (2004), this model can be estimated using a weighted least squares regression of Eq. (14) where the weights are equal to $\left(\frac{1}{T}\right)$.

When estimating the expected IHP, the average time between two trades is used as a proxy for the expected holding period. However, there is not just one dealer on the foreign exchange market, but many dealers. This means that the average time between two trades that we use is too small when looking at an individual dealer’s holding period. Bollen et al. (2004) suggest setting the value of coefficient $\alpha_3$ equal to 1 if one wants to estimate the length of the holding period $\tau_i$ across dealers. The regression model then looks as follows:

$$SPR_i = \alpha_0 + \alpha_1 inv(TV_i) + \alpha_2 MHI_i + IHP_i(\tau_i) + \epsilon_i$$

(18)

We end this section by stating that despite the fact that we have argued above that we will estimate the expected IHP as an ATM option, it is possible to estimate the probability that a trade is informed. This can be done by substituting equation (13) in equation (18). This gives:

$$SPR_i = \alpha_0 + \alpha_1 inv(TV_i) + \alpha_2 MHI_i + IHP_{U,i}(\tau_i) + \alpha_4 \left(IHP_{I,i}(\tau_i) - IHP_{U,i}(\tau_i)\right) + \epsilon_i$$

(19)

Our coefficient $\alpha_4$ then equals the probability of an informed trade. If this coefficient is statistically different from zero we can conclude that we can reject the null hypothesis of a zero probability that the trade is informed. This notation also removes a collinearity issue that could exist when separating $IHP_{U,i}$ and $IHP_{I,i}$ in the equation.
5. Data

In contrast with Bollen et al. (2004) who tested their model with data coming from the stock market i.e. Nasdaq stocks, the data that we use here comes from the inter-dealer spot FX market. More specifically, the data used was obtained from the Moscow Interbank Currency Exchange (the MICEX). Our dataset contains only trade data (instead of trade and quote data). This means that the time-stamped transactions that took place, together with the corresponding transaction prices and the volumes traded for several currency pairs, are at our disposal. We also have information about the direction of the trade. Unlike most other data used in similar studies on the composition of the b/a spread, we lack complementary quote data. Quote data give the prevailing quotes that existed throughout trading days. Bollen et al. (2004) did have quote data at their disposal and for the trades in their sample, they matched the quotes prevailing immediately prior to the trade. Because we lack this data, this means that when we look at a particular transaction in our trade data, we cannot say what the corresponding prevailing quote was at the time. Later on, we will present several methods in order to tackle this problem. Note also that this data is being used for the first time in an empirical research study on the components of the b/a spread. Consequently, in order to test the BSW model, we still need to transform our ‘raw’ data into a workable input for the model. So in this section we elaborate a bit more on how we have proceeded in order to obtain the correct input for the BSW model. To that end, we start with a general qualitative and quantitative description of our dataset.

5.1. Qualitative description of the dataset

Concerning the trade data, we can make a distinction between two types of files. First of all we have those files that give, per year, a global overview of certain variables for each trading day. We call this our ‘daily data’. To make clear out of which variables this data exactly consists, we give an example of how this data looks in figure 5. This is a simplified version leaving out several variables that we did not use in our further work. Furthermore, this illustration is for a certain currency pair, suppose for instance RUB/USD52, whereas, in our original dataset, the data for the different currencies were all in one file. The numbers are purely illustrative.

52 RUB = Russian Ruble, USD = US dollar.
‘Waprice’ is the weighted average price and shows how much (in Russian Ruble) one has to pay for one unit of the foreign currency. ‘Open’ refers to the price at which the market opened that day for that foreign currency. Similarly ‘close’ stands for the closing price. ‘High’ is the highest price at which a transaction took place, ‘low’ is the lowest price of a transaction. Note that, in these cases, an actual transaction took place but it is possible that even higher or lower prices have been quoted throughout the day, however no transactions took place at those prices. ‘Volcur’ gives the total volume in a certain currency traded on a given day. ‘Invcurvol’ is the total price paid for that volume, expressed in Russian Ruble, i.e. the domestic currency. Finally, ‘numtrades’ gives the number of trades that took place on a given day and ‘numpart’ gives the number of parties active in that currency market for that day.

The second type of files we call the ‘intraday data’ files, in which we can see all the transactions that took place in a given year. We have such files of several years. An example of how such a file looks, is given in figure 6. Again this example is purely illustrative. One can assume again that this figure shows data for one single currency pair, e.g. RUB/USD. However, in our original file, the data was not categorized according to the different currency pairs.

<table>
<thead>
<tr>
<th>Tradedate</th>
<th>Tradetime</th>
<th>Price</th>
<th>Volcur</th>
<th>Invcurvol</th>
<th>Buysell</th>
</tr>
</thead>
<tbody>
<tr>
<td>09/01/2011</td>
<td>10:01:00</td>
<td>40.90</td>
<td>20,000</td>
<td>818,000</td>
<td>Buy</td>
</tr>
<tr>
<td>09/01/2011</td>
<td>10:01:05</td>
<td>40.80</td>
<td>30,000</td>
<td>1,224,000</td>
<td>Sell</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

‘Tradedate’ corresponds with the trading day on which the trade took place and ‘tradetime’ is the time at which the trade took place. This is to the second correct. We also have the price at which the transaction took place given by ‘price’\textsuperscript{53}. ‘Volcur’ is the volume bought or sold and ‘invcurvol’ is the amount of money paid or received for it in Russian Ruble. ‘Buysell’ indicates whether the trade was a buy or a sell. Concerning this latter it is very important to know from which perspective this should

\textsuperscript{53} This transaction price is expressed as the amount of Russian rubles that has been paid or received for one unit of a foreign currency.
be interpreted. In our case this is from the perspective of the initiator of the trade. So an active party comes to the market and buys at the prevailing quote, meaning that the price at which the transaction took place matches the ask quote stated by the passive party.

Because we do not have quote data at our disposal (cf. above), we will use the ‘buysell’ information (see figure 6) in order to construct a corresponding quote (cf. subsection 5.3.1.2.). In our data we had this ‘buysell’ variable only for the year 2011. This means that we will only be able to use data from 2011.

The daily data file of 2011 contained data on several more currency pairs than the intraday data file of 2011. As we need the data of both files we can only use those currencies for which the two files are present. This left us with three currency pairs: RUB/EUR, EUR/USD and RUB/USD.54

Examining the dataset of these three currency pairs, we decided not to work with the currency pair EUR/USD in our empirical investigation. EUR/USD is a heavily traded currency pair, however the MICEX is a market on which this currency pair is only traded occasionally when compared to the very liquid markets in this currency pair. In our dataset sometimes less than 5 trades per day took place in this currency pair. Bollen et al. (2004) set a minimum of at least 5 trades every day – in their case for a stock traded on NASDAQ – as a condition for further use in their empirical investigation. Using the same rule of thumb we thus leave this currency pair out of our empirical investigation.

For each of the two currency pairs left, we have two datasets that differ in clearing settlements. We have data of RUB/EUR trades that are cleared the following day. Besides this, we also possess data of RUB/EUR trades that are settled the same day, which is supposedly some form of enhanced clearing. This distinction is made clear by referring to the latter as RUB/EUR TOD and the former as RUB/EUR TOM. The same holds for the RUB/USD currency pair in our dataset. Logically one can assume that the volumes traded per day for an enhanced clearing will be lower than for clearing the next day, as this will cost more. This can be seen in the data when looking at the daily traded volumes, which can be seen in figures 7 and 8.

54 Because the transactions took place on the MICEX, which is in Russia, we explicitly choose to consider the Russian market as the domestic market and express the exchange rates with the Russian Ruble (RUB) in the numerator. This because we want the exchange rate to express how much one unit of a foreign currency is bought and sold for.
To conclude this subsection we have summarized some key information for each of these currency pairs in table 11. This table gives the time span over which we have data. For each currency pair this is from 11/01/11 till 09/06/11. The timeframe – expressed in Moscow time – gives the hours during which trades can take place each day. The last column gives the total number of transactions that took place during that time span.
**Timeframes and the number of transactions for each currency pair**

The timeframes are expressed in Moscow time

<table>
<thead>
<tr>
<th>Currency pair</th>
<th>Start date</th>
<th>End date</th>
<th>Timeframe</th>
<th>Transactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUB/EUR TOD</td>
<td>11/01/11</td>
<td>09/06/11</td>
<td>From 10:00 till 15:00</td>
<td>54,012</td>
</tr>
<tr>
<td>RUB/EUR TOM</td>
<td>11/01/11</td>
<td>09/06/11</td>
<td>From 10:00 till 17:00</td>
<td>98,677</td>
</tr>
<tr>
<td>RUB/USD TOD</td>
<td>11/01/11</td>
<td>09/06/11</td>
<td>From 10:00 till 15:00</td>
<td>230,975</td>
</tr>
<tr>
<td>RUB/USD TOM</td>
<td>11/01/11</td>
<td>09/06/11</td>
<td>From 10:00 till 17:00</td>
<td>462,179</td>
</tr>
</tbody>
</table>

Table 11: Timeframes and number of transactions for each currency pair

In table 11, for RUB/EUR TOD, the market closes at 15:00 Moscow time. Note that before 16 May 2011, this market was only open till 12:30 Moscow time. This is not a once-only event in the existence of the MICEX. Similar decisions about the opening hours have been made in the past. Recently - on June 14th 2011 - for example the MICEX published a press-release to announce they were extending trading hours till 19:00 Moscow time for currency pairs RUB/USD TOM, among others.

### 5.2. Quantitative description of the dataset

Before we present the reader with summary statistics on the different components and spread measures (cf. subsection 5.3.), we provide some general quantitative information on the dataset, which we looked at in order to see whether or not we could see any peculiarities that needed to be dealt with first.

First, we looked at the movement of the weighted average exchange rate according to our dataset and compared this with historical data on the weighted average exchange rate from Reuters. Comparing these two for each currency pair, we can conclude that no abnormal behavior could be seen on the MICEX. This can be seen in figures 9 to 12 on the next two pages. Note that no consistent and fundamental differences existed either between the weighted average prices for the different settlement methods per currency pair.
Figure 9: WA price movement of RUB/USD from Reuters. Source: Reuters

Figure 10: WA price movement of RUB/USD TOD and RUB/USD TOM from dataset

Although the figure indicates that USD/RUB is shown, this actually means that the product of both currencies is shown.
Second, we looked at the daily traded volumes over time. These can be found in figures 7 and 8, for which we refer to subsection 5.1. One can see that there is a lot of variation in the daily traded volumes over time and no clear upward, downward or stable trend can be found. This could, for instance, be due to the small time sample or be typical for the MICEX and the currency pairs under consideration – as the Russian Ruble is not a major currency. Furthermore, we also do not see that

\[\text{WA price movement of RUB/EUR from Reuters.}^{56}\] Source: Reuters

\[\text{WA price movement of RUB/USD TOD and RUB/USD TOM from dataset}\]

\[\text{Although the figure indicates that EUR/RUB is shown, this actually means that the product of both currencies is shown.}\]
volumes are smaller at the beginning of the year – as was argued by some of our respondents in our survey (cf. section 8.2.).

Finally, we took a look at the histograms of these daily traded volumes. These can be seen in figures 13 to 16. For each histogram a complementary table is added with some key figures. Looking at the probabilities from the Jarque-Bera test, we can see that only for RUB/USD TOD are the daily volumes considered normally distributed at a 5% significance level.
Key figures for the RUB/EUR TOD daily volumes

Volumes are expressed in euro

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.12E+08</td>
</tr>
<tr>
<td>Median</td>
<td>1.06E+08</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.91E+08</td>
</tr>
<tr>
<td>Minimum</td>
<td>7.23E+07</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>1.06E+09</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.83</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>3.16</td>
</tr>
<tr>
<td>Jarque-Bera</td>
<td>11.81</td>
</tr>
<tr>
<td>Probability</td>
<td>0.002721</td>
</tr>
<tr>
<td>Observations</td>
<td>102</td>
</tr>
</tbody>
</table>

Table 12: Key figures for the daily volumes of RUB/EUR TOD

Figure 13: Histogram RUB/EUR TOD
Figure 14: Histogram RUB/EUR TOM

Key figures for RUB/EUR TOM daily volumes

Volumes are expressed in euro

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.41E+08</td>
</tr>
<tr>
<td>Median</td>
<td>2.31E+08</td>
</tr>
<tr>
<td>Maximum</td>
<td>4.65E+08</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.34E+08</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>6.68E+07</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.83</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>3.59</td>
</tr>
<tr>
<td>Jarque-Bera</td>
<td>13.45</td>
</tr>
<tr>
<td>Probability</td>
<td>0.001203</td>
</tr>
<tr>
<td>Observations</td>
<td>105</td>
</tr>
</tbody>
</table>

Table 13: Key figures for the daily volumes of RUB/EUR TOM
Figure 15: Histogram RUB/USD TOD

Key figures for RUB/USD TOD daily volumes

<table>
<thead>
<tr>
<th>Volumes are expressed in US dollar</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
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<tr>
<td><strong>Median</strong></td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
</tr>
<tr>
<td><strong>Std. Dev.</strong></td>
</tr>
<tr>
<td><strong>Skewness</strong></td>
</tr>
<tr>
<td><strong>Kurtosis</strong></td>
</tr>
<tr>
<td><strong>Jarque-Bera</strong></td>
</tr>
<tr>
<td><strong>Probability</strong></td>
</tr>
<tr>
<td><strong>Observations</strong></td>
</tr>
</tbody>
</table>

Table 14: Key figures for the daily volumes of RUB/USD TOD
Key figures for RUB/USD TOM daily volumes

- Volumes are expressed in US dollar
- Mean: 3.65E+09
- Median: 3.59E+09
- Maximum: 6.57E+09
- Minimum: 8.73E+08
- Std. Dev.: 1.00E+09
- Skewness: 0.69
- Kurtosis: 4.21
- Jarque-Bera: 14.67
- Probability: 0.000652
- Observations: 105

Table 15: Key figures for the daily volumes of RUB/USD TOM
5.3. Defining the different variables

5.3.1. Spread measures and b/a spread calculation methods

5.3.1.1. Spread measures

Before explaining how we determined the b/a spread, it is useful to give some information about the different spread measures that have been used in past research. Most empirical studies make use of the quoted spread:

\[ Quoted\ spread_i = ask\ price_i - bid\ price_i \]  \hspace{1cm} (20)

Where \( i \) represents the number of the trade in a particular security on a particular trading day. Suppose a trader buys at the ask price quoted by a dealer and he immediately sells what he has bought to this dealer at the offered bid price, then this trader will have incurred a cost equal to the quoted spread. This measure assumes, for simplicity’s sake, that no trades can take place within the quoted spread. In past research work, the quoted spread that prevailed at the end of a trading day was the one used for investigation. Bollen et al. (2004), however, use the equal-weighted average of the quoted spreads (EWQS) in their empirical investigation. The EWQS is calculated by adding up all the quoted spreads that have appeared during the day and is subsequently divided by the number of quoted spreads that prevailed during that day.

Another spread measure is the effective spread. To understand the effective spread, one first needs to know what the midpoint price is.

\[ Midpoint_i = \frac{(bid\ price_i + ask\ price_i)}{2} \]  \hspace{1cm} (21)

Where \( i \) represents the number of the trade in a particular security on a particular trading day. The midpoint price is an approximation for the true price. Suppose the trader we mentioned above only buys or sells a certain security, then the cost he incurs is equal to the deviation from the security’s true price. However, when he immediately reverses this trade, the trader will have to pay this deviation from the true price twice. This is the effective spread:

57 Inspired by Bollen et al. (2004).
58 The b/a spread is a cost incurred by the trader but, at the same time, is revenue earned by the dealer.
Again $i$ represents the number of the trade in a particular security on a particular trading day. The difference with the quoted spread is that the effective spread allows dealers to let trades take place within the spread. In that case, the effective spread is smaller than the quoted spread. If trades do not take place within the spread, then the effective spread, of course, equals the quoted spread. Lyons (1995) noted that in the interdealer foreign exchange market, trades generally are not negotiated within the quoted spread. So this means, that for the foreign exchange market, the quoted spread equals the effective spread.\footnote{So we make the assumption that there is no difference between quoted and effective spread and these terms may be used interchangeably. We will mostly talk about the quoted spread in accordance with Lyons' (1995) argument.} If a trade takes place above the midpoint price, then according to the effective spread measure this trade is a customer buy order. If a trade takes place below the midpoint price, this trade is a customer sell order. If this was not the case (i.e. the customer buys below the midpoint price or the customer sells above the midpoint price), the customer would not incur a cost but instead make a profit. Consequently, the absolute deviation from the midpoint price is the payment the dealer receives for the trade. Multiply this payment by the traded volume and you get the total revenue the dealer makes from a deal. The effective spread has the disadvantage, however, that it involves the participation of a dealer. This does not mean that the effective spread is not a good estimate of the customer costs. It is a better estimate than the quoted spread. However, in general, it still gives an overstated value because it does not take into account trades directly taking place between customers without the intervention of a dealer.

Finally, there is also the volume-weighted effective spread (VWES). The VWES is the volume-weighted average of the effective spreads of the transactions that have occurred throughout a trading day and is also one of the spread measures used in the empirical work of Bollen et al. (2004).

As absolute spread measures, Bollen et al. (2004) used the EWQS and the VWES in their work. Besides these absolute spread measures, they also used relative spread measures: the relative EWQS (REWQS) and the relative VWES (RVWES). The REWQS and the RVWES are the EWQS and the VWES respectively divided by the security’s true price.

\[
Effective \ spread_i = 2|\text{trade price}_i - \text{midpoint}_i| \tag{22}
\]
5.3.1.2. B/a spread calculation methods

As mentioned above (cf. subsection 5.1.), our dataset lacks quote data. This is a huge drawback for our empirical research work. This leads us to construct the b/a spread on the basis of our available trade data. We have defined eight different methods to construct the b/a spread. Note already that we will work with intraday spread values and not daily spread values.

The first method looks for each half-hour at the last transaction price at which a customer sold a certain currency and at the last transaction price at which a customer bought a certain currency. We assume that these transaction prices correspond with the bid and ask quote respectively. Consequently this bid and ask quote make up the b/a spread for that half-hour. The downside is that this sometimes leads to negative spreads, which would mean that the customer can make a profit if he immediately reverses his trade. We call this method the \textbf{LV b/a spread calculation method} or, in brief, the \textit{LV} method, where \textit{LV} stands for ‘last value’. A similar method can be found in the work of McGroarty et al. (2007), who derived the quoted spread from the nearest preceding buy and sell prices. However, they did leave the b/a spread blank when the nearest buy and/or sell prices were older than one minute.

In a second method we took, for each half-hour, the mean of the transaction prices of the customer buy orders that took place in that half-hour and used it as a proxy for the ask quote. The mean of the transaction prices of the customer sell orders was used as a proxy for the bid quote. Again we had some negative b/a spreads for certain half-hours. Another disadvantage of this b/a spread calculation method occurs when buy or sell trades are clustered in a half-hour and almost all happen at the same transaction price. This can influence the b/a spread that is constructed. We call this method the \textbf{AV b/a spread calculation method} or, in brief, the \textit{AV} method, where \textit{AV} stands for ‘average’.

In a third method, we wanted to avoid these negative b/a spreads and consequently worked with the maximum buy price – again from the perspective of the active party - for each half-hour and used this as a proxy for the ask quote corresponding to that half-hour and we used the minimum sell price for each half-hour as a proxy for the bid quote. We call this method the \textbf{MM b/a spread calculation method} or, in brief, the \textit{MM} method, where \textit{MM} stands for ‘minimum and maximum’. The result was that we did not end up with negative b/a spreads. Unfortunately, high volatility in the underlying

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\textsuperscript{60} Because our data comes from an interdealer spot FX market, the term ‘customer’ here means a dealer who takes on the role of the initiator of the trade.
true price will increase the b/a spread in this case, which means that wider spreads mean higher volatility of the true exchange rate.

In a fourth method, we worked with weighted averages. This method was based on the workings of a limit order book, which is essential in foreign exchange trading. This is a somewhat more complex method to explain: for each half-hour the ask quote was constructed by weighing the different buy prices by the time they could have been quoted. The bid quote was determined analogously. Again we ended up with some negative b/a spreads. We call this method the \textit{W}A \textit{b/a spread calculation method} or, in brief, the \textit{W}A method, where \textit{W}A stands for ‘weighted average’.

In a fifth method, we wanted to eliminate the sometimes large time spans between the last customer buy order and the last customer sell order within our \textit{L}V \textit{b/a spread calculation method}. We believed that these could be a possible source of the negative b/a spreads or at least lead to outliers in the data sample. Furthermore, this time span was also recognized by McGroarty et al. (2007), who left the b/a spread blank when the nearest preceding bid and/or ask prices were older than one minute. So instead of working with the last customer buy order and the last customer sell order, we looked at the last change in direction of the orders for each half-hour, i.e. a customer sell order that is immediately followed by a buy order or the other way around. The corresponding prices then were used as a proxy for the bid and ask quotes. We call this method the \textit{L}C \textit{b/a spread calculation method} or, in brief, the \textit{L}C method, where \textit{L}C stands for the ‘last change’. Despite the fact that this method seemed more correct than the \textit{L}V method, we still ended up with some negative b/a spreads.

Careful examination of our data also showed that it happened regularly, within a half-hour period, that when a change in direction of the orders occurred i.e. a customer sell order that is immediately followed by a buy order or the other way around, these actually happen at the same moment in time. Or, in other words, this means that the time between a buy and sell order was equal to zero. So in a sixth method we calculated for each change in direction of orders, the time between those orders. We then used the prices of the last change in direction of orders for which the time between those orders was zero as a proxy for the bid and ask quotes of that half-hour. However, for those half-hours for which there was no change in the direction of orders for which the time between those orders was zero, we used the prices of those orders that changed in direction and for which the time between those orders was the smallest for that half-hour. This method is called the \textit{C}$_0$ \textit{b/a spread calculation method}, or the \textit{C}$_0$ method in brief, where \textit{C}$_0$ stands for the ‘change in direction of orders where time between orders is zero’.
Because it was maybe unrealistic to work with trades that happen at the same time (cf. subsection 6.1.), we defined another method that also looked within each half-hour at those orders that change in direction, i.e. a customer sell order that is immediately followed by a buy order or the other way around and also calculates the time between those orders. However, this time, we do not work with those orders where the time between buy and sell order is zero, but with those that have the smallest time span between those orders (provided it is greater than zero). This method is called the \( C_{05} \) b/a spread calculation method, or the \( C_{05} \) method in brief, where \( C_{05} \) stands for the ‘change in direction of orders where time between orders is minimal, but not zero’. The numbers 0 and 5 stand for the fact that the times between these orders are often situated between zero and five seconds. We expect the number of negative b/a spread values to decrease in comparison with the previous method.

In a last method we did the same as in the \( C_{05} \) b/a spread calculation method however, this time, we worked with the smallest time span that is larger than five seconds. This method was based on the fact that the average time between two trades in our data sample, in general, is larger than five seconds (cf. subsection 5.4.2.). This method is called the \( C_{510} \) b/a spread calculation method, or the \( C_{510} \) method in brief, where \( C_{510} \) stands for the ‘change in direction of orders where time between orders is minimal, but greater than 5 seconds’. The numbers 5 and 10 stand for the fact that the time spans between these orders considered for further use are often situated between five and ten seconds. Note that a huge drawback of the last three methods is, that they in particular look for certain spreads that fulfill a certain condition, which can lead to unreliable b/a spread values.

For each currency pair we constructed the b/a spreads according to these eight methods. Furthermore, for each currency pair, the negative b/a spreads were set equal to zero as negative b/a spreads normally will not occur on one and the same trading platform. This was necessary for all our b/a spread calculation methods, except for the \( MM \) method. We did this because a dealer that quotes bid and ask prices will never set his bid quote higher than his ask price. Furthermore, one of the respondents in our survey (cf. subsection 8.2.) mentioned that this only occurs when a dealer trades on different trading platforms, but this does not happen on one and the same platform. The frequency at which this happens when you trade on different trading platforms was said to be several times per week. In each case, a negative b/a spread that occurs on one trading platform will probably happen very rarely and will never last long. Table 16 gives an idea of the number of negative b/a spreads for each currency pair and for each b/a spread calculation method accordingly, before replacing these negative b/a spreads with zero. One can see that the \( WA \) b/a spread
calculation method has, over all currency pairs, the highest number of negative b/a spreads. The method scoring best regarding the number of negative b/a spreads is the $C_{510}$ method.

Tables 17 to 20 provide the Pearson correlation statistics between the different b/a spread calculation methods. The correlation between the $LV$ method and the $LC$ method is high, as was expected because the $LC$ method was based on the $LV$ method. There is a lot of variation in the correlation between the b/a spread measures over the different currency pairs. For instance, one could say that the correlation between the $C_0$ method and the $C_{05}$ method for RUB/EUR TOD (i.e. a correlation coefficient of 0.48) is not bad. However, for RUB/USD TOM, we find -0.05 as the correlation coefficient between the $C_0$ method and the $C_{05}$ method. Which suggests a negative linear relationship. In general, we could say that the linear correlation between the different b/a spread measures is low and, in most cases, has a positive sign.

### Table 16: Number of negative b/a spreads for each b/a spread calculation method

A further distinction is made for each currency pair.

<table>
<thead>
<tr>
<th>Method</th>
<th>RUB/EUR TOD (Half-hours = 600)</th>
<th>RUB/EUR TOM (Half-hours = 1456)</th>
<th>RUB/USD TOD (Half-hours = 1000)</th>
<th>RUB/USD TOM (Half-hours = 1456)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>%</td>
<td>No.</td>
<td>%</td>
</tr>
<tr>
<td>$LV$</td>
<td>112</td>
<td>19%</td>
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<td>18%</td>
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<td>$AV$</td>
<td>134</td>
<td>22%</td>
<td>143</td>
<td>10%</td>
</tr>
<tr>
<td>$MM$</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>$WA$</td>
<td>235</td>
<td>39%</td>
<td>648</td>
<td>45%</td>
</tr>
<tr>
<td>$LC$</td>
<td>137</td>
<td>23%</td>
<td>135</td>
<td>9%</td>
</tr>
<tr>
<td>$C_0$</td>
<td>111</td>
<td>19%</td>
<td>347</td>
<td>24%</td>
</tr>
<tr>
<td>$C_{05}$</td>
<td>83</td>
<td>14%</td>
<td>105</td>
<td>7%</td>
</tr>
<tr>
<td>$C_{510}$</td>
<td>93</td>
<td>16%</td>
<td>253</td>
<td>17%</td>
</tr>
</tbody>
</table>

No. are the number of half-hours that have a corresponding negative b/a spread. % is the percentage number of half-hours of the total half-hours for that currency pair that have a corresponding negative b/a spread. Method is the b/a spread calculation method.
### Pearson correlation between the different b/a spread calculation methods for RUB/EUR TOD

Linear relationship between the different b/a spread calculation methods for RUB/EUR TOD

<table>
<thead>
<tr>
<th></th>
<th>LV</th>
<th>AV</th>
<th>MM</th>
<th>WA</th>
<th>LC</th>
<th>C₀</th>
<th>C₀₅</th>
<th>C₅₁₀</th>
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</thead>
<tbody>
<tr>
<td>LV</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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</tr>
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<td>0.4774</td>
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<tr>
<td>C₅₁₀</td>
<td>0.1131</td>
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<td>0.1323</td>
<td>0.1800</td>
<td>0.2921</td>
<td>1.0000</td>
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</table>

Table 17: Pearson correlation between the different b/a spread calculation methods for RUB/EUR TOD

### Pearson correlation between the different b/a spread calculation methods for RUB/EUR TOM

Linear relationship between the different b/a spread calculation methods for RUB/EUR TOM

<table>
<thead>
<tr>
<th></th>
<th>LV</th>
<th>AV</th>
<th>MM</th>
<th>WA</th>
<th>LC</th>
<th>C₀</th>
<th>C₀₅</th>
<th>C₅₁₀</th>
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</thead>
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<td></td>
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<td>0.0595</td>
<td>0.5779</td>
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<tr>
<td>C₅₁₀</td>
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<td>0.1126</td>
<td>0.1586</td>
<td>0.2111</td>
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</tbody>
</table>

Table 18: Pearson correlation between the different b/a spread calculation methods for RUB/EUR TOM
Pearson correlation between the different b/a spread calculation methods for RUB/USD TOD

<table>
<thead>
<tr>
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<th>AV</th>
<th>MM</th>
<th>WA</th>
<th>LC</th>
<th>C₀</th>
<th>C₀₅</th>
<th>C₅₁₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AV</td>
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<td></td>
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<td></td>
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</tr>
<tr>
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<td>0.0911</td>
<td>0.1632</td>
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<td>0.0107</td>
<td>0.0947</td>
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</tr>
<tr>
<td>C₅₁₀</td>
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<td>0.0387</td>
<td>0.0287</td>
<td>-0.0041</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

Table 19: Pearson correlation between the different b/a spread calculation methods for RUB/USD TOD

Pearson correlation between the different b/a spread calculation methods for RUB/USD TOM

<table>
<thead>
<tr>
<th></th>
<th>LV</th>
<th>AV</th>
<th>MM</th>
<th>WA</th>
<th>LC</th>
<th>C₀</th>
<th>C₀₅</th>
<th>C₅₁₀</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>1.0000</td>
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<td></td>
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<td></td>
</tr>
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<td>0.1002</td>
<td>0.0081</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WA</td>
<td>0.1270</td>
<td>0.2158</td>
<td>0.2070</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC</td>
<td>0.8410</td>
<td>0.0603</td>
<td>0.1145</td>
<td>0.1230</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₀</td>
<td>0.0177</td>
<td>0.0266</td>
<td>0.0729</td>
<td>0.0508</td>
<td>0.0313</td>
<td>1.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₀₅</td>
<td>0.0180</td>
<td>0.0296</td>
<td>-0.0250</td>
<td>0.0753</td>
<td>0.1037</td>
<td>-0.0488</td>
<td>1.0000</td>
<td></td>
</tr>
<tr>
<td>C₅₁₀</td>
<td>0.0863</td>
<td>-0.0034</td>
<td>0.1405</td>
<td>0.1221</td>
<td>0.1937</td>
<td>0.0267</td>
<td>0.0157</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

Table 20: Pearson correlation between the different b/a spread calculation methods for RUB/USD TOM

After weighing up the pros and cons that we have mentioned above, it seems reasonable to use the b/a spreads calculated according to the WA method, LC method and the C₀ method in our further work. We have decided to work with C₀ and not with C₀₅ because we do, in fact, have buy and sell trades in our sample that occur at the same time. So it must very well be that this is possible and this could lead to interesting results. For each of these b/a spread calculation methods we end up with some negative b/a spreads, which we have replaced by zero.⁶¹

⁶¹ In section 6 we only show extensive regression results of one of these three b/a spread calculations methods, therefore a further elaboration of the advantages and disadvantages of each of these three methods can be found in section 6.
In the light of our different spread measures described above, the b/a spreads (calculated according to our three methods for each half-hour) can be considered the quoted spreads (or the effective spreads). As we construct one spread per half-hour, the EWQS and VWES cannot be applied per half-hour because we need more than one spread at least.62 These spread measures, however, can be calculated on a daily basis for instance.

A summary of the different b/a spread calculation methods and a short description of how they are constructed can be found in table 21.

---

62 In calculating them, we calculate these across half-hours and not across currency pairs.
### Overview of the different b/a spread calculation methods

This table provides a short description of how the b/a spread for every half-hour is constructed.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Short description of the method</th>
<th>Further use</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV</td>
<td>B/a spread calculation method that uses the last transaction price of each buy and sell transaction for every half-hour.</td>
<td>No</td>
</tr>
<tr>
<td>AV</td>
<td>B/a spread calculation method that uses the average transaction price of all buys and the average transaction price of all sells for every half-hour.</td>
<td>No</td>
</tr>
<tr>
<td>MM</td>
<td>B/a spread calculation method that uses the minimum transaction price of a customer sell and the maximum transaction price of a customer buy for each half-hour.</td>
<td>No</td>
</tr>
<tr>
<td>WA</td>
<td>B/a spread calculation method that uses the weighted average of the buy and sell prices for every half-hour, with time as weighing factor.</td>
<td>Yes</td>
</tr>
<tr>
<td>LC</td>
<td>B/a spread calculation method that uses the transaction prices that correspond to the last change in direction of two orders.</td>
<td>Yes</td>
</tr>
<tr>
<td>C₀</td>
<td>B/a spread calculation method that uses the transaction prices that correspond with the last change in direction of two orders and where the time span between those orders is equal to zero.</td>
<td>Yes</td>
</tr>
<tr>
<td>C₀₅</td>
<td>B/a spread calculation method that uses the transaction prices that correspond with the last change in direction of two orders and where the time span between those orders is the minimum time span that is larger than zero seconds for that half-hour.</td>
<td>No</td>
</tr>
<tr>
<td>C₅₁₀</td>
<td>B/a spread calculation method that uses the transaction prices that correspond to the last change in direction of two orders and where the time span between those orders is the minimum time span that is larger than or equal to 5 seconds for that half-hour.</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 21: Overview of the different spread calculation methods

Note that we have defined our own bid/ask spread calculation methods. However, studies exist in which the authors have tried to define a bid-ask spread calculation method based on trade data just like we did. We have not used these methods, because none of these methods proved reliable and also because they do not provide us with bid and ask quotes which we need in our model. They only provide us with b/a spread values. We will discuss these methods very briefly.

---

63 The method that Smith and Whaley (1994) have developed, i.e. the method of moments estimator, could however lead to useful results, but again we lack bid and ask quotes if we use this method. However, the
One of these approaches is the *serial covariance estimator*, that was developed by Roll (1984). According to Roll, the effective bid/ask spread could be constructed as follows:

$$Spread = 2 \sqrt{-Covariance(\Delta P_t^0, \Delta P_{t-1}^0)}$$  \hfill (23)$$

Where $P_t^0$ is the security’s observed price at $t$, and $\Delta P_t^0$ is the change in $P_t^0$. The underlying idea of this method is that if, at the present moment, the trade is a buy, then the next trade could be also a buy and the spread will be zero, but if the next trade is a sell, than this difference will equal the spread. This b/a spread calculation method, however, often results in imaginary values because the covariance estimate is often positive and, consequently, this method does not yield an accurate estimate of the b/a spread.

Another approach used in the past is the *mean absolute price-change estimator* of Thompson and Waller (1988). According to Thompson and Waller (1988), the effective bid/ask spread could be constructed as follows:

$$Spread = |\Delta P^0|$$  \hfill (24)$$

Where $P^0$ is the observed price and $\Delta P^0$ is the change in the observed price. This is a very straightforward method as it simply is the mean value of the absolute price changes of the security under consideration. However, underlying this method is the assumption that the security’s true price change and the variance of the security’s true price change are zero. This latter assumption is an unrealistic assumption and consequently this b/a spread calculation method, just like our MM method, captures the volatility of the security’s underlying true price in addition to the b/a spread.

**5.3.2. Spread determinants**

The determinants of the b/a spread described in the BSW model, need to be extracted from the described dataset (cf. subsection 5.1). In this context some remarks are warranted without going into workings of this method are rather complex to present here briefly. Furthermore, we were not able to provide estimates of the spread according to this method, because this method requires simultaneous solution of two equations.
detail, again because the dataset is not as complete as the one that Bollen et al. (2004) have used in their work.

With respect to the **inventory holding premium** (see Eq. (10) in subsection 4.1.) it is not clear, in the work of Bollen et al. (2004), how the time until an offsetting order $t$ and the return volatility $\sigma$ are calculated. In determining the **time until an offsetting order** $t$, two methods were used.\(^{64}\) In the first method, $t_1$ is the average time (per half-hour\(^{65}\)) between a bid or ask order and the first ask or bid order respectively following this bid or ask order. The second method does not take into consideration differences between bid and ask orders, but just uses the average time (per half-hour) between two orders. This last method can be justified by the fact that Bollen et al. (2004) talk several times about $t$ as the ‘time between trades’ that is used as a proxy for the holding period in the expected IHP. However, when explaining their model they also talk about the time between offsetting orders, which is a plea for the first method. Volumes are not taken into account because this would increase the time between two trades significantly, especially on days where buy or sell volumes are significantly higher than sell or buy volumes respectively. We will see, later on, that the averages we obtain seem reasonable (cf. subsection 5.4.2.). In determining the **return volatility** $\sigma$, Bollen et al. (2004) used the daily returns of the sixty days preceding their sample months. The volatility of these daily returns was then annualized. We did the same, but instead of working with days, we worked with half-hours. The returns were calculated using the returns\(^{66}\) of the 5 half-hours preceding each half-hour. The returns are those of the true exchange rate. The **true exchange rate** $T$ is equal to the midpoint price of our constructed spread for each half-hour.

As a measure for **competition**, Bollen et al. (2004) used the MHI. The problem encountered here is that in order to be able to use the MHI we need to know the different volumes traded by all the dealers in a currency pair. Because we do not have this information, we need to define another measure for competition. What we do have at our disposal in our dataset is the number of parties active each day in a market for a certain currency pair. This allows us to define three different methods to take competition into account. The first method is simply the number of dealers that are active each day as a proxy for the competition that occurs each half-hour. The second method not only looks at the number of dealers per day but also at the distribution of the trades throughout a trading day and argues that when trades are more clustered within a certain half-hour, the

---

\(^{64}\) The first method is denoted by subscript 1, the second method is denoted by subscript 2. Thus we have $t_1$ and $t_2$. We use $t$ when talking about the time until an offsetting order in general, irrespective of the method used.

\(^{65}\) We take the average per half-hour, because we constructed a spread per half-hour.

\(^{66}\) Where the return equals $\ln(T_t) - \ln(T_0)$. 

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competition is higher in that half-hour. Consequently, the number of dealers per day are weighted with the number of trades per half-hour. The last method follows the same logic as the second method, only now we use the different volumes that were traded throughout the different half-hours in a trading day, instead of the number of trades. Thus, the number of dealers per day are weighted with the traded volumes per half-hour. These methods are referred to as \( c_D \), \( c_T \) and \( c_V \) respectively. The subscripts stand for ‘dealers’, ‘trades’ and ‘volumes’ respectively.

For the **order-processing cost** we use the inverse of the total traded volume of the foreign currency pair for each half-hour, referred to it as \( \text{inv(TV)} \). \( TV \) is the total volume of a foreign currency traded each half-hour.

Appendix B contains one set of the MATLAB algorithms we have written in order to obtain the just described b/a spreads according to the \( AV \) and \( MM \) method and the complementary spread determinants.\(^{67}\)

### 5.4. Summary statistics

#### 5.4.1. Spread measures

Tables 22 and 23 contain summary statistics for the spread measures for each of our four currency pairs.

Concerning the **daily spread measures** for each of our four currency pairs, differences between \( EWQS_{WA} \), \( EWQS_{LC} \), \( EWQS_{Co} \) and \( VWES_{WA} \), \( VWES_{LC} \), \( VWES_{Co} \) respectively are rather small. If there have been large differences between the quoted and effective spreads then, normally, this would indicate that many trades had been executed at prices within prevailing quoted prices, however - as mentioned - Lyons (1995) indicated that, on the interdealer foreign exchange market, trades normally are not negotiated within the spread, therefore we assume that the quoted spread equals the effective spread. If there had been a huge difference, then this difference could be attributed to the weights used (i.e. equal-weighted vs. volume-weighted). Looking across the different methods used for calculating the b/a spread, there are some differences in the size of the b/a spread. When making a ranking from highest mean value to lowest mean value, for all currency pairs, the b/a spread calculated according to the \( LC \) method has the highest mean value, followed by

\(^{67}\) All the MATLAB algorithms can be provided to the reader on request.
the b/a spread calculated according to the $C_0$ method. The b/a spread calculated according to the WA method has the smallest mean value.

For the \textit{intraday spread measures}, the same remark can be made. The rank order has the same order as the daily spread measures. If one looks now at the interquartile ranges, - as one can also do for the daily spread measures -, one can see that the higher mean value for the b/a spread calculated according to the $LC$ method is not because there are ‘outliers’, but because values in general cover a wider range of possible values.\footnote{The other methods result in more zero values for the b/a spread. These can be explained as being inherent to the method used or because of the abundance of negative b/a spread values (cf. subsection 5.3.1.2.).} Note also that the number of half-hours in the RUB/EUR TOD sample is much lower than in our other currency pair samples because of the fact that this market was closed much earlier than the other market until 16 May 2011.

The summary statistics of the b/a spread measures calculated according to our other methods mentioned in subsection 5.3.1., can be found in appendix C.

Because the sizes of the b/a spread in tables 22 and 23 are all expressed in Russian Ruble, a comparison is possible across different settlement methods and across currencies. We can see that for the RUB/EUR currency pairs, the size of the b/a spread is larger when settlement is on the next day (except for the b/a spread calculated according to the $C_0$ method). This is a rather peculiar finding as we would expect to see the clearing fees reflected in the b/a spread (cf. subsection 3.1.3.), however this could be explained by lower competition (see the average value of $C_T$ in subsection 5.4.2.) due to the substantially different trading hours.\footnote{The RUB/EUR TOD FX market is only open till 12:30 Moscow time, while the RUB/EUR TOM FX market is open till 17:00 Moscow time.} Another explanation could be that our b/a spread calculation methods do not provide us with reliable spread values. For the $C_0$ method the b/a spread is somewhat smaller for RUB/EUR TOM in comparison with RUB/EUR TOD. For the RUB/USD currency pairs, no huge differences between the different settlement methods were seen concerning the average values of the b/a spread sizes. Comparison across currency pairs shows that the b/a spreads are wider for the RUB/EUR currency pairs. This could be expected given that we mentioned in subsection 3.2.1. that Demsetz (1968) argued that the b/a spread will increase as the price i.e. the true exchange rate increases. This to keep the transaction cost per unit of price equal and to prevent arbitrage.
<table>
<thead>
<tr>
<th>Daily spread measures</th>
<th>RUB/EUR TOD</th>
<th>RUB/EUR TOM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean 25% Median 75%</td>
<td>Mean 25% Median 75%</td>
</tr>
<tr>
<td>$EWQS_{WA}$</td>
<td>0.0115    0.0009 0.0113 0.0020</td>
<td>0.0022    0.0014 0.0021 0.0028</td>
</tr>
<tr>
<td>$VWES_{WA}$</td>
<td>0.0015    0.0008 0.0013 0.0019</td>
<td>0.0025    0.0013 0.0020 0.0020</td>
</tr>
<tr>
<td>$REWQS_{WA}$</td>
<td>0.00038    0.00022 0.00033 0.00050</td>
<td>0.000056    0.000035 0.000052 0.000071</td>
</tr>
<tr>
<td>$RVWES_{WA}$</td>
<td>0.000266    0.000020 0.000031 0.000046</td>
<td>0.000062    0.000032 0.000050 0.000076</td>
</tr>
<tr>
<td>$EWQS_{LC}$</td>
<td>0.0039    0.0025 0.0039 0.0052</td>
<td>0.0057    0.0037 0.0048 0.0064</td>
</tr>
<tr>
<td>$VWES_{LC}$</td>
<td>0.0037    0.0021 0.0035 0.0050</td>
<td>0.0063    0.0036 0.0050 0.0072</td>
</tr>
<tr>
<td>$REWQS_{LC}$</td>
<td>0.000098    0.000061 0.000098 0.000130</td>
<td>0.000141    0.000094 0.000120 0.000159</td>
</tr>
<tr>
<td>$RVWES_{LC}$</td>
<td>0.000092    0.000052 0.000088 0.000125</td>
<td>0.000156    0.000091 0.000125 0.000179</td>
</tr>
<tr>
<td>$EWQS_{C0}$</td>
<td>0.0029    0.0014 0.0025 0.0039</td>
<td>0.0024    0.0012 0.0020 0.0029</td>
</tr>
<tr>
<td>$VWES_{C0}$</td>
<td>0.0028    0.0012 0.0023 0.0036</td>
<td>0.0024    0.0011 0.0017 0.0026</td>
</tr>
<tr>
<td>$REWQS_{C0}$</td>
<td>0.000073    0.000034 0.000061 0.000098</td>
<td>0.000060    0.000030 0.000049 0.000072</td>
</tr>
<tr>
<td>$RVWES_{C0}$</td>
<td>0.000069    0.000029 0.000057 0.000090</td>
<td>0.000060    0.000026 0.000044 0.000066</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intraday spread measures</th>
<th>(half-hours = 595)</th>
<th>(half-hours = 1451)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SPR_{WA}$</td>
<td>0.0016    0.0000 0.0007 0.0027</td>
<td>0.0022    0.0000 0.0006 0.0031</td>
</tr>
<tr>
<td>$RSPR_{WA}$</td>
<td>0.000041    0.000000 0.000018 0.000067</td>
<td>0.000056    0.000000 0.000014 0.000078</td>
</tr>
<tr>
<td>$SPR_{LC}$</td>
<td>0.0040    0.0000 0.0025 0.0060</td>
<td>0.0057    0.0000 0.0028 0.0075</td>
</tr>
<tr>
<td>$RSPR_{LC}$</td>
<td>0.000099    0.000000 0.000063 0.000148</td>
<td>0.000141    0.000000 0.000069 0.000189</td>
</tr>
<tr>
<td>$SPR_{C0}$</td>
<td>0.0029    0.0000 0.0009 0.0043</td>
<td>0.0024    0.0000 0.0000 0.0025</td>
</tr>
<tr>
<td>$RSPR_{C0}$</td>
<td>0.000071    0.000000 0.000023 0.000107</td>
<td>0.000060    0.000000 0.000000 0.000063</td>
</tr>
</tbody>
</table>

$EWQS_{X}$ is the equal-weighted quoted b/a spread, with $X = \{WA, LC, C0\}$ being the method used for calculating the b/a spread. $VWES_{X}$ is the volume-weighted effective b/a spread, with $X$ being the method used for calculating the b/a spread. $REWQS_{X}$ and $RVWES_{X}$ are the equal-weighted quoted and volume-weighted effective b/a spreads divided by the true exchange rate respectively. Both with $X$ being the method used for calculating the b/a spread. $SPR_{X}$ is the quoted b/a spread, with $X$ being the method used for calculating the b/a spread. $RSPR_{X}$ is the quoted b/a spread divided by the true exchange rate and $X$ being the method used for calculating the b/a spread.

Table 22: Summary of the descriptive statistics of the spread measures for the currencies RUB/EUR TOD and RUB/EUR TOM
<table>
<thead>
<tr>
<th>Daily spread measures</th>
<th>RUB/USD TOD</th>
<th>RUB/USD TOM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>25%</td>
</tr>
<tr>
<td>EWQ$S_{WA}$</td>
<td>0.0011</td>
<td>0.0008</td>
</tr>
<tr>
<td>VWES$S_{WA}$</td>
<td>0.0010</td>
<td>0.0007</td>
</tr>
<tr>
<td>REWQ$S_{WA}$</td>
<td>0.000039</td>
<td>0.000029</td>
</tr>
<tr>
<td>RVWES$S_{WA}$</td>
<td>0.000035</td>
<td>0.000025</td>
</tr>
<tr>
<td>EWQ$S_{LC}$</td>
<td>0.0024</td>
<td>0.0016</td>
</tr>
<tr>
<td>VWES$S_{LC}$</td>
<td>0.0021</td>
<td>0.0013</td>
</tr>
<tr>
<td>REWQ$S_{LC}$</td>
<td>0.000085</td>
<td>0.000053</td>
</tr>
<tr>
<td>RVWES$S_{LC}$</td>
<td>0.000074</td>
<td>0.000045</td>
</tr>
<tr>
<td>EWQ$S_{C0}$</td>
<td>0.0012</td>
<td>0.0006</td>
</tr>
<tr>
<td>VWES$S_{C0}$</td>
<td>0.0014</td>
<td>0.0006</td>
</tr>
<tr>
<td>REWQ$S_{C0}$</td>
<td>0.000044</td>
<td>0.000022</td>
</tr>
<tr>
<td>RVWES$S_{C0}$</td>
<td>0.000049</td>
<td>0.000020</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intraday spread measures</th>
<th>RUB/USD TOD</th>
<th>RUB/USD TOM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(half-hours = 995)</td>
<td>(half-hours = 1451)</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>25%</td>
</tr>
<tr>
<td>SPR$WA$</td>
<td>0.0011</td>
<td>0.0002</td>
</tr>
<tr>
<td>RS$PR_{WA}$</td>
<td>0.000039</td>
<td>0.000008</td>
</tr>
<tr>
<td>SPR$LC$</td>
<td>0.0024</td>
<td>0.0000</td>
</tr>
<tr>
<td>RS$PR_{LC}$</td>
<td>0.000085</td>
<td>0.000000</td>
</tr>
<tr>
<td>SPR$C0$</td>
<td>0.0012</td>
<td>0.0000</td>
</tr>
<tr>
<td>RS$PR_{C0}$</td>
<td>0.000044</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

EWQ$S_X$ is the equal-weighted quoted b/a spread, with $X = \{WA, LC, C0\}$ being the method used for calculating the b/a spread. VWES$X$ is the volume-weighted effective b/a spread, with $X$ being the method used for calculating the b/a spread. REWQ$S_X$ and RVWES$S_X$ are the equal-weighted quoted and volume-weighted effective b/a spreads divided by the true exchange rate respectively. Both with $X$ being the method used for calculating the b/a spread. SPR$X$ is the quoted b/a spread, with $X$ being the method used for calculating the b/a spread. RS$PR_X$ is the quoted b/a spread divided by the true exchange rate and $X$ being the method used for calculating the b/a spread.

Table 23: Summary of the descriptive statistics of the spread measures for the currencies RUB/USD TOD and RUB/USD TOM
5.4.2. Spread determinants

Tables 24 and 25 provide the summary statistics of the spread determinants for the different currency pairs. Note that the true exchange rate is calculated using the bid and ask price. Bid and ask prices differ according to the b/a spread calculation method used. Consequently, true exchange rates, but also annualized return volatilities and the inventory holding premiums differ according to the b/a spread calculation method used.

No striking differences can be found in the mean true exchange rate between RUB/EUR TOD and RUB/EUR TOM or between RUB/USD TOD and RUB/USD TOM. This was expected, because no consistent and fundamental differences could be seen between the weighted average prices for the different settlement methods per currency pair (cf. subsection 5.2.). Note, however, that the mean and quartile values of $C_T$ and $C_Y$ are much lower for RUB/EUR TOM and RUB/USD TOM than those for RUB/EUR TOD and RUB/USD TOD. This difference can be explained by the higher number of half-hours over which the number of dealers are weighed during a trading day for RUB/EUR TOM and RUB/USD TOM (cf. subsection 5.1.). For RUB/EUR TOD we have on average 5.95 half-hours per day, whereas for RUB/EUR TOM we have on average 14 half-hours per day. For RUB/USD we have on average 10 half-hours per day, whereas for RUB/USD TOM we have on average 14 half-hours per day. The mean value of the average square root of the time between trades $\sqrt{T_1}$ for each currency pair is higher than the average value of $\sqrt{T_2}$. This can be explained by the different methods used. The second method, i.e. $\sqrt{T_2}$, does not take into account differences between buys and sells. This difference also explains why $IHP_{W,t_1}$, $IHP_{L,t_1}$ and $IHP_{C_{t_1}}$ have a higher average value than $IHP_{W,t_2}$, $IHP_{L,t_2}$ and $IHP_{C_{t_2}}$ respectively. Note that these have a positive value. The differences in the values of the determinants corresponding with the three b/a spread calculation methods are rather small. For now, making a comparison of the evolution of the spread determinants over time for each currency pair would be premature (cf. intraday patterns in section 7).

The summary statistics of the spread determinants corresponding to the spread measures calculated according to our other b/a spread calculation methods mentioned in subsection 5.3.1. i.e. $LV$, $AV$, $MM$, $C_{05}$ and $C_{10}$, can be found in appendix D.
Summary of the descriptive statistics of the spread determinants for the currencies RUB/EUR TOD and RUB/EUR TOM.
The mean and quartile values for the different determinants of the b/a spread.

<table>
<thead>
<tr>
<th></th>
<th>RUB/EUR TOD (half-hours = 595)</th>
<th>RUB/EUR TOM (half-hours = 1451)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>25%</td>
</tr>
<tr>
<td>$T_{WA}$</td>
<td>40.1515</td>
<td>39.9114</td>
</tr>
<tr>
<td>$inv(T_{WA})$</td>
<td>0.0249</td>
<td>0.0247</td>
</tr>
<tr>
<td>$T_{LC}$</td>
<td>40.1499</td>
<td>39.9051</td>
</tr>
<tr>
<td>$inv(T_{LC})$</td>
<td>0.0249</td>
<td>0.0247</td>
</tr>
<tr>
<td>$T_{C_0}$</td>
<td>40.1507</td>
<td>39.9011</td>
</tr>
<tr>
<td>$inv(T_{C_0})$</td>
<td>0.0249</td>
<td>0.0247</td>
</tr>
<tr>
<td>$TV$</td>
<td>18639244</td>
<td>12529500</td>
</tr>
<tr>
<td>$inv(TV)$</td>
<td>7.36E-08</td>
<td>4.30E-08</td>
</tr>
<tr>
<td>$C_D$</td>
<td>183.5042</td>
<td>170.0000</td>
</tr>
<tr>
<td>$\sigma_{WA}$</td>
<td>0.0521</td>
<td>0.0255</td>
</tr>
<tr>
<td>$\sigma_{LC}$</td>
<td>0.0568</td>
<td>0.0304</td>
</tr>
<tr>
<td>$\sigma_{C_0}$</td>
<td>0.0584</td>
<td>0.0308</td>
</tr>
<tr>
<td>$\sqrt{t_1}$</td>
<td>8.7851</td>
<td>7.2443</td>
</tr>
<tr>
<td>$\sqrt{t_2}$</td>
<td>4.7688</td>
<td>4.0498</td>
</tr>
<tr>
<td>$IH_{P,WA,t1}$</td>
<td>0.0042</td>
<td>0.0022</td>
</tr>
<tr>
<td>$IH_{P,WA,t2}$</td>
<td>0.0023</td>
<td>0.0012</td>
</tr>
<tr>
<td>$IH_{P,LC,t1}$</td>
<td>0.0046</td>
<td>0.0027</td>
</tr>
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<td>$IH_{P,LC,t2}$</td>
<td>0.0025</td>
<td>0.0014</td>
</tr>
<tr>
<td>$IH_{P,G0,t1}$</td>
<td>0.0048</td>
<td>0.0027</td>
</tr>
<tr>
<td>$IH_{P,G0,t2}$</td>
<td>0.0026</td>
<td>0.0015</td>
</tr>
</tbody>
</table>

$T_x$ is the true exchange rate, corresponding to the b/a spread calculated according to method $X=\{W_{A,LC}, C_D\}$. $inv(T_x)$ is the inverse of $T_x$. $C_V$ is a measure for competition, with $Y=\{D,T,V\}$ being the method used. $\sigma_T$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{t_x}$ is the average square root of the number of seconds between trades according to method $Z=\{1,2\}$. $IH_{P,x,t2}$ is the inventory holding premium based on $T_x$, $\sigma_T$ and $\sqrt{t_x}$.

Table 24: Summary of the descriptive statistics of the spread determinants for the currencies RUB/EUR TOD and RUB/EUR TOM
### Summary of the Descriptive Statistics of the Spread Determinants for the Currencies RUB/USD TOD and RUB/USD TOM.

The mean and quartile values for the different determinants of the b/a spread.

<table>
<thead>
<tr>
<th></th>
<th>RUB/USD TOD (half-hours = 995)</th>
<th></th>
<th></th>
<th>RUB/USD TOM (half-hours = 1451)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>25%</td>
<td>Median</td>
<td>75%</td>
<td>Mean</td>
<td>25%</td>
</tr>
<tr>
<td>inv($T_{WA}$)</td>
<td>0.0350</td>
<td>0.0342</td>
<td>0.0353</td>
<td>0.0357</td>
<td>0.0350</td>
<td>0.0342</td>
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<tr>
<td>inv($T_{LC}$)</td>
<td>0.0350</td>
<td>0.0342</td>
<td>0.0353</td>
<td>0.0357</td>
<td>0.0350</td>
<td>0.0342</td>
</tr>
<tr>
<td>inv($T_{C_0}$)</td>
<td>0.0350</td>
<td>0.0342</td>
<td>0.0353</td>
<td>0.0357</td>
<td>0.0350</td>
<td>0.0342</td>
</tr>
<tr>
<td>$TV$</td>
<td>113985988</td>
<td>64729750</td>
<td>10285700</td>
<td>15265400</td>
<td>260211284</td>
<td>158670250</td>
</tr>
<tr>
<td>inv($TV$)</td>
<td>1.30E-08</td>
<td>6.55E-09</td>
<td>9.72E-09</td>
<td>1.54E-08</td>
<td>5.24E-09</td>
<td>3.00E-09</td>
</tr>
<tr>
<td>$C_D$</td>
<td>268.2060</td>
<td>263.0000</td>
<td>270.0000</td>
<td>277.0000</td>
<td>234.0469</td>
<td>228.0000</td>
</tr>
<tr>
<td>$\sigma_{WA}$</td>
<td>0.0551</td>
<td>0.0216</td>
<td>0.0375</td>
<td>0.0700</td>
<td>0.0512</td>
<td>0.0219</td>
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<td>$\sigma_{LC}$</td>
<td>0.0611</td>
<td>0.0267</td>
<td>0.0461</td>
<td>0.0771</td>
<td>0.0593</td>
<td>0.0287</td>
</tr>
<tr>
<td>$\sigma_{C_0}$</td>
<td>0.0603</td>
<td>0.0279</td>
<td>0.0465</td>
<td>0.0777</td>
<td>0.0576</td>
<td>0.0291</td>
</tr>
<tr>
<td>$\sqrt{T_1}$</td>
<td>6.6311</td>
<td>5.1411</td>
<td>6.3749</td>
<td>7.7814</td>
<td>5.5165</td>
<td>4.5130</td>
</tr>
<tr>
<td>$\sqrt{T_2}$</td>
<td>3.1197</td>
<td>2.3878</td>
<td>2.9497</td>
<td>3.7391</td>
<td>2.5563</td>
<td>2.1630</td>
</tr>
<tr>
<td>$IHPI_{WA,t1}$</td>
<td>0.0017</td>
<td>0.0008</td>
<td>0.0013</td>
<td>0.0021</td>
<td>0.0012</td>
<td>0.0006</td>
</tr>
<tr>
<td>$IHPI_{WA,t2}$</td>
<td>0.0008</td>
<td>0.0004</td>
<td>0.0006</td>
<td>0.0010</td>
<td>0.0005</td>
<td>0.0003</td>
</tr>
<tr>
<td>$IHPI_{LC,t1}$</td>
<td>0.0019</td>
<td>0.0010</td>
<td>0.0015</td>
<td>0.0025</td>
<td>0.0014</td>
<td>0.0007</td>
</tr>
<tr>
<td>$IHPI_{LC,t2}$</td>
<td>0.0009</td>
<td>0.0005</td>
<td>0.0007</td>
<td>0.0011</td>
<td>0.0006</td>
<td>0.0003</td>
</tr>
<tr>
<td>$IHPI_{C_0,t1}$</td>
<td>0.0019</td>
<td>0.0010</td>
<td>0.0016</td>
<td>0.0024</td>
<td>0.0013</td>
<td>0.0007</td>
</tr>
<tr>
<td>$IHPI_{C_0,t2}$</td>
<td>0.0009</td>
<td>0.0005</td>
<td>0.0008</td>
<td>0.0011</td>
<td>0.0006</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

$T_X$ is the true exchange rate, corresponding to the b/a spread calculated according to method $X=(WA,LC,C_0)$. $\text{inv}(T_X)$ is the inverse of $T_X$. $C_Y$ is a measure for competition, with $Y=(D,T,V)$ being the method used. $\sigma_Y$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{T_Z}$ is the average square root of the number of seconds between trades according to method $Z=(1,2)$. $IHPI_{X,tZ}$ is the inventory holding premium based on $T_X$, $\sigma_X$ and $\sqrt{T_Z}$.

Table 25: Summary of descriptive statistics of the spread determinants for the currencies RUB/USD TOD and RUB/USD TOM
5.4.3. Cross-correlations between spread measures and determinants

Because we have several determinants corresponding to each b/a spread method, we need to make a choice as to which b/a spread determinants to use in the empirical investigation of our model (cf. section 6). Remember, for instance, that we have three different methods for the competition component. We need to make a decision, which one(s) to use in our regressions. To make this decision, one would normally use the Pearson correlation tables and choose those determinants that have the best suited correlation coefficient, both in size and sign.

The Pearson correlation tables for each currency pair and for each b/a spread calculation method i.e. WA, LC and C₀, can be found in tables 26 to 37. Note that the daily spread measures are not included in these tables. We will not use these in our empirical investigation because this would substantially decrease the size of our sample.

First, looking at tables 26 to 37, one can see that there are many differences in both size and sign not only across currency pairs, but also across methods. Let us consider an example. For instance, for the WA b/a spread calculation method the signs of the correlation coefficients between both the \(IHP_{WA,t_1}\) and \(IHP_{WA,t_2}\) on the one hand and the \(SPR_{WA}\) on the other hand, are sometimes positive and sometimes negative across the different currency pairs. Furthermore, comparing then again the signs of the correlation coefficients between both the \(IHP_{WA,t_1}\) and \(IHP_{WA,t_2}\) on the one hand and the \(SPR_{WA}\) on the other hand with the signs of the correlation coefficients of both the \(IHP_{C_0,t_1}\) and \(IHP_{C_0,t_2}\) on the one hand and the \(SPR_{C_0}\) on the other hand for RUB/USD TOM, we can see that for the first two inventory holding premiums, these are negative and for the latter two inventory holding premiums, these are positive. The same can be said for the different competition measures. Because there are so many differences, we believe it would not only be difficult but also wrong to choose those determinants that have the ‘best suited’ correlation coefficients, both in size and sign.

Furthermore, as our survey will show (cf. subsection 8.2.), there can be an explanation for why these determinants do not behave as expected. Consequently, we will choose the determinants and the final b/a spread calculation method for further use in our regressions purely based on weighing the advantages and the disadvantages of each of the variables (cf. section 6). This also means that we do not follow the method of working used in the early empirical studies i.e. take up several factors and look what fits best (cf. subsection 3.2.1.).
Second, looking at tables 26 to 37, one can see that the correlations between $SPR_{WA}$, $SPR_{LC}$, $SPR_{C_0}$ and $RSPR_{WA}$, $RSPR_{LC}$, $RSPR_{C_0}$ respectively are very high i.e. almost a perfect positive linear relationship. The minimum correlation coefficient has a value of 0.9994. This is for the correlation between $SPR_{WA}$ and $RSPR_{WA}$ for the currency pair RUB/USD TOM. This means that both the absolute b/a spread measure and the relative b/a spread measure here describe the same phenomena. Consequently, in our regressions, we will only work with the absolute b/a spread measures.

Third, we can see that there is multicollinearity that will affect our results. This is because the correlations between the spread determinants, in general, are larger than the correlations between the spread determinants and the spread measures. Unfortunately we cannot correct for this.

Fourth, none of the regressors are notably high upon correlation with the spread measures. This observation, together with multicollinearity, could indicate that no single regressor has a clear relationship with the spread measure.

The Pearson correlation tables for the b/a spreads calculated according to the other methods i.e. $LV$, $AV$, $MM$, $C_{05}$ and $C_{10}$, can be found in appendix E.
### Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the WA method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>SPRWA</th>
<th>RSPWRWA</th>
<th>TW</th>
<th>inv(TW)</th>
<th>TV</th>
<th>inv(TV)</th>
<th>CD</th>
<th>CT</th>
<th>CV</th>
<th>σWA</th>
<th>√t1</th>
<th>√t2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPRWA</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSPWRWA</td>
<td>1.0000</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TW</td>
<td>-0.0939</td>
<td>-0.0992</td>
<td>1.0000</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inv(TW)</td>
<td>0.0929</td>
<td>0.0982</td>
<td>-0.9999</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TV</td>
<td>-0.1418</td>
<td>-0.1410</td>
<td>-0.0256</td>
<td>0.0274</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inv(TV)</td>
<td>0.2177</td>
<td>0.2178</td>
<td>0.0312</td>
<td>-0.0323</td>
<td>-0.6609</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD</td>
<td>0.1011</td>
<td>0.1016</td>
<td>-0.1047</td>
<td>0.1034</td>
<td>-0.1450</td>
<td>0.2501</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CT</td>
<td>-0.2169</td>
<td>-0.2162</td>
<td>-0.0540</td>
<td>0.0561</td>
<td>0.7159</td>
<td>-0.6235</td>
<td>-0.3388</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>-0.1651</td>
<td>-0.1644</td>
<td>-0.0443</td>
<td>0.0461</td>
<td>0.9077</td>
<td>-0.6704</td>
<td>-0.2819</td>
<td>0.8089</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>σWA</td>
<td>-0.0399</td>
<td>-0.0390</td>
<td>-0.1077</td>
<td>0.1090</td>
<td>0.2303</td>
<td>-0.2447</td>
<td>-0.3601</td>
<td>0.2877</td>
<td>0.2366</td>
<td>1.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>√t1</td>
<td>0.2539</td>
<td>0.2533</td>
<td>0.0146</td>
<td>-0.0160</td>
<td>-0.5397</td>
<td>0.6467</td>
<td>0.2327</td>
<td>-0.6645</td>
<td>-0.5529</td>
<td>-0.2468</td>
<td>1.0000</td>
<td></td>
</tr>
<tr>
<td>√t2</td>
<td>0.2805</td>
<td>0.2804</td>
<td>-0.0263</td>
<td>0.0244</td>
<td>-0.6581</td>
<td>0.7397</td>
<td>0.2270</td>
<td>-0.8407</td>
<td>-0.6730</td>
<td>-0.2570</td>
<td>0.7625</td>
<td>1.0000</td>
</tr>
<tr>
<td>IHPWA1t1</td>
<td>0.0250</td>
<td>0.0257</td>
<td>-0.1131</td>
<td>0.1140</td>
<td>0.0775</td>
<td>-0.1037</td>
<td>-0.3231</td>
<td>0.1155</td>
<td>0.0933</td>
<td>0.9441</td>
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</tr>
<tr>
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<td>0.1253</td>
<td>0.0698</td>
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<td>0.0818</td>
<td>0.9660</td>
<td>-0.0969</td>
<td>-0.0466</td>
</tr>
</tbody>
</table>

SPRWA is the b/a spread calculated according to the WA method. RSPWRWA is the relative spread, which is equal to the SPRWA divided by the true exchange rate. TW is the true exchange rate. inv(TW) is the inverse of TW. TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. CV is a measure for competition, with Y={D,T,V} being the corresponding method being used. σWA is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. √t1 is the average square root of the number of seconds between trades according to method Z={1,2}. IHPWA1t1 is the inventory holding premium based on SPRWA, σWA, and √t2.

Table 26: Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the WA method.
**Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the LC method**

Summary of the correlations between the variables used for regressions

<table>
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<tr>
<th></th>
<th>$SPR_{LC}$</th>
<th>$RSPR_{LC}$</th>
<th>$T_{LC}$</th>
<th>$inv(T_{LC})$</th>
<th>$TV$</th>
<th>$inv(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{LC}$</th>
<th>$\sqrt{t_1}$</th>
<th>$\sqrt{t_2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SPR_{LC}$</td>
<td>1.0000</td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$RSPR_{LC}$</td>
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<td>1.0000</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>$T_{LC}$</td>
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<tr>
<td>$inv(T_{LC})$</td>
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<td></td>
</tr>
<tr>
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<tr>
<td>$inv(TV)$</td>
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<td>0.0366</td>
<td>-0.0377</td>
<td>-0.6609</td>
<td>1.0000</td>
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</tr>
<tr>
<td>$C_D$</td>
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<td>0.0299</td>
<td>-0.1047</td>
<td>0.1034</td>
<td>-0.1450</td>
<td>0.2501</td>
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<tr>
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<td>-0.3243</td>
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<tr>
<td>$\sqrt{t_2}$</td>
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<td>0.0156</td>
<td>-0.6581</td>
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<td>0.2270</td>
<td>-0.8407</td>
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<td>-0.2432</td>
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<tr>
<td>$IHP_{LC,t_1}$</td>
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<td>0.1730</td>
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<td>0.9297</td>
<td>0.0793</td>
<td>-0.0252</td>
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<tr>
<td>$IHP_{LC,t_2}$</td>
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<td>0.1851</td>
<td>0.0247</td>
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<td>-0.3019</td>
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<td>0.0461</td>
<td>0.9569</td>
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<td>0.0063</td>
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</table>

$SPR_{LC}$ is the b/a spread calculated according to the LC method. $RSPR_{LC}$ is the relative spread, which is equal to the $SPR_{LC}$ divided by the true exchange rate. $T_{LC}$ is the true exchange rate. $inv(T_{LC})$ is the inverse of $T_{LC}$. $TV$ is the total volume traded per half-hour. $inv(TV)$ is the inverse of $TV$. $C_V$ is a measure for competition, with $Y = \{D,T,V\}$ being the corresponding method being used. $\sigma_{LC}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{t_1}$ is the average square root of the number of seconds between trades according to method $Z = \{1,2\}$. $IHP_{LC,t_1}$ is the inventory holding premium based on $SPR_{LC}$, $\sigma_{LC}$, and $\sqrt{t_2}$. $IHP_{LC,t_2}$ is the inventory holding premium based on $SPR_{LC}$, $\sigma_{LC}$, and $\sqrt{t_2}$.

Table 27: Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the LC method
Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the $C_0$ method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>$SPR_{C_0}$</th>
<th>$RSPR_{C_0}$</th>
<th>$T_{C_0}$</th>
<th>$\text{inv}(T_{C_0})$</th>
<th>$TV$</th>
<th>$\text{inv}(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{C_0}$</th>
<th>$\sqrt{\bar{t}_1}$</th>
<th>$\sqrt{\bar{t}_2}$</th>
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<td>$\text{inv}(T_{C_0})$</td>
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<tr>
<td>$TV$</td>
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<td>-0.0529</td>
<td>-0.0235</td>
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</tr>
<tr>
<td>$\text{inv}(TV)$</td>
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<tr>
<td>$C_T$</td>
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<td>$C_V$</td>
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<tr>
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<td>0.7397</td>
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<td>-0.2501</td>
<td>0.7625</td>
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<tr>
<td>$IHPC_{0,t_1}$</td>
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<td>0.1078</td>
<td>0.0492</td>
<td>-0.0719</td>
<td>-0.3143</td>
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<td>0.9310</td>
<td>0.0651</td>
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<td>0.0512</td>
<td>0.9556</td>
<td>-0.0614</td>
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$SPR_{C_0}$ is the b/a spread calculated according to the $C_0$ method. $RSPR_{C_0}$ is the relative spread, which is equal to the $SPR_{C_0}$ divided by the true exchange rate. $T_{C_0}$ is the true exchange rate. $\text{inv}(T_{C_0})$ is the inverse of $T_{C_0}$. $TV$ is the total volume traded per half-hour. $\text{inv}(TV)$ is the inverse of $TV$. $C_D$ is a measure for competition, with $Y={D,T,V}$ being the corresponding method being used. $\sigma_{C_0}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{\bar{t}_1}$ is the average square root of the number of seconds between trades according to method $Z={1,2}$. $IHPC_{0,t_1}$ is the inventory holding premium based on $SPR_{C_0}$, $\sigma_{C_0}$ and $\sqrt{\bar{t}_2}$.

Table 28: Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the $C_0$ method
Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the WA method

Summary of the correlations between the variables used for regressions

<table>
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<th></th>
<th>SPR_{WA}</th>
<th>RSPR_{WA}</th>
<th>T_{WA}</th>
<th>inv(T_{WA})</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C_D</th>
<th>C_T</th>
<th>C_V</th>
<th>σ_{WA}</th>
<th>√{τ_1}</th>
<th>√{τ_2}</th>
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<tbody>
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<tr>
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</tr>
<tr>
<td>inv(TV)</td>
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<td>-0.1147</td>
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<td>1.0000</td>
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<tr>
<td>C_D</td>
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<td>0.0172</td>
<td>-0.1902</td>
<td>0.1920</td>
<td>0.2151</td>
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<tr>
<td>C_T</td>
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<td>-0.0204</td>
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<tr>
<td>C_V</td>
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<tr>
<td>√{τ_1}</td>
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<td>-0.2172</td>
<td>-0.8007</td>
<td>-0.5009</td>
<td>-0.0864</td>
<td>0.5848</td>
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<tr>
<td>IHP_{WA,t_1}</td>
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<td>0.0026</td>
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<td>0.9380</td>
<td>0.1393</td>
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</tbody>
</table>

SPR_{WA} is the b/a spread calculated according to the WA method. RSPR_{WA} is the relative spread, which is equal to the SPR_{WA} divided by the true exchange rate. T_{WA} is the true exchange rate. inv(T_{WA}) is the inverse of T_{WA}. TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. C_y is a measure for competition, with Y∈{D,T,V} being the corresponding method being used. σ_{WA} is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. √{τ_1} is the average square root of the number of seconds between trades according to method Z∈{1,2}. IHP_{WA,t_y} is the inventory holding premium based on SPR_{WA}, σ_{WA} and √{τ_y}.

Table 29: Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the WA method
Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the LC method

Summary of the correlations between the variables used for regressions

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<th>$RSPR_{LC}$</th>
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<th>$TV$</th>
<th>$inv(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{LC}$</th>
<th>$\sqrt{t_1}$</th>
<th>$\sqrt{t_2}$</th>
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<td>$IHP_{LC,t_1}$</td>
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<td>0.1060</td>
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<td>0.2986</td>
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</tr>
<tr>
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</tbody>
</table>

$SPR_{LC}$ is the b/a spread calculated according to the LC method. $RSPR_{LC}$ is the relative spread, which is equal to the $SPR_{LC}$ divided by the true exchange rate. $T_{LC}$ is the true exchange rate. $inv(T_{LC})$ is the inverse of $T_{LC}$. $TV$ is the total volume traded per half-hour. $inv(TV)$ is the inverse of $TV$. $C_V$ is a measure for competition, with $Y\in\{D,T,V\}$ being the corresponding method being used. $\sigma_{LC}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{t_1}$ is the average square root of the number of seconds between trades according to method $Z=(1,2)$. $IHP_{LC,t_z}$ is the inventory holding premium based on $SPR_{LC}$, $\sigma_{LC}$ and $\sqrt{t_z}$.

Table 30: Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the LC method
### Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the $C_0$ method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>$SPR_{C_0}$</th>
<th>$RSPR_{C_0}$</th>
<th>$T_{C_0}$</th>
<th>$inv(T_{C_0})$</th>
<th>$TV$</th>
<th>$inv(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{C_0}$</th>
<th>$\sqrt{\hat{\epsilon}_1}$</th>
<th>$\sqrt{\hat{\epsilon}_2}$</th>
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<td>$SPR_{C_0}$</td>
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<td>0.0593</td>
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<td>0.0507</td>
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<tr>
<td>$\sigma_{C_0}$</td>
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<td>$\sqrt{\hat{\epsilon}_1}$</td>
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<td>0.0810</td>
<td>-0.1318</td>
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<td>0.9092</td>
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<td>$IHP_{C_0,t_2}$</td>
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<td>0.9184</td>
<td>0.1516</td>
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</table>

$SPR_{C_0}$ is the b/a spread calculated according to the $C_0$ method. $RSPR_{C_0}$ is the relative spread, which is equal to the $SPR_{C_0}$ divided by the true exchange rate. $T_{C_0}$ is the true exchange rate. $inv(T_{C_0})$ is the inverse of $T_{C_0}$. $TV$ is the total volume traded per half-hour. $inv(TV)$ is the inverse of $TV$. $C_D$ is a measure for competition, with $Y\{D,T,V\}$ being the corresponding method being used. $\sigma_{C_0}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{\hat{\epsilon}_1}$ is the average square root of the number of seconds between trades according to method $Z\{1,2\}$. $IHP_{C_0,t_1}$ is the inventory holding premium based on $SPR_{C_0}$, $\sigma_{C_0}$ and $\sqrt{\hat{\epsilon}_2}$.

Table 31: Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the $C_0$ method
Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the WA method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>SPR$_{WA}$</th>
<th>RSPR$_{WA}$</th>
<th>T$_{WA}$</th>
<th>inv(T$_{WA}$)</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C$_D$</th>
<th>C$_T$</th>
<th>C$_V$</th>
<th>$\sigma_{WA}$</th>
<th>$\sqrt{t_1}$</th>
<th>$\sqrt{t_2}$</th>
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<tbody>
<tr>
<td>SPR$_{WA}$</td>
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<tr>
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<tr>
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<td>inv(TV)</td>
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<tr>
<td>C$_D$</td>
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<td>0.1287</td>
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<tr>
<td>C$_T$</td>
<td>-0.1766</td>
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<td>-0.0329</td>
<td>0.0322</td>
<td>0.7642</td>
<td>-0.5670</td>
<td>0.0998</td>
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<tr>
<td>C$_V$</td>
<td>-0.1572</td>
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<td>-0.0303</td>
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<td>0.9411</td>
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<tr>
<td>$\sigma_{WA}$</td>
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<tr>
<td>$\sqrt{t_1}$</td>
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<td>-0.1109</td>
<td>-0.9038</td>
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<td>-0.4691</td>
<td>0.8050</td>
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<tr>
<td>IHP$_{WA,t_1}$</td>
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<td>-0.0612</td>
<td>-0.0877</td>
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<td>-0.2037</td>
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<td>0.9399</td>
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<td>IHP$_{WA,t_2}$</td>
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<td>-0.1833</td>
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<td>0.9535</td>
<td>-0.2713</td>
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</tr>
</tbody>
</table>

SPR$_{WA}$ is the b/a spread calculated according to the WA method. RSPR$_{WA}$ is the relative spread, which is equal to the SPR$_{WA}$ divided by the true exchange rate. T$_{WA}$ is the true exchange rate. inv(T$_{WA}$) is the inverse of T$_{WA}$. TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. C$_y$ is a measure for competition, with $Y=\{D,T,V\}$ being the corresponding method being used. $\sigma_{WA}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{t_1}$ is the average square root of the number of seconds between trades according to method $Z=\{1,2\}$. IHP$_{WA,t_z}$ is the inventory holding premium based on SPR$_{WA}$, $\sigma_{WA}$ and $\sqrt{t_z}$.

Table 32: Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the WA method
### Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the LC method

Summary of the correlations between the variables used for regressions:

<table>
<thead>
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<th>$SPR_{LC}$</th>
<th>$RSPR_{LC}$</th>
<th>$T_{LC}$</th>
<th>$inv(T_{LC})$</th>
<th>$TV$</th>
<th>$inv(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{LC}$</th>
<th>$\sqrt{t_1}$</th>
<th>$\sqrt{t_2}$</th>
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<td>$\sqrt{t_1}$</td>
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<td>-0.4733</td>
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</tr>
<tr>
<td>$IHP_{LC,t_1}$</td>
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<td>-0.0029</td>
<td>-0.0863</td>
<td>0.0877</td>
<td>0.2506</td>
<td>-0.1684</td>
<td>0.0438</td>
<td>0.2173</td>
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<td>0.9251</td>
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</tr>
<tr>
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<td>-0.0008</td>
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<td>0.2331</td>
<td>-0.1370</td>
<td>0.0403</td>
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<td>0.1765</td>
<td>0.9355</td>
<td>-0.2401</td>
<td>-0.2188</td>
</tr>
</tbody>
</table>

$SPR_{LC}$ is the b/a spread calculated according to the LC method. $RSPR_{LC}$ is the relative spread, which is equal to the $SPR_{LC}$ divided by the true exchange rate. $T_{LC}$ is the true exchange rate. $inv(T_{LC})$ is the inverse of $T_{LC}$. $TV$ is the total volume traded per half-hour. $inv(TV)$ is the inverse of $TV$. $C_V$ is a measure for competition, with $Y\in\{D,T,V\}$ being the corresponding method being used. $\sigma_{LC}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{t_1}$ is the average square root of the number of seconds between trades according to method $Z\in\{1,2\}$. $IHP_{LC,t_1}$ is the inventory holding premium based on $SPR_{LC}$, $\sigma_{LC}$ and $\sqrt{t_2}$.

Table 33: Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the LC method.
### Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the $C_0$ method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>$SPR_{C_0}$</th>
<th>$RSPR_{C_0}$</th>
<th>$T_{C_0}$</th>
<th>$inv(T_{C_0})$</th>
<th>$TV$</th>
<th>$inv(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{C_0}$</th>
<th>$\sqrt{T_1}$</th>
<th>$\sqrt{T_2}$</th>
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<tbody>
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</tr>
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<td>$RSPR_{C_0}$</td>
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<td>$inv(TV)$</td>
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<td>1.0000</td>
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<td>$C_T$</td>
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<td>$C_V$</td>
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<tr>
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<td>-0.0091</td>
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<td>0.5604</td>
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<td>-0.7781</td>
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<td>-0.0010</td>
<td>-0.1052</td>
<td>0.1061</td>
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<td>0.0253</td>
<td>0.1842</td>
<td>0.1594</td>
<td>0.9210</td>
<td>-0.1163</td>
<td>-0.2344</td>
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<td>$IHP_{C_0,T_2}$</td>
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<td>0.0054</td>
<td>-0.0951</td>
<td>0.0959</td>
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<td>0.0227</td>
<td>0.1528</td>
<td>0.1480</td>
<td>0.9340</td>
<td>-0.2023</td>
<td>-0.1885</td>
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</table>

$SPR_{C_0}$ is the b/a spread calculated according to the $C_0$ method. $RSPR_{C_0}$ is the relative spread, which is equal to the $SPR_{C_0}$ divided by the true exchange rate. $T_{C_0}$ is the true exchange rate. $inv(T_{C_0})$ is the inverse of $T_{C_0}$. $TV$ is the total volume traded per half-hour. $inv(TV)$ is the inverse of $TV$. $C_D$ is a measure for competition, with $Y\in\{D,T,V\}$ being the corresponding method being used. $\sigma_{T_1}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{T_2}$ is the average square root of the number of seconds between trades according to method $Z\in\{1,2\}$. $IHP_{C_0,T_1}$ is the inventory holding premium based on $SPR_{C_0}$, $\sigma_{C_0}$ and $\sqrt{T_2}$.

Table 34: Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the $C_0$ method
<table>
<thead>
<tr>
<th></th>
<th>SPRWA</th>
<th>RSPRWA</th>
<th>TWA</th>
<th>inv(TWA)</th>
<th>TV</th>
<th>inv(TV)</th>
<th>CD</th>
<th>CT</th>
<th>CV</th>
<th>1WA</th>
<th>\sqrt{t_1}</th>
<th>\sqrt{t_2}</th>
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</thead>
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<td>SPRWA</td>
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</tr>
<tr>
<td>RSPRWA</td>
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</tr>
<tr>
<td>TWA</td>
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<td>-0.0808</td>
<td>1.0000</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>inv(TWA)</td>
<td>0.0596</td>
<td>0.0808</td>
<td>-0.9996</td>
<td>1.0000</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>TV</td>
<td>-0.0286</td>
<td>-0.0245</td>
<td>-0.1411</td>
<td>0.1432</td>
<td>1.0000</td>
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<tr>
<td>inv(TV)</td>
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<td>0.0940</td>
<td>0.0959</td>
<td>-0.0976</td>
<td>-0.7214</td>
<td>1.0000</td>
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<tr>
<td>CD</td>
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<td>0.0138</td>
<td>-0.0512</td>
<td>0.0463</td>
<td>0.1090</td>
<td>-0.0900</td>
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<tr>
<td>CT</td>
<td>-0.0391</td>
<td>-0.0384</td>
<td>-0.0066</td>
<td>0.0058</td>
<td>0.6770</td>
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<tr>
<td>CV</td>
<td>-0.0300</td>
<td>-0.0284</td>
<td>-0.0070</td>
<td>0.0063</td>
<td>0.8445</td>
<td>-0.6568</td>
<td>0.0875</td>
<td>0.8039</td>
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<tr>
<td>\sigma(1WA)</td>
<td>-0.0834</td>
<td>-0.0819</td>
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<td>0.1334</td>
<td>0.3611</td>
<td>-0.3091</td>
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<td>0.3175</td>
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<tr>
<td>\sqrt{t_1}</td>
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<td>0.0299</td>
<td>0.1074</td>
<td>-0.1105</td>
<td>-0.6491</td>
<td>0.6782</td>
<td>-0.0877</td>
<td>-0.6114</td>
<td>-0.5903</td>
<td>-0.3115</td>
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<td>\sqrt{t_2}</td>
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<td>0.7474</td>
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<td>-0.8059</td>
<td>-0.6598</td>
<td>-0.3554</td>
<td>0.7592</td>
<td>1.0000</td>
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<tr>
<td>IHPWA,t1</td>
<td>-0.0875</td>
<td>-0.0874</td>
<td>-0.0817</td>
<td>0.0819</td>
<td>0.1798</td>
<td>-0.1810</td>
<td>0.1113</td>
<td>0.1577</td>
<td>0.1153</td>
<td>0.9419</td>
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<td>-0.0779</td>
<td>-0.1014</td>
<td>0.1019</td>
<td>0.1963</td>
<td>-0.1896</td>
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<td>0.1331</td>
<td>0.1198</td>
<td>0.9594</td>
<td>-0.1673</td>
<td>-0.1617</td>
</tr>
</tbody>
</table>

SPRWA is the b/a spread calculated according to the WA method. RSPRWA is the relative spread, which is equal to the SPRWA divided by the true exchange rate. TWA is the true exchange rate. inv(TWA) is the inverse of TWA. TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. CV is a measure for competition, with Y = {D,T,V} being the corresponding method being used. \sigma(1WA) is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. \sqrt{t_1} is the average square root of the number of seconds between trades according to method \{1,2\}. IHPWAt1 and IHPWAt2 is the inventory holding premium based on SPRWA, \sigma(1WA) and \sqrt{t_2}.

Table 35: Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the WA method.
Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the LC method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>SPR_{LC}</th>
<th>RSPR_{LC}</th>
<th>T_{LC}</th>
<th>inv(T_{LC})</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C_D</th>
<th>C_T</th>
<th>C_V</th>
<th>σ_{LC}</th>
<th>√t_1</th>
<th>√t_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPR_{LC}</td>
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<tr>
<td>RSPR_{LC}</td>
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<tr>
<td>T_{LC}</td>
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<td>-0.0494</td>
<td>1.0000</td>
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<tr>
<td>inv(T_{LC})</td>
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<tr>
<td>inv(TV)</td>
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<td>-0.0083</td>
<td>0.0969</td>
<td>-0.0987</td>
<td>-0.7214</td>
<td>1.0000</td>
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<tr>
<td>C_D</td>
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<td>0.0323</td>
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<td>0.0462</td>
<td>0.1090</td>
<td>-0.0900</td>
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<tr>
<td>C_T</td>
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<tr>
<td>C_V</td>
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<tr>
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<td>√t_2</td>
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<tr>
<td>IHP_{LC,t_1}</td>
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<td>0.1097</td>
<td>0.9497</td>
<td>-0.1732</td>
<td>-0.1606</td>
</tr>
</tbody>
</table>

SPR_{LC} is the b/a spread calculated according to the LC method. RSPR_{LC} is the relative spread, which is equal to the SPR_{LC} divided by the true exchange rate. T_{LC} is the true exchange rate. inv(T_{LC}) is the inverse of T_{LC}. TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. C_V is a measure for competition, with Y={D,T,V} being the corresponding method being used. σ_{LC} is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. √t_1 is the average square root of the number of seconds between trades according to method Z={1,2}. IHP_{LC,t_1} and IHP_{LC,t_2} is the inventory holding premium based on SPR_{LC}, σ_{LC} and √t_2.

Table 36: Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the LC method
Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the $C_0$ method

<table>
<thead>
<tr>
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<th>$RSPR_{C_0}$</th>
<th>$T_{C_0}$</th>
<th>$inv(T_{C_0})$</th>
<th>$TV$</th>
<th>$inv(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{C_0}$</th>
<th>$\sqrt{t_1}$</th>
<th>$\sqrt{t_2}$</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>$T_{C_0}$</td>
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<td>-0.5350</td>
<td>0.1053</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_V$</td>
<td>0.1125</td>
<td>0.1140</td>
<td>-0.0050</td>
<td>0.0044</td>
<td>0.8445</td>
<td>-0.6568</td>
<td>0.0875</td>
<td>0.8039</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_{C_0}$</td>
<td>0.0427</td>
<td>0.0445</td>
<td>-0.1938</td>
<td>0.1949</td>
<td>0.3466</td>
<td>-0.3037</td>
<td>0.1313</td>
<td>0.2635</td>
<td>0.2298</td>
<td>1.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sqrt{t_1}$</td>
<td>-0.0977</td>
<td>-0.0994</td>
<td>0.1060</td>
<td>-0.1091</td>
<td>-0.6491</td>
<td>0.6782</td>
<td>-0.0877</td>
<td>-0.6114</td>
<td>-0.5903</td>
<td>-0.3051</td>
<td>1.0000</td>
<td></td>
</tr>
<tr>
<td>$\sqrt{t_2}$</td>
<td>-0.1051</td>
<td>-0.1068</td>
<td>0.0407</td>
<td>-0.0436</td>
<td>-0.7008</td>
<td>0.7474</td>
<td>-0.0470</td>
<td>-0.8059</td>
<td>-0.6598</td>
<td>-0.3374</td>
<td>0.7592</td>
<td>1.0000</td>
</tr>
<tr>
<td>$IHP_{C_0,t_1}$</td>
<td>0.0062</td>
<td>0.0071</td>
<td>-0.1394</td>
<td>0.1396</td>
<td>0.1354</td>
<td>-0.1421</td>
<td>0.1091</td>
<td>0.0747</td>
<td>0.0485</td>
<td>0.9278</td>
<td>-0.0232</td>
<td>-0.1318</td>
</tr>
<tr>
<td>$IHP_{C_0,t_2}$</td>
<td>0.0143</td>
<td>0.0154</td>
<td>-0.1613</td>
<td>0.1617</td>
<td>0.1517</td>
<td>-0.1512</td>
<td>0.1240</td>
<td>0.0441</td>
<td>0.0531</td>
<td>0.9479</td>
<td>-0.1285</td>
<td>-0.0982</td>
</tr>
</tbody>
</table>

$SPR_{C_0}$ is the b/a spread calculated according to the $C_0$ method. $RSPR_{C_0}$ is the relative spread, which is equal to the $SPR_{C_0}$ divided by the true exchange rate. $T_{C_0}$ is the true exchange rate. $inv(T_{C_0})$ is the inverse of $T_{C_0}$. $TV$ is the total volume traded per half-hour. $inv(TV)$ is the inverse of $TV$. $C_Y$ is a measure for competition, with $Y\in\{D,T,V\}$ being the corresponding method being used. $\sigma_Y$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{t_Y}$ is the average square root of the number of seconds between trades according to method $Y\in\{1,2\}$. $IHP_{C_0,t_Y}$ is the inventory holding premium based on $SPR_{C_0}$, $\sigma_{C_0}$ and $\sqrt{t_Y}$.

Table 37: Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the $C_0$ method
6. Empirical Results

In this section we give an overview of the outcomes of our empirical research work. We start by presenting the regression model that we have estimated.

6.1. Benchmark regression

At the end of the previous section - when discussing collinearity between our variables - we did not make a proposition of which variables would be best suited to include in our regression model. Looking however at advantages and disadvantages of each different method (for both calculating the b/a spread and the spread determinants), we come to the following regression model:

\[ SPR_{X_i} = \alpha_0 + \alpha_1 inv(TV)_i + \alpha_2 C_T + \alpha_3 IHP_{X,t1} + \epsilon_i \]  

(25)

Where \( SPR_{X_i} \) is the b/a spread calculated according to method \( X \), with \( X = \{ WA, LC, C_0 \} \) (cf. subsection 5.3.1.). \( inv(TV)_i \) is the inverse of the traded volume \( TV \) per half-hour, representing the OPC. \( C_T \) is the competition measure that uses the number of dealers active each trading day weighted with the number of trades per half-hour as a proxy for competition. This competition measure is chosen over \( C_O \) because it better reflects the intraday competition and therefore seems more correct as we work with intraday data. Furthermore, no huge differences are seen between \( C_T \) and \( C_V \), but we prefer to work with \( C_T \) because collinearity with the traded volume \( TV \) is lower. \( IHP_{X,t1} \) is the inventory holding premium that is calculated based on the true exchange rate \( T_X \), the annualized return volatility and the average of the square root between trades. We have chosen \( \sqrt{T_1} \) over \( \sqrt{T_2} \) because the first method works with the time between offsetting trades and not just time between trades. In the context of the IHP this seems to be a more appropriate measure. Again \( X \) represents the method according to which the b/a spread is calculated, i.e. \( X = \{ WA, LC, C_0 \} \). We consider Eq. (20) the benchmark equation, which we will further refine.

Note also that the arguments of why we have chosen to present the results for these three b/a spread calculation methods, can be found in section 5.3.1.. However we recapitulate: the \( WA \) method is based on the workings of the limit order book and each sell or buy is weighed with the time before the previous sell or buy respectively took place. The \( LC \) method is an enhanced version of the \( LV \) method which tries to tackle the possible outliers in the \( LV \) method due to possible huge time spans between last buy order and last sell order (which could be the source of negative b/a
spreads). Furthermore, this method also can also be linked to the limit order book: the last customer sell and the last customer buy order following each other can represent the best bid and ask in the limit order book and because they immediately follow each other (independent of whether the buy or sell is first), there is not much time for new limit orders to come in and change the size of the b/a spread. And, finally, the $C_0$ method is a method that originates in the corrections that the $LC$ method provides to the $LV$ method, i.e. the $C_0$ method looks at those buy and sell trades for each half-hour where the time span between these trades is equal to zero.

### 6.2. Regression results

#### 6.2.1. Results using an ATM option to value the IHP

The regression results of Eq. (25) can be found in tables 38 to 40. Each table presents the results for a different b/a spread calculation method used i.e. $WA$, $LC$, $C_0$ respectively. Note that the standard errors have been corrected for heteroscedasticity and autocorrelation in the residuals (if necessary). Just like in the original model of Bollen et al. (2004) the method of least squares was used.

Regarding the three b/a spread calculation methods just mentioned, one would expect the $LC$ b/a spread calculation method to provide the most meaningful results because it is not only the most obvious and straightforward method, it can also be linked with the limit order book which is an important instrument when talking about the b/a spread. This was also mentioned by respondent H in our survey (cf. appendix H). Furthermore, it should be considered an enhanced version of the $LV$ b/a spread method. Concerning the $C_0$ b/a spread, it can be argued that this method amplifies those rather exceptional moments when trades happen at the same time, whereas most of the time at least some seconds are between trades (cf. subsection 5.4.2.). The $WA$ b/a spread method then again can be criticized that when a trade takes place at a certain price, this price could have arrived in the limit order book only seconds before the actual trade took place and before this limit order arrived, another price had been in place the whole time. This could lead to an unreliable b/a

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70 Most of the time there is no autocorrelation as the Durbin-Watson statistic has a value close to 2.

71 For an estimation with least squares no normality assumption is needed. However, in order to allow for inference we need to assume that our residuals have a normal distribution. This is not the case. Therefore we base ourselves on the central limit theorem, which is possible due to the considerably large size of our data sample. If we would work with daily data, this would probably not be applicable anymore because then the size of our sample becomes rather small.

72 Of course, the prices talked about are either both best buys or best sells.
spread. Furthermore, when the time between trades increases a higher weight will be given to that price (i.e. the best buy or best sell that just arrived in the limit order book), but also the probability that such limit orders arrive that change the best buy or sell price increases. This in turn will further increase the measurement error. For these reasons, we will only discuss the results of the LC b/a spread in depth. However, under this subsection we nevertheless provide the reader with the regressions results of the spreads that were calculated according to the WA method and the C₀ method in way of comparison and to allow the reader to see that our expectations are confirmed i.e. the LC method provides the most meaningful results. Consequently, the regression results of this method will be discussed here.

As to table 39, which presents the regression results of the b/a spread calculated according to the LC method, some interesting results can be seen. The inventory holding premium - which is argued to be the single most important explanatory determinant of the b/a spread in the BSW model – is only for the currency pair RUB/EUR TOD significant at the 1% level. In this case, it also has the expected positive sign. The other currency pairs have a value for α₃ that is not significant at the 10% level and for RUB/EUR TOM this coefficient even has a negative sign. Under the assumption that our b/a spread calculation method provides us with reliable b/a spreads, then the question becomes how we can explain this negative coefficient for RUB/EUR TOM. First, looking at the results of our survey (cf. subsection 8.2.), not much unanimity exists on the suggested positive relationship between the b/a spread and the IHP. Almost half of our respondents argued that an increase in a dealer’s inventory position would result in a midpoint price movement, whereas the b/a spread size does not need to change. Furthermore, if a dealer increases his inventory position and consequently increases his b/a spread (in both directions), this will result in an increased sell price and as a consequence the probability that this dealer will be able to sell his increased inventory holdings will decrease. And last but not least, some of our respondents argued that an increase in the inventory position can be perceived as increased liquidity, which should result in a smaller b/a spread. These different arguments can explain the diverse results we obtain. So, whether or not there is a positive or negative, significant or insignificant relationship could depend on how the majority of the dealers perceives this relationship. Second, the IHP also contains the adverse selection component and again opinions differ whether or not there is a relationship between the size of the b/a spread and the ASC (cf. subsection 8.2.). Note that McGroarty et al. (2007) also have shown that in an inter-dealer market the share of the ASC as a determinant of the b/a spread is much less compared to the share of the IHC and the OPC component (cf. subsection 3.2.4.). In any way, the coefficient of the IHP is also influenced by the relationship between the b/a spread and the ASC. In section 6.2.4. we come back to this.
As one can see in table 39, the competition component has the expected negative sign for all currency pairs. For the currencies that have an enhanced settlement, coefficient $\alpha_2$ is significant at the 1% level. Looking at our data, the number of traders active on the market are more or less the same for both markets with an enhanced settlement and markets where trades are settled the next day (cf. subsection 5.4.2.). However, the numbers of trades are much lower on the markets with enhanced clearing i.e. the weighing factor in our competition measure (cf. subsection 5.1). This could mean that when traders start to trade more actively certain half-hours on markets with an enhanced trading, this has a proportionally larger influence on the size of the spread because the number of trades originally is small. This could explain the difference. However, competition was mentioned by our respondents in our survey to be an important determinant for the size of the b/a spread (cf. subsection 8.2.). So we should expect to see significant relationships in all four cases. As this is not the case, we can cast some doubt on whether or not our proxy for competition is a reliable measure. And if this is the case, then maybe an unreliable b/a spread measure could explain the results obtained.

The coefficient $\alpha_1$ belonging to the OPC component never has a significant value, nor does it yield consistent results considering the sign. In practice, this component is not taken into consideration in trading rooms (cf. subsection 8.2.), which could explain these results. However, we can argue that traded volume also can represent liquidity on the market, so we could at least expect positive signs in all four cases.\footnote{A possible explanation for the negative sign can be that the larger traded volumes consist of larger single trades, and some dealers will widen the spread when the trade size increases (cf. subsection 8.2.)} Liquidity namely - as was argued by our respondents - has a huge influence on the spread. This expectation is not confirmed by our results. Remember also that Bjønnes and Rime (2005) found that for a less liquid currency pair (i.e. NOK/DEM) a larger share of the spread could be attributed to the OPC (cf. subsection 3.2.6.). They argued that this might be related to the fact that, first of all, the market in a minor currency is less competitive and, second, the fixed costs are distributed over fewer trades. But in their work they also argued that for a less liquid currency pair the inter-transaction time is short if there are less than five minutes between to trades. For major currency pairs they argued that inter-transaction time is short if there is less than one minute between two trades. As the average time between two trades is shorter than one minute, we can argue that the currency pairs used here can be classified in their work as major currency pairs and this can contribute to the fact that there is no significant relationship. Nevertheless, the share of the Russian Ruble in the foreign exchange market turnover is low (cf. table 5, section 2.4.).
The model of Bollen et al. (2004) is constructed in such a way that the intercept equals the minimum tick size. In table 39 the reader can see that the estimates are small and reasonable values. However the intercept in our work has not the same meaning as in Bollen et al. (2004) i.e. the minimum b/a spread. This is due to the different proxy for competition.74 Despite the fact that the intercept does not have the same meaning, we still include this intercept term in our regression specification. In our work it represents that part of the b/a spread that cannot be explained by the just discussed components. The sign is positive and significant at the 1% level for all currency pairs, which seems reasonable as not many significant relations are found with the other components.

Having discussed the components, figure 17 gives an idea of the economic significance75 of each of the components according to currency pair. One can clearly see that the biggest share of the spread cannot be explained by the components. Looking solely at the defined components, competition scores best, except for RUB/USD TOD, where the OPC has a higher economic significance than competition. The IHP has a lower share than expected because they in fact comprise two components i.e. the IHC and the ASC. However, given the arguments provided when discussing the relationship between the IHP and the spread, this lower share can very well be.

The determination coefficients (i.e. the R-squared values) of our model are very low for all currency pairs, especially if you would compare them with values found on the stock market (see for instance Bollen et al. (2004) who use the same model and where the lowest determination coefficient already is 54%). Nevertheless a lower explanatory power has been found for decomposition models on the foreign exchange market (see for instance Frömmel and Van Gysegem (2011)), so this is in line with these works.

Like we said, the results for the b/a spreads calculated according to the WA and \( C_0 \) b/a spread calculation methods are provided in way of comparison. First of all in table 40 we can see that for the b/a spread calculated according to the \( C_0 \) method, the competition measure never has the expected negative sign which casts some doubt on whether this is a reliable spread measure. Suppose the method does yield reliable spread values, then our competition measure \( C_T \) is not a good proxy for competition because, like we already argued, all our respondents argued that competition does have an influence on the b/a spread. Furthermore, for the b/a spread calculated according to the \( WA \) not many consistency in the values and signs can be found (see table 38). The IHP for RUB/USD TOM

74 When competition increases, the value of our competition measure does not go to zero.
75 Economic or substantive significance has little to do with statistical significance (Ziliak and McCloskey, 2004). Economic significance is about how much a certain variable matters in the outcome in order to identify those with the biggest influence (Miller and Rodgers, 2008).
yields a coefficient significant at the 1% level, however with the ‘wrong’ sign. The same arguments, however, as above can be used in explaining the signs here. Nevertheless, we will not discuss the results belonging to these methods in depth, because we believe the LC method gives the most reliable results. In what follows, we will not only use Eq. (25) as the benchmark regression but henceforth we will also solely discuss the results of the LC b/a spread calculation method.

The regression results for the five other b/a spread calculation methods can be found in appendix F and are provided to the reader, again, in way of comparison.

Table 41 contains the estimation results of the following regression model, which is simply the relative form of Eq. (25):

$$\frac{SPR_{LCi}}{T_{LCi}} = \alpha_0 \left( \frac{1}{T_{LCi}} \right) + \alpha_1 \left( \frac{inv(TV)_i}{T_{LCi}} \right) + \alpha_2 \left( \frac{C_{Ti}}{T_{LCi}} \right) + \alpha_3 \left( \frac{IHPL_{LCi}}{T_{LCi}} \right) + \gamma_i \quad (26)$$

All the variables are divided by the true exchange rate $T_{LC}$ i.e. the midpoint price between the bid and ask price. Consequently, there is no longer an intercept term. As Bollen et al. (2004) note, a weighted least squares is performed. We expect no striking differences between the results of the absolute regression and the relative regression, because, first of all, we have seen in our collinearity tables that the absolute and relative spread measures show an almost perfect positive linear relationship (cf. subsection 5.4.3.), second, because we correct our standard errors for autocorrelation and heteroscedasticity and, finally, because they are the same model. The regression results prove to be very similar when comparing tables 39 and 41 with each other. In general one should work with the regression that has the residuals that behave most appropriate, but because of the similarity this is not a key issue here. Remark that $\alpha_0$ does not have a meaning here.

For the relative regressions that belong with the WA and the $C_0$ method, we also refer the reader to appendix F. The conclusions are the same.
## Regression results for $SPR_{WA}$

Regression results for $SPR_{WA_i} = \alpha_0 + \alpha_1 inv(TV)_i + \alpha_2 C_T_i + \alpha_3 IHP_{WA,t_i} + \epsilon_i$

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\alpha_0$</td>
</tr>
<tr>
<td>$SPR_{WA}$</td>
<td>RUB/EUR TOD</td>
<td>595</td>
<td>0.061159</td>
<td>0.001940</td>
</tr>
<tr>
<td></td>
<td>RUB/EUR TOM</td>
<td>1451</td>
<td>0.002048</td>
<td>0.002939</td>
</tr>
<tr>
<td></td>
<td>RUB/USD TOD</td>
<td>995</td>
<td>0.033987</td>
<td>0.001412</td>
</tr>
<tr>
<td></td>
<td>RUB/USD TOM</td>
<td>1451</td>
<td>0.014765</td>
<td>0.000992</td>
</tr>
</tbody>
</table>

$SPR_{WA}$ is the b/a spread calculated according to the WA method. $inv(TV)$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{WA,t_i}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{WA}$, the annualized return volatility $\sigma_{WA}$ and the average of the square root of the time between trades $\sqrt{T_j}$.

***Indicates significance at the 1% level

**Indicates significance at the 5% level

*Indicates significance at the 10% level

Table 38: Regression results for $SPR_{WA}$
### Regression results for \( SPR_{LC} \)

Regression results for \( SPR_{LC_i} = \alpha_0 + \alpha_1 \text{inv}(TV)_i + \alpha_2 C_T + \alpha_3 IHP_{LC,t,i} + \epsilon_i \)

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>( R^2 )</th>
<th>Coefficient estimates and t-ratios</th>
</tr>
</thead>
</table>
| \( SPR_{LC} \)       | RUB/EUR TOD   | 595          | 0.034279  | \( \begin{align*} 
\alpha_0 &= 0.004954 \\
\alpha_1 &= 1051.40 \\
\alpha_2 &= -0.000063 \\
\alpha_3 &= 0.182039 
\end{align*} \) |
|                      | RUB/EUR TOM   | 1451         | 0.002146  | \( \begin{align*} 
\alpha_0 &= 0.006883 \\
\alpha_1 &= -7687.16 \\
\alpha_2 &= -0.000020 \\
\alpha_3 &= -0.060545 
\end{align*} \) |
|                      | RUB/USD TOD   | 995          | 0.017219  | \( \begin{align*} 
\alpha_0 &= 0.003635 \\
\alpha_1 &= 6317.37 \\
\alpha_2 &= -0.000048 \\
\alpha_3 &= 0.009444 
\end{align*} \) |
|                      | RUB/USD TOM   | 1491         | 0.000675  | \( \begin{align*} 
\alpha_0 &= 0.002667 \\
\alpha_1 &= -31312.25 \\
\alpha_2 &= -0.000023 \\
\alpha_3 &= 0.122452 
\end{align*} \) |

\( SPR_{LC} \) is the b/a spread calculated according to the \( LC \) method. \( \text{inv}(TV) \) is the inverse of the volume traded. \( C_T \) is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. \( IHP_{LC,t,i} \) is the inventory holding premium that is calculated based on the true exchange rate \( T_{LC} \), the annualized return volatility \( \sigma_{LC} \) and the average of the square root of the time between trades \( \sqrt{T_i} \).

**Indicates significance at the 1% level

**Indicates significance at the 5% level

*Indicates significance at the 10% level

Table 39: Regression results for \( SPR_{LC} \)
### Regression results for $SPR_{c_0}$

Regression results for $SPR_{c_0} = \alpha_0 + \alpha_1 inv(TV)_i + \alpha_2 C_T + \alpha_3 IHP_{c_0,t_1} + \epsilon_i$

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\alpha_0$ $\alpha_1$ $\alpha_2$ $\alpha_3$</td>
</tr>
<tr>
<td>$SPR_{c_0}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RUB/EUR TOD</td>
<td>595</td>
<td>0.047148</td>
<td>-0.001246</td>
<td>16563.96 0.000062 0.207484</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-1.20</td>
<td>4.34*** 2.48** 3.05***</td>
</tr>
<tr>
<td>RUB/EUR TOM</td>
<td>1451</td>
<td>0.001834</td>
<td>0.001244</td>
<td>4838.462 0.000041 0.042092</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.47</td>
<td>1.55 0.99 0.56</td>
</tr>
<tr>
<td>RUB/USD TOD</td>
<td>995</td>
<td>0.020964</td>
<td>-0.000123</td>
<td>23729.36 0.000043 -0.051854</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.32</td>
<td>2.15** 4.58*** -0.69</td>
</tr>
<tr>
<td>RUB/USD TOM</td>
<td>1451</td>
<td>0.014658</td>
<td>0.000150</td>
<td>-10669.27 0.000057 -0.013960</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.38</td>
<td>-0.37 3.72*** -0.15</td>
</tr>
</tbody>
</table>

$SPR_{c_0}$ is the b/a spread calculated according to the $C_0$ method. $inv(TV)_i$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{c_0,t_1}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{c_0}$, the annualized return volatility $\sigma_{c_0}$ and the average of the square root of the time between trades $\sqrt{T_1}$.

***Indicates significance at the 1% level

**Indicates significance at the 5% level

*Indicates significance at the 10% level

Table 40: Regression results for $SPR_{c_0}$
### Regression results for $\frac{\text{SPR}_{LC}}{T_{LC}}$

Regression results for $\frac{\text{SPR}_{LC}}{T_{LC_i}} = \alpha_0 \left( \frac{1}{T_{LC_i}} \right) + \alpha_1 \left( \frac{\text{Inv}(TV)_i}{T_{LC_i}} \right) + \alpha_2 \left( \frac{C_T_i}{T_{LC_i}} \right) + \alpha_3 \left( \frac{\text{IH}p_{LC_i}}{T_{LC_i}} \right) + \gamma_i$

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{\text{SPR}<em>{LC}}{T</em>{LC}}$</td>
<td>EUR/RUB TOD</td>
<td>595</td>
<td>0.034497</td>
<td>$\alpha_0$ 0.004955, $\alpha_1$ 1039.429, $\alpha_2$ -0.000063, $\alpha_3$ 0.181088</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EUR/RUB TOM</td>
<td>1451</td>
<td>0.002832</td>
<td>$\alpha_0$ 0.006931, $\alpha_1$ -7881.068, $\alpha_2$ -0.000021, $\alpha_3$ -0.061134</td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td></td>
<td>USD/RUB TOD</td>
<td>995</td>
<td>0.018650</td>
<td>$\alpha_0$ 0.003677, $\alpha_1$ 5826.373, $\alpha_2$ -0.000050, $\alpha_3$ 0.008014</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>USD/RUB TOM</td>
<td>1451</td>
<td>0.001430</td>
<td>$\alpha_0$ 0.002684, $\alpha_1$ -31536.38, $\alpha_2$ -0.000023, $\alpha_3$ 0.119798</td>
</tr>
</tbody>
</table>

This table presents the regression results of the relative b/a spread of $\text{SPR}_{LC}$. $\text{SPR}_{LC}$ is the quoted b/a spread calculated according to the LC method. $\text{Inv}(TV)$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $\text{IH}p_{LC_i}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{LC}$, the annualized return volatility $\sigma_{LC}$ and the average of the square root of the time between trades $\sqrt{T_i}$. $T_{LC}$ is the true exchange rate by which all variables are scaled i.e. here the midpoint between the bid and ask price.

***Indicates significance at the 1% level

**Indicates significance at the 5% level

*Indicates significance at the 10% level

Table 41: Regression results for the relative b/a spread $R\text{SPR}_{LC}$
Figure 17: Economic significance of the components of the spread calculated according to the LC method
6.2.2. Regression results and outliers

Outliers are observations that have a value that is considerably different when you compare them with the rest of the data values in the sample. However, as we saw previously, when we talked about the volumes traded (cf. subsection 5.2.), we could see that these traded volumes have a heavy-tailed distribution (i.e. a high kurtosis) and a positive skewness, therefore eliminating them normally is not the solution as they belong to the dataset. This is not only true for the volumes traded, but also for most of our determinants and the b/a spread (see table 42). In this subsection, we will shortly present the results of what happens when we assume them to be outliers and redo the estimation of the benchmark regression.\footnote{Note that we try to stay true to the original model of Bollen et al. (2004) and as already mentioned, they worked with the method of least squares. We suppose the central limit theorem holds.}

<table>
<thead>
<tr>
<th>Skweness</th>
<th>Kurtosis</th>
<th>Skweness</th>
<th>Kurtosis</th>
<th>Skweness</th>
<th>Kurtosis</th>
<th>Skweness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>B/a spread</td>
<td>OPC $inv(TV)$</td>
<td>Competition $C_T$</td>
<td>IHP $IHP_{LC,T_1}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPR$_{LC}$</td>
<td>SPR$_{LC}$</td>
<td>SPR$_{LC}$</td>
<td>SPR$_{LC}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RUB/EUR TOD</td>
<td>2.11</td>
<td>10.62</td>
<td>4.17</td>
<td>26.21</td>
<td>0.01</td>
<td>3.07</td>
<td>1.80</td>
</tr>
<tr>
<td>RUB/EUR TOM</td>
<td>9.43</td>
<td>127.42</td>
<td>3.76</td>
<td>32.50</td>
<td>1.99</td>
<td>13.71</td>
<td>2.02</td>
</tr>
<tr>
<td>RUB/USD TOD</td>
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<td>299.04</td>
<td>4.80</td>
<td>42.15</td>
<td>0.55</td>
<td>2.34</td>
<td>1.85</td>
</tr>
<tr>
<td>RUB/USD TOM</td>
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<td>338.54</td>
<td>2.91</td>
<td>19.85</td>
<td>0.99</td>
<td>4.60</td>
<td>1.90</td>
</tr>
</tbody>
</table>

$SPR_{LC}$ is the b/a spread calculated according to the $LC$ method. $Inv(TV)$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{LC,T_1}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{LC}$, the annualized return volatility $\sigma_{LC}$ and the average of the square root of the time between trades $\sqrt{t_1}$.

Table 42: Skewness and kurtosis of the b/a spread and the b/a spread determinants

Table 43 is the estimation of the benchmark regression in Eq. (25) with elimination of the top 1% of the $LC$ b/a spread values. Table 44 gives the regression results of the estimation of the benchmark regression with elimination of the zero values, consequently those spreads that were originally negative are eliminated.\footnote{This also means that some values are eliminated that did not have a negative b/a spread but just a zero b/a spread value. Considering these also rather unusual, we also leave them out of our sample.} Table 45 gives the results of the estimation where the top 1% of the traded volume values per half-hour are eliminated. In each of these tables, the elimination of these suggested outliers leads to the introduction of at least one coefficient that becomes significant but
does not have the proper expected sign that is in accordance with the BSW model. However, like we already argued, some of these negative signs can be given an explanation. Note that eliminating the zero values in table 44, which eliminates the negative b/a spread values does not lead to considerable better results and it reduces our sample size, which in turn leads to less reliable results. Furthermore, one can see that for about half of the cases the predictive power decreases in comparison with the regression results from table 39. So, like we already argued, we should consider these outliers not as real errors, but belonging to our dataset. Consequently, we need to take these into account when we discuss our results i.e. their elimination or addition leads to changes in signs and significance of a few coefficients, therefore these outliers can be seen as influential data points. We consider the LC method inherent correct and consequently this method should provide us with reliable estimates of the b/a spread.

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78 Our regressions are based on the assumption that the central limit theorem holds. Furthermore, the smaller the sample size, the larger the sampling process error.

79 This, of course, is an assumption.
Regression results for $SPR_{LC}$ without top 1% b/a spread values

Regression results for $SPR_{LC} = \alpha_0 + \alpha_1 \ln(V(T)) + \alpha_2 C_T + \alpha_3 IHP_{LC,t+1} + \epsilon_i$

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\alpha_0$</td>
</tr>
<tr>
<td>RUB/EUR TOD</td>
<td>589</td>
<td>0.030055</td>
<td></td>
<td>0.004554</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RUB/EUR TOM</td>
<td>1436</td>
<td>0.001419</td>
<td></td>
<td>0.003961</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>RUB/USD TOD</td>
<td>985</td>
<td>0.026888</td>
<td></td>
<td>0.002439</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RUB/EUR TOM</td>
<td>1436</td>
<td>0.003224</td>
<td></td>
<td>0.001847</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$SPR_{LC}$ is the b/a spread calculated according to the $LC$ method. $\ln(V(T))$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{LC,t+1}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{LC}$, the annualized return volatility $\sigma_{LC}$ and the average of the square root of the time between trades $\sqrt{T_t}$.

***Indicates significance at the 1% level
**Indicates significance at the 5% level
*Indicates significance at the 10% level

Table 43: Regression results for $SPR_{LC}$ without top 1% b/a spread values
### Regression results for SPR<sub>LC</sub> without zero b/a spread values

Regression results for SPR<sub>LC</sub> = \( \alpha_0 + \alpha_1 ln(TV) + \alpha_2 C_T + \alpha_3 IHP_{LC,t1} + \epsilon_i \)

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>R(^2)</th>
<th>Coefficient estimates and t-ratios</th>
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</thead>
<tbody>
<tr>
<td>SPR&lt;sub&gt;LC&lt;/sub&gt;</td>
<td>RUB/EUR TOD</td>
<td>382</td>
<td>0.049032</td>
<td>( \alpha_0 ) ( \alpha_1 ) ( \alpha_2 ) ( \alpha_3 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.006763</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.61***</td>
</tr>
<tr>
<td></td>
<td>RUB/EUR TOM</td>
<td>930</td>
<td>0.005133</td>
<td>( \alpha_0 ) ( \alpha_1 ) ( \alpha_2 ) ( \alpha_3 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.011017</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.02***</td>
</tr>
<tr>
<td></td>
<td>RUB/USD TOD</td>
<td>664</td>
<td>0.017195</td>
<td>( \alpha_0 ) ( \alpha_1 ) ( \alpha_2 ) ( \alpha_3 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.005227</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.02***</td>
</tr>
<tr>
<td></td>
<td>RUB/USD TOM</td>
<td>859</td>
<td>0.002751</td>
<td>( \alpha_0 ) ( \alpha_1 ) ( \alpha_2 ) ( \alpha_3 )</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.004258</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.24***</td>
</tr>
</tbody>
</table>

SPR<sub>LC</sub> is the b/a spread calculated according to the LC method. \( ln(TV) \) is the inverse of the volume traded. \( C_T \) is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. \( IHP_{LC,t1} \) is the inventory holding premium that is calculated based on the true exchange rate \( T_{LC} \), the annualized return volatility \( \sigma_{LC} \) and the average of the square root of the time between trades \( \sqrt{T_i} \).

***Indicates significance at the 1% level
**Indicates significance at the 5% level
*Indicates significance at the 10% level

Table 44: Regression results for SPR<sub>LC</sub> without zero b/a spread values
Regression results for $SPR_{LC}$ without top 1% volume outliers

Regression results for $SPR_{LC_i} = \alpha_0 + \alpha_1 (\ln(TV)_i) + \alpha_2 C_T + \alpha_3 IHP_{LC,t_i} + \epsilon_i$

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SPR_{LC}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RUB/EUR TOD</td>
<td>589</td>
<td>0.041191</td>
<td></td>
<td>$\alpha_0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.003564</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>2.74***</td>
</tr>
<tr>
<td>RUB/EUR TOM</td>
<td>1436</td>
<td>0.004874</td>
<td></td>
<td>$\alpha_0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.007920</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.72***</td>
</tr>
<tr>
<td>RUB/USD TOD</td>
<td>985</td>
<td>0.017202</td>
<td></td>
<td>$\alpha_0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.003578</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>3.93***</td>
</tr>
<tr>
<td>RUB/USD TOM</td>
<td>1436</td>
<td>0.001596</td>
<td></td>
<td>$\alpha_0$</td>
</tr>
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<td></td>
<td>0.003298</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.51***</td>
</tr>
</tbody>
</table>

$SPR_{LC}$ is the b/a spread calculated according to the LC method. $ln(TV)_i$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{LC,t_i}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{LC}$, the annualized return volatility $\sigma_{LC}$ and the average of the square root of the time between trades $\sqrt{T_i}$.

***Indicates significance at the 1% level
**Indicates significance at the 5% level
*Indicates significance at the 10% level

Table 45: Regression results for $SPR_{LC}$ without top 1% volume outliers
### 6.2.3. Results using ad hoc model specifications

In tables 46 and 47 the reader is provided with the regression results when the determinants are specified in an *ad hoc* fashion. Bollen et al. (2004) have modeled the IHP - which embeds the IHC and the ASC - as an ATM option. However, here we take a look at what happens when we do not model the IHP as an ATM option, but include each of the variables out of which the IHP is constructed (i.e. the true exchange rate, the return volatility and the average time between trades) as a separate variable in the model specification. We include them as linear\(^\text{80}\) variables in a new regression. Consequently, we test the following model:

\[
SPR_{LCi} = \alpha_0 + \alpha_1 \text{inv}(TV)_i + \alpha_2 C_{Ti} + \alpha_3 T_{LC} + \alpha_4 \sigma_{LCi} + \alpha_5 t_{Li} + \varepsilon_i
\]  

(27)

For ease of comparison, the top panel of table 46 contains the regression results of Eq. (25). The bottom panel contains the regression results of Eq. (27). One would expect the coefficient of the true exchange rate to have a positive sign. This to keep the transaction cost per unit of price equal and to prevent arbitrage (cf. subsection 3.2.1.).\(^\text{81}\) Furthermore, the annualized return volatility is expected to have a positive sign, because, as volatility increases, the shorter the odds of the price for one unit of a foreign currency moving in an undesired direction, which in turn will lead to higher holding costs and thus a wider b/a spread (cf. subsection 3.1.3.). Finally the time between offsetting trades is expected to have a positive sign, seen as it could be considered as a proxy for the IHC, where the shorter the time a currency is kept in inventory, the smaller the inventory cost and consequently the smaller the size of b/a spread.

The results in table 46 are striking in several ways. First of all, a lot of the variables enter the model with a different sign than expected. For instance, for all four currency pairs the coefficient \(\alpha_3\) of the true exchange rate has a negative sign. Again, in the assumption that our b/a spread calculation method not only provides us with reliable b/a spreads, but also with reliable true exchange rates\(^\text{82}\), the question becomes how we can explain this negative sign. An explanation is important, because our results show that for RUB/EUR TOM the coefficient of the true exchange rate is significant at the 5% level and for RUB/USD TOD this coefficient is significant at the 1% level. Following the way of

\(^\text{80}\) We follow Bollen et al. (2004) who assume the relation is linear.

\(^\text{81}\) Benston and Hagerman (1974) argue that the spread should be positively related to the stock price. This relationship does not have to be proportionally, but they do state that *ceteris paribus* the spread per unit of dollar should be equal. We assume this relation also is true for the foreign exchange market.

\(^\text{82}\) The true exchange rate equals the midpoint price between the bid and ask price. The bid and ask price in turn depend on the b/a spread calculation method used, as these are used to calculate the b/a spread.
thinking concerning the IHC of some of our respondents in our survey (cf. subsection 6.2.1. and subsection 8.2.), we can state that an increase in the value of a currency – i.e. the foreign currency becomes more expensive - is the result of a higher demand of that currency. A higher demand also means that more parties will become interested to sell\textsuperscript{83}, therefore liquidity increases – or the majority of the dealers start to believe that the market will become more liquid. A liquid market in turn leads to a narrower b/a spread.

Looking at the coefficient $\alpha_4$ of the annualized return volatility, we can see that this coefficient also does not have the expected sign in half of the cases. Only for RUB/EUR TOD we find a statistical significant relationship at the 10%. However, it is reasonable to argue again that the sign can depend on how the majority of the dealers active on the market interpret their positions and volatility. If the majority of the market perceives higher volatility as a higher risk – and the dealers are risk averse -, than the b/a spread will widen and we should see the expected positive sign. However, if the majority of the dealers reasons in another way and they have a higher risk appetite, we can say that they perceive this higher volatility as a higher probability that the value of the currency will move in their advantage. Therefore this can have a negative relation with the size of the b/a spread.

The variable representing the time between trades enters the model with its expected sign, except for RUB/USD TOD for which the sign is negative. Furthermore, only for RUB/EUR TOD the coefficient $\alpha_5$ is significant in a statistical sense (this is at the 1% level). Although there is no significant relationship in a statistical sense for RUB/USD TOD and the t-ratio is small, there still can be a reason why the sign is negative. Suppose the majority of the dealers hold on to a certain currency and their time between trades increases, then there is also more time for the value of that currency to move in a favorable way (whether or not volatility is high or low), which in turn will lead to a smaller b/a spread when they are bought or sold, because they will want to act fast when the value is moving in their favor.

A second striking finding is that, in contrast with the results of Bollen et al. (2004), the adjusted R-squared levels in the ad hoc specification are higher than in the structured model. Sometimes the difference is very large (e.g., 0.000077 for RUB/EUR TOM in the structured model versus 0.002337 in the ad hoc regression model). This indicates that the ad hoc specification model performs better in explaining the size of the b/a spread. Given the above mentioned arguments and the fact that the three variables out of which the IHP is constructed can have a different influence (concerning sign)

\textsuperscript{83} Or the government will take actions to prevent their currency from becoming even more expensive (cf. subsection 2.5.).
on the b/a spread, this does not come as a surprise. Now, although the adjusted R-squared values are higher, they are still very low. Note that for RUB/USD TOM these are even negative. This indicates that the model probably contains some regressors that do not help to explain the size of the b/a spread.

Let us take a look at the economic significance of the variables in the ad hoc specification model defined in Eq. (27). The results can be found in figure 18. It is immediately clear that if you compare these results with those in figure 17, which shows the economic significance of the components in the case of the structured model defined in Eq. (25), one can see that, when the ad hoc regression model is used, the components altogether have a larger impact on the b/a spread. We can see that the true exchange rate, especially, has a huge impact on the b/a spread. Although both the true exchange rate and the spread are constructed using one and the same method, we cannot argue that this could be the reason why the economic significance is so large. The LC method could also lead to wider b/a spreads, while the midpoint price can remain the same. Furthermore, correlation between the true exchange rate and the b/a spread calculated according to the LC method is low (cf. subsection 5.4.3.). So in general, we can state that the true exchange rate is a variable with a large impact on the size of the b/a spread. This sounds reasonable, given the reasons we mentioned for why it can have a negative sign i.e. it can be linked with liquidity which according to our respondents is a crucial determinant of the size of the b/a spread (cf. subsection 8.2.).

In table 47 we reported in the top panel the regression results when the b/a spread is regressed solely on the IHP, the bottom panel contains the regression results when the variables out of which the IHP is constructed, are used as determinants of the b/a spread. The regression models are:

\[
SPR_{LC_i} = \alpha_0 + \alpha_1 IHP_{LC_i} + \epsilon_i \quad (28)
\]

\[
SPR_{LC_i} = \alpha_0 + \alpha_1 T_{LC_i} + \alpha_2 \sigma_{LC_i} + \alpha_3 t_{1_i} + \epsilon_i \quad (29)
\]

Again, looking at the adjusted R-squared values, we can see that the ad hoc model specification scores better in explaining the size of the b/a spread. Concerning the size and the significance of the coefficients in the ad hoc regression specification, not much changes in comparison with the results in table 46, except for the coefficient \( \alpha_3 \), which becomes negative for RUB/EUR TOM, indicating a negative relationship between the time between trades and the size of the b/a spread. This coefficient also becomes positive for RUB/USD TOD. Leaving out competition and the OPC

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84 Bollen et al. (2004) provide proof that the IHP is linear dependent on the three determinants out of which the IHP is constructed.
component consequently have an impact of the sign of this coefficient, which can be due to the collinearity problem we discussed above.

Figures 19 and 20 show the economic significance of the IHP and of the components of the IHP in explaining the spread. Clearly one can also see that when we use the *ad hoc* specification model, the unexplained component of the b/a spread decreases due to the fact that the true exchange rate has a large impact on the size of the spread. Using the true exchange rate as a component of the IHP that is modeled as an option together with the time between trades and the annualized return volatility leads to a component (the IHP) that does not have such a large impact on the b/a spread. This is confirmed by looking at the adjusted R-squared values in the top panel in table 47. These are almost for all currency pairs negative, which indicates that the IHP as a regressor does not really help to explain the size of the b/a spread. So the impact of the true exchange rate on the b/a spread becomes obfuscated.
Regression results: Comparison of the structural model versus the ad hoc specification model

Structural model: regression results for $SPR_{LC} = a_0 + a_1 \ln(V) + a_2 C_{T1} + a_3 IHP_{LC,T1} + e_i$

Ad hoc specification: regression results for $SPR_{LC} = a_0 + a_4 \ln(V) + a_2 C_{T1} + a_5 \sigma_{LC} + a_5 t_{T1} + e_i$

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>$a_0$</td>
</tr>
<tr>
<td>A. Structural model</td>
<td>RUB/EUR TOD</td>
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<td>0.004954</td>
</tr>
<tr>
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<td>RUB/EUR TOM</td>
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<td>0.000077</td>
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</tr>
<tr>
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<td>RUB/USD TOD</td>
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<td>0.014243</td>
<td>0.003635</td>
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<td>0.002667</td>
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<td>B. Ad hoc specification</td>
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<td>RUB/USD TOD</td>
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<td>1451</td>
<td>-0.001281</td>
<td>0.012809</td>
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</table>

$SPR_{LC}$ is the b/a spread calculated according to the LC method. $\ln(V)$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{LC,T1}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{LC}$, the annualized return volatility $\sigma_{LC}$ and the average of the square root of the time between trades $\sqrt{T_i}$.

***Indicates significance at the 1% level; **Indicates significance at the 5% level; *Indicates significance at the 10% level

Table 46: Regression results of structural model versus ad hoc specification model
Regression results: Comparison of the inventory holding premium with the determinants of the inventory-holding premium

Structural model: regression results for $SPR_{LC} = \alpha_0 + \alpha_1 IHP_{LC,t_{i-1}} + \varepsilon_i$

Ad hoc specification: regression results for $SPR_{LC} = \alpha_0 + \alpha_1 T_{LC} + \alpha_2 \sigma_{LC,t_{i-1}} + \alpha_3 t_{i-1} + \varepsilon_i$

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>R²</th>
<th>$\alpha_0$</th>
<th>$\alpha_1$</th>
<th>$\alpha_2$</th>
<th>$\alpha_3$</th>
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<tr>
<td>A. Inventory holding premium</td>
<td>RUB/EUR TOD</td>
<td>595</td>
<td>0.008513</td>
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<td>2.18**</td>
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B. Determinants of the inventory holding premium

<table>
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<th>Currency pair</th>
<th>Observations</th>
<th>R²</th>
<th>$\alpha_0$</th>
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<th>$\alpha_2$</th>
<th>$\alpha_3$</th>
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<tr>
<td>RUB/USD TOM</td>
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<td>0.000003</td>
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</table>

$SPR_{LC}$ is the b/a spread calculated according to the LC method. $IHP_{LC,t_{i-1}}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{LC}$, the annualized return volatility $\sigma_{LC,t_{i-1}}$ and the average of the square root of the time between trades $\sqrt{t_i}$.

***Indicates significance at the 1% level; **Indicates significance at the 5% level; *Indicates significance at the 10% level.

Table 47: Regression results of the comparison of the IHP with the determinants of the IHP
Figure 18: Economic significance of the components in the ad hoc regression model defined in Eq. (27)
Figure 19: Economic significance of the components of the regression model in Eq. (23)

<table>
<thead>
<tr>
<th>Component</th>
<th>RUB/EUR TOD</th>
<th>RUB/EUR TOM</th>
<th>RUB/USD TOD</th>
<th>RUB/USD TOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unexplained</td>
<td>80.93%</td>
<td>95.98%</td>
<td>92.86%</td>
<td>92.61%</td>
</tr>
<tr>
<td>IHP</td>
<td>19.07%</td>
<td>4.02%</td>
<td>7.14%</td>
<td>7.39%</td>
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</table>
Figure 20: Economic significance of the components of the ad hoc regression model in Eq. (24)
6.2.4. Estimating the probability of informed trades

When we explained the model in section 4, we said that the average time between two offsetting trades is used as a proxy for the expected holding period. Furthermore, we also argued that there is not one dealer active on the foreign exchange market but many dealers, which means that the average time between trades underestimates an individual dealer’s holding period. At that point, we noted that the model could be changed in such a way so that the square root of the average time between trades across dealers $\tau_i$ can be estimated. This could be done by making the value of the coefficient of the IHP equal 1, which is done by using the coefficient estimate of $\alpha_3$ in Eq. (25). To be more specific, if we multiply the average square root of time between trades with the value of the coefficient estimate of $\alpha_3$ in Eq. (25), then the coefficient in the new regression will equal 1. In that case, the regression model looks as follows, where $\alpha_3$ is constrained to equal 1:

$$SPR_{LC_i} = \alpha_0 + \alpha_1 \ln(TV)_i + \alpha_2 C_{T_i} + \alpha_3 IHP_{LC_i}(\tau_i) + \varepsilon_i$$

(30)

The estimation results can be found in table 48. In our results we indeed get a coefficient estimate that is equal to one for $\alpha_3$. The coefficient estimates of the average of the square root of the time between offsetting trades can also be used to estimate the probability that a trade is informed (cf. subsection 4.4). This could be done by estimating the following equation:

$$SPR_{LC_i} = \alpha_0 + \alpha_1 \ln(TV)_i + \alpha_2 C_{T_i} + \alpha_3 IHP_{LC_i}(\tau_i) + \alpha_4 \left( IHP_{LC_i}(\tau_i) - IHP_{OC_i}(\tau_i) \right) + \varepsilon_i$$

(31)

As mentioned above (cf. subsection 4.4.), coefficient $\alpha_4$ now equals the probability of an informed trade. If this coefficient is statistically different from zero we can reject the null hypothesis of a zero probability that the trade is informed. Note that we also mentioned that in this case we do not work with an ATM option as a proxy for the IHP. We now use an OTM option to represent the IHP towards uninformed traders and an ITM option to represent the IHP towards informed traders. Using the option formula in Eq. (11) for a trade that is exercised at the ask price (i.e. a buy from the perspective of the active party), then the value of both the ITM and OTM option equals:

$$IHP_{k,i} = T_{k,i} N \left( \frac{\ln(T_{k,i})}{\sigma_1 \sqrt{\tau_i}} + 0.5 \sigma_1 \sqrt{\tau_i} \right) - X_i N \left( \frac{\ln(T_{k,i})}{\sigma_1 \sqrt{\tau_i}} - 0.5 \sigma_1 \sqrt{\tau_i} \right)$$

(32)

---

85 This is possible because Bollen et al. (2004) show that the IHP is linear in dependent of its determinants.
Where $k = U$ or $I$. $U$ stands for uninformed and $I$ stands for an informed. Considering the dataset at our disposal, the true price $T$ is assumed to be the true exchange rate in our dataset $(T_{LC})$ and the exercise price $X$ equals the ask price for the OTM option. For the ITM option this is somewhat more complex. The exercise price $X$ is, again, the ask price. However, in this case, we do not know the true price $T$. For an option to be in-the-money, the true price $T$ must exceed the exercise price, therefore we define the true price as the exercise price enhanced with a premium from 1 to 10%.

Results of the regression specification defined in Eq. (31) can be found in table 49. The first thing that can to be said about these results is that the signs of the coefficients $\alpha_3$ en $\alpha_4$ are in most cases negative, whereas in the BSW model these were all positive. For an ATM option – which we have used up to now for the IHP -, the value of the option itself has always been positive. However, now, we start using OTM options for which values are expected to be negative – as they are out-of-the-money – and their intrinsic value equals zero. Remember that, in our case, we have defined our own methods for constructing the b/a spread which sometimes resulted in negative values for the b/a spread due to the fact that the bid price was sometimes higher than the ask price when the method was strictly followed (cf. subsection 5.3.1.2.). Because of this i.e. a bid price higher than the ask price, we do not only have negative values for the OTM option but we also have positive values. Actually, in those cases where the bid price is higher than the ask price, our option becomes ITM. This should normally not be the case, so this will bias our results.\footnote{Note that eliminating the OTM options with a positive value, still leads to a negative coefficient.} The ITM options, then again, always have a positive value since the exercise price is assumed to be a certain percentage on top of the true exchange rate. Now because in general the value of the OTM option is negative, this means that when the value of the OTM option increases or thus becomes less negative (or sometimes thus more positive because we also have positive values), according to the sign of the coefficient $\alpha_3$ the size of the b/a spread decreases (in most cases). Stated otherwise, there is a negative relation between the IHC and the b/a spread.\footnote{Here the OTM option represents the cost for providing liquidity services.} The explanation for this kind of sign was already given above (cf. subsection 6.2.1.).

However, this subsection deals with the estimating the probability of informed trades. Consequently, we focus on coefficient $\alpha_4$, just like in the BSW model, and on its meaning as the probability of a trade being informed. The negative sign of $\alpha_4$ is strange, as – like we just said - it should represent a probability. Consequently, we assume that the probability equals the absolute value of this coefficient. Again, these negative signs can indicate that the used b/a spread calculation method is not a reliable method. However, the negative sign of $\alpha_4$ could also be explained due to the negative
sign of $\alpha_3$ and the value of the IHC, which have – taking into account Eq. (31) - an influence on the sign of $\alpha_4$. Now clearly remark that we do not state here how much of the IHP can be explained by the IHC and how much can be explained by the ASC, as our coefficient $\alpha_4$ represents a probability of a trade being informed.\textsuperscript{88} The first thing that can be said about these results is that as the true price in the ITM option increases in comparison to the exercise price, then the probability $\alpha_4$ of the trade being executed by an insider decreases – this is if one looks at the absolute values of the coefficient.\textsuperscript{89} This is as expected, because Bollen et al. (2004) have argued that when you keep the b/a spread constant, then a tradeoff will take place (i.e. when the true price is slightly above the exercise price, the probability of the trade being informed is high, whereas when the true price exceeds the exercise price by a larger amount, the probability of the trade being informed decreases). Consequently, such a tradeoff is also the case here. Note that the probabilities of an informed trade are rather low.

The coefficient $\alpha_4$ is not significantly greater than zero for RUB/EUR TOD and RUB/USD TOM, so this means that the null hypothesis stating that the probability of an informed trade is equal to zero can be accepted. So in these cases, dealers do not ask an incremental cost on top of the normal IHP for traders that could possibly be informed. For RUB/EUR TOM and RUB/USD TOD, the coefficient $\alpha_4$ is significant at the 5% level. The reason we get significant results on these markets – and not on the other markets- can again be explained by different traders with a different mindset concerning the counterparties they are dealing with (cf. subsection 8.2.). Given the t-ratio’s of $\alpha_3$, none of the coefficients are significantly different from one (except twice), which indicates that there is no significant influence from the IHC on the spread. Furthermore, looking at their value, most times they do not approximate a value equal to one.

What we also can see is that the adjusted R-squared levels remain much or less constant. This means that the ASC in the IHP can be considered as approximating a constant (cf. above). Comparing these furthermore with the adjusted R-squared values of the regression model in Eq. (25), we can see that the R-squared values sometimes increase and sometimes decrease in line with the model results of Bollen et al. (2004). The other variables’ influence on the b/a spread does not change much. This is as expected because we only split-up the IHP.

Note that a difference is made between actively and inactively traded stocks in the work of Bollen et al. (2004). Because our work is separated per currency pair, we cannot perform this exercise here.

\textsuperscript{88} So we will not give an analysis of the economic significance of the components
\textsuperscript{89} Because negative probabilities are not possible.
Regression results for estimating the average of the square root of time between trades for a single dealer

Regression results for $SPR_{LCL} = \alpha_0 + \alpha_1 \log(TV)_i + \alpha_2 C_T + \alpha_3 HPR_{LCL,t_{11}} + \epsilon_i$ where $\alpha_3$ is constrained to equal one.

<table>
<thead>
<tr>
<th>Independent variable $SPR_{LCL}$</th>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
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</thead>
<tbody>
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<td></td>
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<td>$\alpha_0$</td>
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<td>RUB/EUR TOD</td>
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<td>3.22***</td>
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For each currency pair, the first line of results concerns the first regression specification, the second line of results concerns the second regression specification. $SPR_{LCL}$ is the b/a spread calculated according to the LC method. $\log(TV)_i$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $HPR_{LCL,t_{11}}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{LCL}$, the annualized return volatility $\sigma_{LC}$ and the average of the square root of the time between trades $\sqrt{T_1}$.

***Indicates significance at the 1% level; **Indicates significance at the 5% level; *Indicates significance at the 10% level

Table 48: Regression results for estimating the average of the square root of time between trades for a single dealer
<table>
<thead>
<tr>
<th>Currency pair</th>
<th>Observations</th>
<th>Percent ITM</th>
<th>R$^2$</th>
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<table>
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<td>RUB/USD TOM</td>
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<td></td>
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<td>0.30</td>
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<tr>
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<td>2.53**</td>
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<td>2.53**</td>
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<tr>
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<td>2.53**</td>
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<tr>
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<td>0.018208</td>
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</tr>
<tr>
<td></td>
<td>2.53**</td>
<td>0.30</td>
</tr>
</tbody>
</table>

129
SPR_{LC} is the b/a spread calculated according to the LC method. Inv(TV)_{i} is the inverse of the volume traded. C_{T} is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour day as a proxy for competition for each half-hour within that trading day. IHPR_{LC}&_{i} is the inventory holding premium that is calculated based on the true exchange rate T_{LC}, the annualized return volatility σ_{LC} and the average of the square root of the time between trades √τ_{i}. Note that for a trade at the ask, the value of the IHPR_{K,i} is calculated as follows: IHPR_{K,i} = T_{K,i}N \left( \frac{ln(T_{K,i})}{σ_{TV}} + 0.5σ_{TV}√τ_{i} \right) - X_{i}N \left( \frac{ln(T_{K,i})}{σ_{TV}} - 0.5σ_{TV}√τ_{i} \right), where IHPR_{K,i} is valued as an OTM call option with an exercise price equal to the ask price and a true price equal to the b/a midpoint price. IHPR_{I,i} is valued as an ITM call option with an exercise price equal to the ask price and a true price that is a certain percentage amount above the exercise price. These percentages range from 1 to 10%.

***Indicates significance at the 1% level
**Indicates significance at the 5% level
*Indicates significance at the 10% level

Table 49: Regression results for estimating the probability of informed trades

<table>
<thead>
<tr>
<th>10</th>
<th>-0.000898</th>
<th>0.012435</th>
<th>-25397.65</th>
<th>-0.000022</th>
<th>0.010080</th>
<th>-0.003388</th>
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</thead>
<tbody>
<tr>
<td>1.85*</td>
<td>-0.41</td>
<td>-0.64</td>
<td>0.08</td>
<td>-1.44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.3. Conclusion

In estimating the BSW model with data obtained from the MICEX, an inter-dealer spot FX market in Russia, we get different results than those obtained by Bollen et al. (2004). In their model the IHP – that embeds both the IHC and the ASC – was the single most important explanatory determinant of the b/a spread. Our results, however, show that this component does not explain much of the size of the b/a spread and the results of one currency pair even indicate a negative relationship. Our results, then again, did show a negative relationship between competition and the spread. However, this relationship was not always significant in a statistical sense and it also did not explain a large part of the spread. The OPC could not be considered a determinant of the b/a spread according to our results. In general, a great deal of the size of the b/a spread could not be explained by the components in the BSW model specification.

First, note that differences in market structures could lead to unreliable results when applying one and the same model for different datasets (cf. subsection 3.2.2.). As the NASDAQ is a (centralized) multiple dealer market and the same can be said for the MICEX, we assume the BSW model can be tested for data obtained from the MICEX.

Second, other empirical research studies showed us that it was not unreasonable to expect different shares to be attributed to the different components of the b/a spread when the market under study changes (cf. subsections 3.2.2. and 3.2.4.). It would be reasonable to expect – because our data is obtained from a FX market - that the largest part of the b/a spread could be attributed to the IHP, even more so than on the stock market (cf. subsection 3.2.3.). However, this is not the case when we look at our results. One reason could be that on the inter-dealer spot FX market the ASC is more obscured (cf. subsection 3.2.3.).

Third, as our dataset is for a transition economy, the market is expected to be less liquid and smaller than the markets in major currencies. Like we argued in subsections 3.2.6. and 3.2.7., it would also be reasonable to expect the OPC and the IHC (i.e. IHP) to play important roles as determinants of the b/a spread. Again, also for the OPC, these roles were not confirmed by our results. However, looking at the time between trades in our sample, this market can be considered liquid.

Despite the fact that literature did not provide us with clear explanations for our results, the respondents in our survey gave us some interesting insights into the matter that could explain our results (cf. subsection 8.2.). For instance, some of them – in contrast with literature - argued that
they would expect the ASC to explain a larger share of the spread on the stock market and a smaller share on the FX market. They also mentioned that there could be a negative relationship between the IHC and the spread. Concerning the OPC, all respondents agreed that, in practice, there is no relationship between the OPC and the spread.

Finally, we can conclude this section by arguing that - although our respondents can explain most of our results – it could of course also be possible that our b/a spread calculation method i.e. LC does not provide us with reliable b/a spread values. This could also explain our results. For example, the serial covariance estimator of Roll (1984) was said to not yield accurate estimates of the spread because this method often led to imaginary values. As we also have negative b/a spread values when applying the LC method, the same can be true for our method.

In general we can see that the explanatory power of the BSW model is low when data on FX trades is used and that the ad hoc specification model performs better. The variables do not behave as expected, both in sign and statistical significance. Finally, we need to take into account that our results are influenced by multicollinearity.
7. Intraday patterns

Because it is the first time this dataset is used, it is interesting to see whether or not we can find intraday patterns. Consequently, this section starts with a small review of the existing literature on this subject. The intraday patterns that have been found for the b/a spread, volume and exchange rate volatility on the foreign exchange market are presented. We end this section by taking a look at whether or not we find similar patterns for the traded volumes, b/a spreads and annualized return volatilities in our dataset.

7.1. Literature overview

The work of ap Gwilym and Sutcliffe (1999) teaches us that intraday patterns can be found for volume, volatility and the b/a spread on different financial markets. In their work ap Gwilym and Sutcliffe (1999) argue that in most studies these intraday patterns turn out to be U-shaped. This means that the value of the variable under consideration is larger at the opening and the close of the market and is lower in between the opening and close. Variations on this U-shape also exist. These are the L-shape, the J-shape and the W-shape. The L-shape means that the value is only larger at the opening of the market, whereas the J-shape implies that the value is only larger at the close of the market. The W-shape means that the value is not only larger at the opening and the close, but also at lunchtime.\footnote{In our survey (cf. section 8) there is a question on whether or not traders notice intraday patterns.}

As our study concerns the foreign exchange market and as this market is a global market, one cannot talk about the opening and close of the foreign exchange market. One can trade around the clock in this market. This was also mentioned by ap Gwilym and Sutcliffe (1999). Nevertheless, in their research they conclude that the intraday pattern of the b/a spread on the foreign exchange market has a U-shape.\footnote{The complete work of ap Gwilym and Sutcliffe (1999) was not publicly available. Because of this we cannot say for which currency pairs the intraday patterns were found. We only have the main conclusions of their work at our disposal.} Volume and exchange rate volatility, however, have M-shaped patterns. Interestingly enough, Danielsson and Payne (2001) do not find the same patterns, despite the fact that they also made use of data coming from the foreign exchange market.\footnote{Danielsson and Payne (2001) used data from the DEM/USD spot exchange market. This data came from Reuters global inter-dealer FX trading platform.} For the b/a spread they
find a W-shaped pattern and for volume they find an M-shaped pattern. McGroarty, ap Gwilym and Thomas (2009) also looked at whether or not they could find intraday patterns on the foreign exchange market. McGroarty et al. (2009) found that the b/a spread has a U-shaped intraday pattern. Furthermore, they found that the size of b/a spread is minimal when the London and New York markets are trading. For exchange rate volatility and volume they found M-shaped patterns. These two variables spike when the markets in London and New York open.

The work of ap Gwilym and Sutcliffe (1999) also identifies some reasons why these patterns emerge. One explanation mentioned by ap Gwilym and Sutcliffe (1999) is based on the work of Brock and Kleidon (1992) who examine what the effect is of the periodic closure of the stock market on trade demand and volume. They conclude that at the opening and close of the market, trade demand is higher and less elastic and that a smart market-maker will charge a higher price. Spreads should widen, which they were able to test empirically. This is considered by ap Gwilym and Sutcliffe (1999) as ‘differences in trading behavior during the day’ as a cause for intraday patterns. Another explanation has its roots in the work of Admati and Pfleiderer (1988a). Admati and Pfleiderer (1988a) argue that intraday trading patterns are the consequence of strategies followed by informed traders. These will defer their trades to moments when the market has a greater presence of liquidity traders i.e. uninformed traders (cf. subsection 3.1.3.). At such moments b/a spreads seem to be narrower, which lowers transaction costs for these informed traders. The transaction costs are represented by the b/a spread. So, basically, this is considered by ap Gwilym and Sutcliffe (1999) as ‘strategic behavior’ as a cause of intraday patterns.

As the foreign exchange market is open 24 hours a day, McGroarty et al. (2009) believe that the second explanation is more relevant to the foreign exchange market. Whether or not we agree with this we shall not discuss. However, we do want to mention that it may be reasonable to believe that the opening and close of a local foreign exchange market could lead to intraday patterns on that local market.

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93 The values are low at the opening and close of the market. Twin peaks, however, are reached during the day and a low is reached at lunchtime.
94 This was the case for two samples that contained data obtained from a large spot FX database, containing the following currency pairs: DEM/USD, USD/CHF, DEM/CHF, DEM/JPY, EUR/USD, USD/JPY, EUR/JPY, EUR/CHF.
95 In the work of McGroarty, ap Gwilym and Thomas (2009), the exchange rates involving the JPY showed slightly different patterns. There was an additional peak for exchange rate volatility and volume, as well as an additional low in the pattern of the b/a spread. This could be linked to activity on the Tokyo market.
7.2. Results

7.2.1. Volume

Figures 21 to 24 give the boxplots of the traded volumes for each of our four currency pairs. Some patterns can be seen. However, we do not find the M-shaped pattern for volume as described in subsection 7.1.. For RUB/EUR TOD and RUB/USD TOD, the traded volumes are larger in the morning and tend to decrease towards the close of the market. Looking at the trading hours of other foreign exchange markets and comparing them with the trading hours of the MICEX, it is difficult to say that these larger volumes traded in the morning could be linked with other markets being open at the time. As we can see in figure 25, when the forex in Tokyo and Sydney closes, not much later the London market opens. For RUB/USD TOM, one could argue that a U-shaped pattern appears, however, this is not very pronounced.

Figure 21: Boxplot of the volumes traded for RUB/EUR TOD
Figure 22: Boxplot of the volumes traded for RUB/EUR TOM

Figure 23: Boxplot of the volumes traded for RUB/USD TOD
Figure 24: Boxplot of the volumes traded for RUB/USD TOM

Figure 25: Trading hours of the MICEX and other foreign exchange markets

7.2.2. B/a spread

Figures 26 to 29 give the boxplots of the b/a spreads for each of our four currency pairs. Note that the b/a spread is calculated using the LC method. In appendix G the boxplots of the b/a spreads calculated according to the WA method and the C₀ method can be found. It is clear that we cannot see any pronounced patterns in figures 26 to 29. A reason for this could be that the FX market is a global market, or that our b/a spread calculation method results in unreliable spread values.
Figure 26: Boxplot of the LC b/a spread for RUB/EUR TOD

Figure 27: Boxplot of the LC b/a spread for RUB/EUR TOM
7.2.3. Volatility

Figures 30 to 33 give the boxplots of the annualized return volatility for the four currency pairs in our dataset. Note that this is the volatility of the true exchange rate return. The true exchange rate is calculated as the midpoint price between the bid and the ask price. The bid and ask price in turn are constructed for each half-hour according to the LC b/a spread calculation method (cf. subsection 5.3.1.). The annualized return volatility used here, is the return volatility calculated using the returns of 2 preceding half-hours instead of 5 preceding half-hours. Again, it is clear that we cannot see any pronounced patterns in figures 30 to 33.
Figure 30: Boxplot of the annualized return volatility for RUB/EUR TOD

Figure 31: Boxplot of the annualized return volatility for RUB/EUR TOM
Figure 32: Boxplot of the annualized return volatility for RUB/USD TOD

Figure 33: Boxplot of the annualized return volatility for RUB/USD TOM
8. Survey

In his book ‘The Microstructure Approach to Exchange Rates’, Lyons (2006) indicated a gap between theory and practice which has led to the microstructure approach on the foreign exchange market (cf. subsection 2.5.).

Inspired by his work and the importance of a multiperspective approach in order to have a more complete understanding of a certain topic, we believed it could be interesting to speak to dealers active on different financial markets that are recognized by the presence of bid-ask quotes in order to get an idea of what these dealers themselves believe are the components of the b/a spread and to see how familiar they are with existing literature on these components.

It should be stressed that the purpose of this paper is quantitative research, i.e. the empirical testing of the decomposition model of Bollen et al. (2004) on the foreign exchange market. However, comparing the results obtained here with the theory on the components of the b/a spread leads to some interesting insights. Furthermore, some of the findings here were used to explain our regression results (cf. section 6).

8.1. Approach

We have contacted a number of people active on different financial markets recognized by bid-ask quotes. They were asked whether or not they wanted to participate in a survey, which means answering several questions about the components of the b/a spread. Bearing in mind the busy work-life of these people, we let them choose whether they wanted to participate via e-mail or by phone. The survey was conducted anonymous.

Regardless of their choice to participate via e-mail or by phone each participant received the same questions. These questions were:

1. Have you ever been in a job where you came in contact with bid/ask quotes? If so, which position was this?
2. What are – in your experience – the factors that determine the size of the b/a spread? Note that this deals with the size of the b/a spread and not the movement of the midpoint price.
3. Have you ever heard about the literature and research work done on the components of the b/a spread? If so, what can you tell me about this?

4. In my research – where I apply a decomposition model of Bollen, Smith and Whaley (2004) to the b/a spread – the components of the b/a spread consist of the following:\footnote{These were briefly explained by examples in our survey, but considering the fact that we have discussed these determinants in depth in section 3 we assume the reader understands the components.}
   a. A component that includes the risk of holding a certain position, i.e. the inventory holding component.
   b. A component that includes the risk of dealing with better informed parties, i.e. the adverse selection component.
   c. A component that takes competition into account, i.e. a competition component.
   d. An order costs component
   Have you ever heard of one of these components? If so, can you tell me what you know?

5. Does it seem reasonable to assume that when a dealer increases his position in a certain asset – so he buys that certain asset –, his b/a spread will widen?

6. Does it seem reasonable to assume that the b/a spread will widen when a dealer believes his counterparty has superior information at his disposal?

7. What is your view on the deduction of information from order flow? Does it happen regularly that market-makers do not have enough information?

8. Does it seem reasonable that when order costs increase, a dealer will widen his spread?

9. Does it seem realistic that when competition increases, the b/a spread will narrow?

10. On the market that is your domain of experience, which determinant do you believe accounts for the biggest share of the b/a spread? Why?

11. Do you think that dealers, who set the b/a spread by quoting prices, in reality take determinants into account? Also those summed up by us?

12. Will you – as a party that wishes to buy/sell – postpone your trade because of the b/a spread?

13. Have you, at certain moments in time, experienced strange behavior of the b/a spread? If so, when?

14. Have you sometimes had the feeling that the b/a spread moved in a certain direction without a specific reason for it?

15. Do you see a daily recurring shift in the b/a spread – moments at which the size of the b/a spread is at its maximum/minimum (i.e. intraday pattern)?

16. Do you know whether or not there are differences in the size and behavior of the b/a spread on different markets? If so, what can you tell me about this?
17. Do you think that market-making – where one realizes the spread by a consecutive buy-sell transaction – is a profitable activity?

8.2. Results

We summarize here the main findings after going through the answers of our 10 respondents. Most of the respondents answered by e-mail. As the purpose of this overall work is quantitative research, we try to give a good summary without going into detail. However, in appendix A, we have provided the reader, by way of example, with a transcript of an interview with one of our respondents, because we believe this is, in general, very interesting to read and it provides the reader with more background information on the logic behind certain answers.

We start with an overview of the different profiles of the respondents in our sample. This can be seen in table 50.

The most striking finding is that all ten of our respondents - with only two exceptions – have never heard of the literature on the b/a spread components, despite the fact that they are active or have been active in posts where they deal or have dealt with these b/a spreads. They have learned to analyze the b/a spread and the behavior of the b/a spread by practical experience. Both respondent H and J, who have heard of the literature on the b/a spread components, only know that such literature exists but they do not have any experience with it. Consequently they could not tell us anything more than that.

Interesting also are the respondents’ answers on what, in their experience, are the factors that determine the size of the b/a spread. These answers are summarized in table 51. One can see there are no two respondents with the same answer. However, some determinants are mentioned several times by different respondents in the same or in other words. The determinants most frequently mentioned are liquidity and competition. Explaining liquidity we use the definition of Hirshleifer (1971): “Liquidity is an asset, with the capability, over time, of being realized in the form of funds available for immediate consumption or reinvestment.” One of the respondents also made an explicit distinction between perspectives from which the b/a spread is approached: a general perspective, a customer perspective and a trader perspective. Unfortunately, on looking at the components mentioned, very few of these clearly refer to the IHC, the ASC or the order costs. However, when we talked about Stoll’s multi-perspective approach, we did mention the fact that liquidity as well as
volatility have an influence on the IHC (cf. subsection 3.1.3.). Supply and demand stated as a determinant by respondent E and respondent I could be linked to the ASC in the sense that each dealer can see the supply and demand of his customers and thus these signed trades can be considered as private information. Also the type of customer, mentioned once as a determinant, can for instance be linked to the ASC.

Profiles of the different respondents within our sample
Position(s) in which each of the different respondents within our sample have had contact with b/a quotes$^\dagger$.

<table>
<thead>
<tr>
<th>Person</th>
<th>Function(s)</th>
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<tbody>
<tr>
<td>Person A</td>
<td>Government bond trader</td>
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<tr>
<td></td>
<td>Interest rate swap trader</td>
</tr>
<tr>
<td></td>
<td>Long-term foreign exchange trader</td>
</tr>
<tr>
<td>Person B</td>
<td>Dealer in derivatives and structured products</td>
</tr>
<tr>
<td>Person C</td>
<td>Fund manager</td>
</tr>
<tr>
<td></td>
<td>Market-maker/inflation trader</td>
</tr>
<tr>
<td>Person D</td>
<td>Foreign exchange trader</td>
</tr>
<tr>
<td>Person E</td>
<td>Market-maker</td>
</tr>
<tr>
<td></td>
<td>Foreign exchange trader</td>
</tr>
<tr>
<td>Person F</td>
<td>Foreign exchange trader</td>
</tr>
<tr>
<td></td>
<td>Sales person financial products</td>
</tr>
<tr>
<td>Person G</td>
<td>Market-maker in bonds and interest derivatives</td>
</tr>
<tr>
<td>Person H</td>
<td>Market-maker in shares</td>
</tr>
<tr>
<td></td>
<td>Trader in shares</td>
</tr>
<tr>
<td>Person I</td>
<td>Government bond market maker</td>
</tr>
<tr>
<td>Person J</td>
<td>Foreign exchange spot trader</td>
</tr>
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<td></td>
<td>Foreign exchange FX forwards</td>
</tr>
<tr>
<td></td>
<td>Trader in interest rate derivatives</td>
</tr>
<tr>
<td></td>
<td>Government bond trader</td>
</tr>
</tbody>
</table>

$^\dagger$ They do not necessarily do that job nowadays and they may have exercised multiple positions, in which they had contact with b/a quotes.

Table 50: Profiles of the different respondents in our sample
**Determinants of the b/a spread according to the respondents**

Short overview of the b/a spread according to the respondents in our sample.\(^1\)

<table>
<thead>
<tr>
<th>Person</th>
<th>Determinants</th>
</tr>
</thead>
</table>
| Person A | - Liquidity  
- Uncertainty |
| Person B | - Liquidity  
- Book appetite  
- Emotions |
| Person C | In general:  
- Type of product  
- State of the market  
As customer:  
- Size of total portfolio  
- Number of products being traded  
As trader:  
- Liquidity  
- Size of trade request  
- Number of banks in competition  
- Hit ratio targets  
- Type of customer  
- Positioning of the market and of own book |
| Person D | - Market conformity  
- Competition  
- Currency combination |
| Person E | - Supply and demand  
- Liquidity  
- Size of the trade  
- Time of transaction |
| Person F | - Volatility  
- Liquidity  
- Number of market participants  
- Market-events (economic numbers, announcements, worldwide events like natural disasters, threat of war in Iraq, 9/11, etc.)  
- Technological developments (e.g. algo-computers have led to narrower |
Table 51: Determinants of the b/a spread according to the respondents

<table>
<thead>
<tr>
<th>Component</th>
<th>Person G</th>
<th>Person H</th>
<th>Respondent I</th>
<th>Respondent J</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Type of currency</td>
<td>- Volatility</td>
<td>- Number of interveners</td>
<td>- Liquidity</td>
<td>- Volatility</td>
</tr>
<tr>
<td>- Liquidity</td>
<td>- Liquidity</td>
<td>- Free float</td>
<td>- Risk appetite of parties involved</td>
<td>- Competition</td>
</tr>
<tr>
<td>- Competition</td>
<td>- Competition</td>
<td>- Market authorities</td>
<td>- Supply and demand</td>
<td>- Depth of the market</td>
</tr>
<tr>
<td>- Limits on trading</td>
<td>- Limits on trading</td>
<td>- Drift</td>
<td>- Hedging possibilities</td>
<td>- Hedging possibilities</td>
</tr>
<tr>
<td>- Hedging instruments</td>
<td>- Hedging instruments</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

These components can be influenced by the different financial markets the participants are active in. These are the answers as given by the respondents.

In a next question, we presented the determinants used in the work of Bollen et al. (2004) and asked whether the respondents have ever heard of any of these determinants or if they were familiar with any of these components. Again, the answers varied. Some could agree with the logic behind (most of) these components, however two respondents remarked that these components are rather theoretical and, in that sense, the determinants summarized in table 51 are the determinants used in practice.

We sounded the respondents out about whether or not a positive relation between the IHC and the b/a spread was realistic. Four out of the ten respondents answered that a midpoint price movement was more realistic and would result from holding a certain inventory position. This means that if you have a huge amount of a certain asset in your inventory, you will lower your midpoint price in order to sell that inventory more quickly and thus lower your risk. Respondent B mentioned that if you set your b/a spread wider as a reaction to holding a higher amount in inventory, this will not lead to a
deal because you set your sell price higher if you do this and no one will buy. Several argued that the size of the b/a spread did not necessarily have to widen or become narrower. One of the respondents also said that this depends on the market you are active in. For instance, authorities have put limits on the maximum position you can hold for interest swaps. Interestingly, two other respondents said the b/a spread should become narrower, because the higher your inventory, the higher your liquidity position which, in turn, leads to a more liquid market and this, in turn, leads to a narrower spread. Respondent D answered that he would widen the b/a spread if the active party wants to trade a higher volume.

The answers of our respondents concerning the ASC and its positive relation with the b/a spread are also quite diverse. One of the respondents, respondent A, mentions that in perfect markets you do not have superior information thus this is not the case. However, respondent H argues that, as a trader, you automatically assume that the people you trade with almost always have better information than yourself. That is, however, only on a stock market. Respondent C argues that this probably holds more for the stock market than any other market. Respondent H – also active in the stock market - furthermore adds that, as a trader, it is more important to know which way the market is moving rather than why the market is moving in a certain way and this is based, according to him, on the dealer’s gut feeling. He gives an example of a market that anticipates good results from a certain company and that, in anticipation of the company's press-release, traders have build up an inventory. However, it may well be that, at the moment of the press-release, the market is rather a seller than a buyer. Thus the market has its own way of interpreting information. According to him, the market has its own life and that this is probably also the case for the b/a spread. In the end, the market is always right: you can, in an extreme case, have insider information, but you can still make a loss because the market does not agree with you. Furthermore, even if you have superior information, you also need good timing. So, according to respondent H, you would do better to follow the market, rather than trying to outsmart it because of the risk of having the market against you. That is why he concludes by saying that the momentum - the drift of the asset - is more important than widening your b/a spread because of a counterparty that could have superior information. Conversely, three other respondents agreed with the above suggested relationship. They argue that, after a while, you know which customers are better informed and you will set your b/a spread wider towards those customers because you want to protect your position. Finally, although respondent B does not agree with our suggested relationship, he does however say that it may happen that if you trade with someone of whom you know upfront that they receive a lot of good information, e.g. Goldman Sachs, that you can react emotionally and set your b/a spread wider only because of who they are, but that is subjective and varies from dealer to dealer. The reason why
respondent B does not agree with our suggested relationship is because he believes that someone with more information will want to buy or sell more quickly than the rest of the market and thus will set its own b/a spread narrower. As the other party trading with this party, you get the best prices.

The question regarding the deduction of information out of transactions was a difficult one because several respondents could not properly answer this. The main conclusion here is that order flow is used to provide information about the general market movement and this is important because you do not want the market moving against you. Furthermore, the particular party you are dealing with, gives you information about how much information they have (cf. above). Respondent H argues that there is a lot of information out there, but that the main difficulty lies in deciding which information is more important and how this information will be interpreted by the market as a whole. In any case, you can have a lot of information at your disposal if you want to, e.g. there are hedge funds that have strategic machines to distill information out of the evolution of the financial market. Respondent J furthermore adds that, although you can have a lot of information, it will never be complete.

All the respondents agreed that, in practice, there is no relationship between the order costs and the size of the b/a spread. They can agree with the theoretical logic behind it, but in the trading rooms it is not taken into consideration. They approach it more as follows: with the b/a spreads they realize or the profits that they make on their trades, they pay their costs. These costs are not taken into account in advance.

Everybody that took the survey agreed that competition has a negative relation with the b/a spread. This was also one of the components frequently mentioned when we asked our respondents what were, in their experience, the determinants of the b/a spread. Interestingly enough, some respondents make the link with liquidity: the more competition, the more liquid the market and the narrower the b/a spread becomes. In addition, respondent F mentioned that algo-trading (cf. further down) leads, in turn, to more competition.

When we asked our respondents what they believed were the determinants that proportionally could explain the biggest share of the b/a spread, this mainly boiled down to two determinants: liquidity and competition.

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97 This concerns algorithmic trading. We come back to this later.
When we asked, in a next question, whether or not they took these determinants into account in the trading rooms, we got some respondents saying yes while others said no. The main conclusion here should probably be – as respondent E argued - that it varies from dealer to dealer and is independent of whether or not these determinants do affect the b/a spread. Respondent E tells us that, on the one hand, you have dealers who just go with the flow and if the market moves in one way, they just go along with the market. If the market is very volatile and rather restless, they will play a waiting game. They do not really care about the determinants. On the other hand, there are also those dealers that are more analytic and try to discover a pattern for which they will make use of determinants. Respondent E is an advocate of the first category of dealers, because a dealer that can make use of determinants to discover a pattern in order to predict price trends, would no longer be a dealer but be out living life after profitably selling his solution.

Most dealers will seldom postpone their trades because of the size of the b/a spread. In very exceptional situations, traders are forced to postpone trades because there are no bids or asks or because b/a spreads are too wide.

All but one of our respondents have observed bizarre behavior of the b/a spread. For example, after the attack of 9/11, the order book was emptied because it was uncertain what effect it would have on asset prices. This, in turn, led to a sudden narrowing of the spread. All of our respondents can agree when we say that that there is always an explanation for why the b/a spread suddenly increases or decreases, despite that the fact that this explanation sometimes only becomes clear after the change has taken place and taking into consideration that investors’ emotions like panic and uncertainty can also be used to explain a change in the size of the b/a spread.

Interestingly, respondent J also mentioned that sometimes the ask price is lower than the bid price, which he explains by citing the existence of different trading systems. So, to be clear, this does not occur on one and the same trading platform. According to him, the market is not always efficient. He, however, was the only respondent who made this remark.

Intraday patterns (cf. section 7) were noticed by our respondents. Especially before and after the opening and closing of certain markets. When, for instance, Europe and London (ca. 8:00 am GMT) start to work, then the b/a spread will narrow because liquidity increases. When they go home the b/a spread widens again because there is less liquidity. When the USA starts working (ca. 2:00 pm GMT), liquidity increases again and this reveals itself in a narrower b/a spread. When certain economic numbers are revealed or press-releases are issued – most of the time around the opening
of the US or European market - this also influences the size of the b/a spread. Dealers waiting for this kind of news to be announced will postpone trades until the news is released. Consequently, just before the news is released, trading is slacker and thus liquidity is lower, which leads to a wider b/a spread. At noon, when dealers go out to eat something, it is not unusual to see a wider or narrower b/a spread – the two are possible.

There are differences between markets with regard to size and reaction of the b/a spread. Most respondents say that this depends on the liquidity of the market and the type of instruments traded on that market. Some instruments are more liquid than others: vanilla products, e.g. bonds, interest rate swaps,... Respondent F also argued that in Asia the b/a spread is wider, but probably this can be related to a less liquid market over there.

There are people or companies that follow market making strategies without being appointed by the regulator. For instance, people that have constructed models and are present at markets without having a license.

Finally, opinions differ when respondents were asked if they believed market-making is a profitable activity. Respondent H points out the importance of the type of instrument to be profitable, but also the liquidity of the market, drift, volatility, free float, etc. Respondent C assumes that stable markets are necessary, which rarely is the case. Respondent A points out the importance of order flow. However, if the activity in itself does not yield proceeds, then there can be some kind of customer binding that leads those customers to buying other bank products that are profitable. Respondent F has his doubts because he believes that we, as humans, are not quick enough to respond. You have, for instance, algo-trading that uses computers for trades and these systems react within milliseconds, so maybe a good algorithm can generate some profits. In general, we can say here that the answer is no or yes, but if it is yes then there are some conditions that need to be fulfilled.

8.3. Some interesting determinants from practical experience

As was already stated, almost all respondents said liquidity is a determinant of the b/a spread. After evaluating all answers to all questions we came to the following finding: a lot of the other determinants mentioned by the respondents were, in turn, by these same respondents, related to liquidity. Take competition for instance. Respondent B argued, for example, that more market-makers lead to a more liquid market which, in turn, leads to a narrower b/a spread. For those
determinants where that link is not explicitly made, it is often possible to establish this relationship. We discuss some interesting determinants and, where possible, we try to identify this relationship.

Drift is one of the determinants mentioned by respondent H. For example, suppose a company has good results, then you have an upward-oriented drift. In such a market, sellers leave the market and it is very difficult to buy stocks of that company. This leads to a wide b/a spread. However, if the drift is more stable, you have a market with a better balance between buyers and sellers, which does not lead to such a wide b/a spread. Consequently, you could argue that when drift is upwards or downward-oriented, this will lead to a less liquid market than one in which drift is more stable.

Market events are mentioned as a determinant by respondent F. Although this determinant is not explicitly mentioned by the other respondents in the second question, some of the respondents however referred to the effect of events in their answers to other questions. Market events can be announcements, press releases, worldwide events like natural disasters, etc. What happens when such events take place is that a market can become more or less liquid. For example, when the attacks of 9/11 took place, the responsible authorities on the stock market decided to close all positions which led to a sudden peak in the number of stocks in circulation. This creates competition between dealers to get rid of these positions, which can have narrowing effect on the b/a spread. Also, uncertainty or certain emotions that exist among dealers can lead to a very liquid or illiquid market which, in turn, affects the size of the b/a spread.

Algorithmic trading or algo-trading is making use of computers that perform algorithms, based on which these computers place trades. Because of the fact that use is made of algorithms and computers, this allows market-makers to react more quickly. Several respondents mentioned that the advent of algo-trading increased competition and resulted in narrower b/a spreads. This was also found by Hendershott, Jones and Menkveld (2011). They showed that algo-trading leads to narrower b/a spreads and also reduces adverse selection. This was investigated on the stock market in their research work. They end by concluding that algo-trading improves liquidity.
8.4. Conclusion

First, only two of our respondents had ever heard of the literature on the components on the b/a spread.

Second, we can conclude that all the dealers agreed that determinants exist which influence the size of the b/a spread. However, not much unanimity exists between what those determinants are and whether they are used or not varies from dealer to dealer. Two important and frequently mentioned determinants that are present in all markets are competition and liquidity. Furthermore, a lot of the other determinants mentioned, could possibly be linked or have been linked by the respondents to liquidity.

Third, the IHC and ASC are argued to be rather theoretic components and, surprisingly, not much unanimity exists around the suggested relationships. Some agree, others not. In trading rooms they are not taken into consideration or at least not by our respondents.

Fourth, order flow is mainly used to tell dealers where the market is going. This is important for dealers to know so that you can move with the market, because ‘the market is always right’. This does not mean that you cannot move against the market, but this can adversely affect the revenues of the dealers.

Finally, the respondents in our survey are active in different markets and in different functions. This leads us to believe that – in examining the b/a spread, an approach where one first surveys dealers present on the market under consideration to arrive at a list of frequently mentioned determinants and then examine the significance of these components on the b/a spread – would certainly be a good approach too.
9. Summary

A good understanding of the determinants of the bid-ask spread is important because they not only provide information about the fairness of a dealer’s rents, but they are also important in evaluating the merits of competing trading mechanisms. In literature, the bid-ask spread is typically considered a function of several cost components: the order processing component, the inventory holding component, the adverse selection component and competition. We contribute to existing literature by discussing these components in a chronological fashion. This chronology allows us to see that the first theoretical models only considered the bid-ask spread to be a compensation for holding an inventory. Next, models appeared that considered the bid-ask spread to be the compensation dealers ask to protect them against the losses they incur to informed traders. Only later on, starting with the work of Stoll (1978b), authors began to realize that these different determinants, like the order processing cost component, the inventory holding component and the adverse selection component could have an influence at the same time and thus co-exist in models. Authors even began to argue that it is hard to disentangle the influence of the different components.

In this paper we tested the bid-ask spread decomposition model constructed by Bollen, Smith and Whaley (2004). This model is a simple model in which the bid-ask spread is a function of an order processing component, an inventory-holding premium – that comprises both the inventory holding component and the adverse selection component –, and a competition component. The inventory-holding premium is modeled as an at-the-money option with a stochastic time to expiration. Unlike Bollen et al. (2004), whose data sample contained Nasdaq stocks and, consequently, is applied to data from the stock market, our sample contains data on FX trades from the MICEX, an inter-dealer spot foreign exchange market. The dataset contains trades in four currency pairs RUB/EUR TOD, RUB/EUR TOM, RUB/USD TOD and RUB/USD TOM.98

The results we obtain are considerably different of those obtained by Bollen et al. (2004). First, in their model, the IHP – a component that embeds both the inventory holding component and the adverse selection component – was the single most important explanatory determinant of the bid-ask spread. Our results, however, show that this component does not explain much of the size of the bid-ask spread. For only one currency pair we got a coefficient for the inventory holding premium that was significant at the 1% level. Estimation results of one currency pair even indicated a negative

98 ‘TOD’ refers to a market with an enhanced clearing, ‘TOM’ refers to a market where trades are cleared on the next trading day.
relationship. However, this relationship was not significant in a statistical sense. Second, the competition component did have, as expected, a negative relationship with the bid-ask spread, however this relationship was only significant in a statistical sense in half of the cases. Furthermore, this component also did not have a large influence on the spread. Finally, the order processing component could not help to explain the size of the bid-ask spread.

In general, we can conclude that a great deal of the size of the bid-ask spread could not be explained by the components in the model specification of Bollen et al. (2004) and, consequently, our study does not confirm most of the results from previous theoretical and empirical studies. Furthermore, the estimation of an ad hoc specification model shows a higher explanatory power, which casts some doubt on the model specification of Bollen et al. (2004) and its usefulness for data on the FX market. This, however, is in the assumption that the variables used in the model have reliable values.

Note that differences in market structures could lead to unreliable results when applying one and the same model to different datasets. As the NASDAQ is a (centralized) multiple dealer market and the same can be said for the MICEX, we assume that the model of Bollen et al. (2004) can be used for data from the MICEX.

Because our study does not confirm most of the results from previous theoretical and empirical studies, literature does not provide us with many clear explanations for our results. Obviously, the expectations that result from an in-depth study of literature concerning the shares and importance of the different components of the spread for the case of the foreign exchange market, were not confirmed by our results. For instance, as our dataset is for a transition economy, the market is expected to be less liquid and smaller than in major currencies. For such markets, the order processing component and the inventory holding component typically play important roles as determinants of the bid-ask spread.

However, inspired by the work of Lyons (2006), who indicated a gap between theory and practice and which has led to the microstructure approach to the foreign exchange market, we conducted a survey in order to get an idea of how dealers perceive the relationship between the determinants used in our model and the bid-ask spread. The respondents in our survey gave us some interesting insights that could explain our results.

In general, we can say that all the dealers in our survey agree that there exist determinants which have an influence on the size of the bid-ask spread. However, not much unanimity exists between
what those determinants are and whether they are used varies from dealer to dealer. Two important determinants mentioned by our respondents were liquidity and competition. Concerning the components of the bid-ask spread proposed in the model of Bollen et al. (2004), besides from competition, not much unanimity existed around the suggested relationships with the bid-ask spread as seen in literature. For instance, some of our respondents believe that the relationship between the inventory holding component and the spread has a negative sign. They perceive a higher inventory as higher liquidity on the market. Important is, that every relationship (i.e. positive or negative, significant or insignificant) in our estimation results could be explained using the results of our survey. In general, the influence of a component depends on whether the majority of the dealers take this determinant into account and it also depends on how they perceive the relationship between the bid-ask spread and this determinant. In the end, it can be said, that the components taken into account vary from dealer to dealer and this is independent of whether or not these determinants do affect the bid-ask spread.

Considering that our dataset did not contain quote data but only trade data, we needed to specify our own method for determining the prevailing quotes and spreads. This means that, although we could use the explanations given by our respondents to explain our results, it could also be possible that the bid-ask spread calculation method that we have used does not provide us with reliable bid-ask spread estimates. Consequently, this could also explain our results and therefore, one must be careful when interpreting these results.

An interesting topic for further research could be re-estimating the model but this time with a dataset that contains not only trade data but also quote data on the foreign exchange market. Furthermore, as we did not define one but eight different methods for constructing quotes and determining spread values based on available trade data, it could be interesting to perform a study to investigate how reliable these spread values are for each of these methods and to compare them with the already existing estimators, like for instance the serial covariance estimator of Roll (1984). Furthermore, since it is the first time this dataset is used, it could also be used for the execution of a technical analysis.
References


Appendix A: Proof for ATM call and put

We provide proof that the price of an ATM call option equals the price of an ATM put option.

The Black-Scholes formula for the price of an European\textsuperscript{99} call option is:

\[
\text{call option} = TN\left( \frac{\ln\left( \frac{X}{E} \right) + (r + \frac{\sigma^2}{2})T}{\sigma \sqrt{T}} \right) - Xe^{-rT}N\left( \frac{\ln\left( \frac{X}{E} \right) + (r - \frac{\sigma^2}{2})T}{\sigma \sqrt{T}} \right)
\]

(1)

Assumptions:

(2) \quad r = 0

(3) \quad T = X

Replacing (2) and (3) in (1):

\[
\text{call option} = T\left( N\left( 0.5\sigma\sqrt{T} \right) - N\left( -0.5\sigma\sqrt{T} \right) \right)
\]

(4)

The Black-Scholes formulas for the price of an European put options is:

\[
\text{put option} = Xe^{-rT}N\left( -\frac{\ln\left( \frac{X}{E} \right) + (r + \frac{\sigma^2}{2})T}{\sigma \sqrt{T}} \right) - TN\left( -\frac{\ln\left( \frac{X}{E} \right) + (r - \frac{\sigma^2}{2})T}{\sigma \sqrt{T}} \right)
\]

(5)

Replacing (2) and (3) in (5):

\[
\text{put option} = T\left( N\left( -0.5\sigma\sqrt{T} \right) - N\left( 0.5\sigma\sqrt{T} \right) \right)
\]

(6)

\[\Rightarrow \quad \text{put option} = T\left( N\left( 0.5\sigma\sqrt{T} \right) - N\left( -0.5\sigma\sqrt{T} \right) \right)\]

As (6) equals (5), quod erat demonstrandum.

\textsuperscript{99} Note that an European option can be exercised only on the expiration date and not before the expiration date, while American options can be exercised any time before expiration and on the expiration date. This difference in terms does not refer to a geographic location where options are traded.
Appendix B: Algorithms

In this appendix we provide the reader with 1 set of the MATLAB algorithms used to transform our raw data into a usable set of spread measures and spread determinants.\footnote{The algorithms can be provided to the reader on request.} We have one set of algorithms for RUB/EUR TOD, another set for RUB/USD TOD and a set for both RUB/EUR TOM and RUB/USD TOM. The differences between these sets are caused by the different opening hours. Within each set we have several algorithms for the different b/a spread calculation methods. In this case we show the algorithms for the $AV$ and $MM$ b/a spread calculation methods.\footnote{The algorithms belonging to these methods take the least space.}

The set of algorithms provided here is the one we used for RUB/EUR TOD. We have chosen for the set of algorithms belonging to this currency pair because they deal with a ‘jump’ in opening hours on May 16, 2011 (cf. subsection 5.1.) and take the least space. This set exists in total of 10 algorithms. We will present them in the order they should be used and we will discuss briefly at the beginning of each algorithm what exactly the algorithm does.

Before we start presenting the algorithms, we give an overview of all of them and their order. Consequently, in order to obtain the spreads and the spread determinants calculated according to the $AV$ and $MM$ method for RUB/EUR TOD, the following algorithms should be executed:

1) \( \text{spreads\_vol\_prijs\_eur\_rub\_tod}=\text{ba\_vol\_prijs\_eur\_rub\_tod}(\text{intraday\_data\_2011\_eur\_rub\_tod}) \);
2) \( \text{spreads\_vol\_prijs\_eur\_rub\_tod\_2}=\text{verwijdernegatieve\_spreads}(\text{spreads\_vol\_prijs\_eur\_rub\_tod}) \);
3) \( \text{stochastictime1\_eur\_rub\_tod}=\text{stochastictime\_eur\_rub\_tod}(\text{intraday\_data\_2011\_eur\_rub\_tod}) \);
4) \( \text{stochastictime2\_eur\_rub\_tod}=\text{stochastictime2\_eur\_rub\_tod}(\text{intraday\_data\_2011\_eur\_rub\_tod}) \);
5) \( \text{spreads\_vol\_price\_comp\_truerate\_time\_eur\_rub\_tod}=\text{competitie\_exchangerate\_stochastictime\_AV\_MM}(\text{data\_2011\_eur\_rub\_tod\_corrected}, \text{spreads\_vol\_prijs\_eur\_rub\_tod\_2}, \text{stochastictime1\_eur\_rub\_tod}, \text{stochastictime2\_eur\_rub\_tod}) \);
6) \( \text{intermezzo}=\text{verwijderNaN\_voorvolatiliteit}(\text{spreads\_vol\_price\_comp\_truerate\_time\_eur\_rub\_tod}) \);
7) \( d_{\text{minus}} \text{ihp}_{} \text{eur}_{} \text{rub}_{} \text{tod} = \text{volatiliteit}_{} \text{eur}_{} \text{rub}_{} \text{tod} (\text{intermezzo}); \)

8) \( \text{intermezzo1} = \text{verwijderNaN}_{} \text{navolatiliteit}(d_{\text{minus}} \text{ihp}_{} \text{eur}_{} \text{rub}_{} \text{tod}); \)

9) \( d_{\text{eur}_{} \text{rub}_{} \text{tod}} \text{LV}_{} \text{WA} = \text{ihp}_{} \text{eur}_{} \text{rub}_{} \text{tod} (\text{intermezzo1}) \)

10) \( d_{\text{dagelijks}_{} \text{eur}_{} \text{rub}_{} \text{tod}_{} \text{LV}_{} \text{WA}} = \text{maakdagelijks}_{} \text{LV}_{} \text{WA}(d_{\text{eur}_{} \text{rub}_{} \text{tod}} \text{LV}_{} \text{WA}); \)
Algorithm 1:

spreads_vol_prijs_eur_rub_tod=ba_vol_prijs_eur_rub_tod(intraday_data_2011_eur_rub_tod);

Description:
This algorithm calculates the AV and MM b/a spreads, the traded volumes per half-hour and the average price per half-hour at which the trade took place.

Function \[ y \] = ba_vol_prijs_eur_rub_tod( x )

dagen=unique(x(:,1));
tussenwaarde=size(dagen);
aantaldagen=tussenwaarde(1);

rijen=size(x);
rowsx=rijen(1);

starttimeday=(datenum('30-dec-1899 10:00:00')-datenum('30-dec-1899 00:00:00'));
halfhour=datenum('30-dec-1899 00:30:00')-datenum('30-dec-1899 00:00:00');

i=1; tellerdagen=1;
a=1;
b=1;c=1;d=1;
e=1;
f=1;g=1;
h=1;
l=1;
m=1;
n=1;
o=1;
p=1;
q=1;
r=1;
s=1;
t=1;
u=1;
v=1;
w=1;

t1=1;
t2=1;
t3=1;
t4=1;
t5=1;
t6=1;
t7=1;
t8=1;
t9=1;
t10=1;
t11=1;
t12=1;
t13=1;
t14=1;
t15=1;
t16=1;
t17=1;
t18=1;
t19=1;
t20=1;

aa=1;

buyshalfuureen=[];
sellshalfuureen=[];
buyshalfuurtwee=[];
sellshalfuurtwee=[];
buyshalfuurdrie=[];
sellshalfuurdrie=[];
buyshalfuurvier=[];
sellshalfuurvier=[];
buyshalfuurvijf=[];
sellshalfuurvijf=[];
buyshalfuurzes=[];
sellshalfuurzes=[];
buyshalfuurzeven=[];
sellshalfuurzeven=[];
buyshalfuuuracht=[];
sellshalfuuuracht=[];
buyshalfuurnegen=[];
sellshalfuurnegen=[];
buyshalfuurtien=[];
sellshalfuurtien=[];

DateVector1=[];
DateVector2=[];
DateVector3=[];
DateVector4=[];
DateVector5=[];
DateVector6=[];
DateVector7=[];
DateVector8=[];
DateVector9=[];
DateVector10=[];
DateVector11=[];
DateVector12=[];
DateVector13=[];
DateVector14=[];
DateVector15=[];
DateVector16=[];
DateVector17=[];
DateVector18=[];
DateVector19=[];
DateVector20=[];
DateVector21=[];
DateVector22=[];
DateVector23=[];
DateVector24=[];
DateVector25=[];
DateVector26=[];
DateVector27=[];
for tellerdagen = 1:aantaldagen
    while x(i)==dagen(tellerdagen)
        if x(1*rowsx+i) <= (x(i,1)+starttimeday+halfhour)
            if x(5*rowsx+i)==1
                buyshalfuureen(a,1)=x(2*rowsx+i);
                buyshalfuureen(a,2)=x(1*rowsx+i);
                buyshalfuureen(a,7)=x(3*rowsx+i);
                a=a+1;
            else
                sellshalfuureen(b,1)=x(2*rowsx+i);
                sellshalfuureen(b,2)=x(1*rowsx+i);
                sellshalfuureen(b,7)=x(3*rowsx+i);
                b=b+1;
            end
        elseif x(1*rowsx+i) <= (x(i,1)+starttimeday+2*halfhour)
            if x(5*rowsx+i)==1
                buyshalfuurtwee(c,1)=x(2*rowsx+i);
                buyshalfuurtwee(c,2)=x(1*rowsx+i);
                buyshalfuurtwee(c,7)=x(3*rowsx+i);
                c=c+1;
            else
                sellshalfuurtwee(d,1)=x(2*rowsx+i);
                sellshalfuurtwee(d,2)=x(1*rowsx+i);
                sellshalfuurtwee(d,7)=x(3*rowsx+i);
                d=d+1;
            end
        elseif x(1*rowsx+i) <= (x(i,1)+starttimeday+3*halfhour)
            if x(5*rowsx+i)==1
                buyshalfuur(drie(e,1)=x(2*rowsx+i);
                buyshalfuur(drie(e,2)=x(1*rowsx+i);
                buyshalfuur(drie(e,7)=x(3*rowsx+i);
                e=e+1;
            else
                sellshalfuur(drie(f,1)=x(2*rowsx+i);
                sellshalfuur(drie(f,2)=x(1*rowsx+i);
                sellshalfuur(drie(f,7)=x(3*rowsx+i);
                f=f+1;
            end
        elseif x(1*rowsx+i) <= (x(i,1)+starttimeday+4*halfhour)
            if x(5*rowsx+i)==1
                buyshalfuurvier(g,1)=x(2*rowsx+i);
                buyshalfuurvier(g,2)=x(1*rowsx+i);
                buyshalfuurvier(g,7)=x(3*rowsx+i);
                g=g+1;
else
    sellshelfuurvier(h,1)=x(2*rowsx+i);
    sellshelfuurvier(h,2)=x(1*rowsx+i);
    sellshelfuurvier(h,7)=x(3*rowsx+i);
    h=h+1;
end

elseif x(1*rowsx+i) <= (x(i,1)+starttimeday+5*halfhour)
    if x(5*rowsx+i)==1
        buyshelfuurr(v(1),1)=x(2*rowsx+i);
        buyshelfuurr(v(1,2)=x(1*rowsx+i);
        buyshelfuurr(v(1,7)=x(3*rowsx+i);
        v1=v1+1;
    else
        sellshelfuurr(v(2),1)=x(2*rowsx+i);
        sellshelfuurr(v(2,2)=x(1*rowsx+i);
        sellshelfuurr(v(2,7)=x(3*rowsx+i);
        v2=v2+1;
    end

elseif x(1*rowsx+i) <= (x(i,1)+starttimeday+6*halfhour)
    if x(5*rowsx+i)==1
        buyshelfuurr(s(1),1)=x(2*rowsx+i);
        buyshelfuurr(s(1,2)=x(1*rowsx+i);
        buyshelfuurr(s(1,7)=x(3*rowsx+i);
        s1=s1+1;
    else
        sellshelfuurr(s(2),1)=x(2*rowsx+i);
        sellshelfuurr(s(2,2)=x(1*rowsx+i);
        sellshelfuurr(s(2,7)=x(3*rowsx+i);
        s2=s2+1;
    end

elseif x(1*rowsx+i) <= (x(i,1)+starttimeday+7*halfhour)
    if x(5*rowsx+i)==1
        buyshelfuurr(t(1),1)=x(2*rowsx+i);
        buyshelfuurr(t(1,2)=x(1*rowsx+i);
        buyshelfuurr(t(1,7)=x(3*rowsx+i);
        t1=t1+1;
    else
        sellshelfuurr(t(2),1)=x(2*rowsx+i);
        sellshelfuurr(t(2,2)=x(1*rowsx+i);
        sellshelfuurr(t(2,7)=x(3*rowsx+i);
        t2=t2+1;
    end

else
    sellshelfuurt(t,1)=x(2*rowsx+i);
    sellshelfuurt(t,2)=x(1*rowsx+i);
    sellshelfuurt(t,7)=x(3*rowsx+i);
    t=t+1;
end

Appendix B.6
Appendix B.

```plaintext
sellshalfuurnegen(u,1)=x(2*rowsx+i);
sellshalfuurnegen(u,2)=x(1*rowsx+i);
sellshalfuurnegen(u,7)=x(3*rowsx+i);

u=u+1;
end

elseif x(1*rowsx+i) <= (x(i,1)+starttimeday+10*halfhour)
if x(5*rowsx+i)==1
buyshalfuurtien(v,1)=x(2*rowsx+i);
buyshalfuurtien(v,2)=x(1*rowsx+i);
buyshalfuurtien(v,7)=x(3*rowsx+i);
v=v+1;
else
sellshalfuurtien(w,1)=x(2*rowsx+i);
sellshalfuurtien(w,2)=x(1*rowsx+i);
sellshalfuurtien(w,7)=x(3*rowsx+i);
w=w+1;
end

end

i=i+1;
end

if size(buyshalfuureen) ~= 0

    grootte_1=size(buyshalfuureen);
aantal_waarden_1=grootte_1(1)-1;

    buyshalfuureen(1,3)=dagen(tellerdagen)+starttimeday;
    for t1=1:aantal_waarden_1
        buyshalfuureen((t1+1),3)=buyshalfuureen(t1,2);
t1=t1+1;
    end

    DateVector1=datevec(buyshalfuureen(:,2));
    DateVector1(:,6)=round(DateVector1(:,6));
    DateVector1(:,7)=DateVector1(:,4).*3600+DateVector1(:,5).*60+DateVector1(:,6);

    DateVector2=datevec(buyshalfuureen(:,3));
    DateVector2(:,6)=round(DateVector2(:,6));
    DateVector2(:,7)=DateVector2(:,4).*3600+DateVector2(:,5).*60+DateVector2(:,6);

    buyshalfuureen(:,4)=DateVector1(:,7)-DateVector2(:,7);
    sum_1=sum(buyshalfuureen(:,4));
    buyshalfuureen(:,5)=buyshalfuureen(:,4)/sum_1;
    buyshalfuureen(:,6)=buyshalfuureen(:,1).*buyshalfuureen(:,5);
end

if size(sellshalfuureen) ~= 0

    grootte_2=size(sellshalfuureen);
aantal_waarden_2=grootte_2(1)-1;

    sellshalfuureen(1,3)=dagen(tellerdagen)+starttimeday;
```

Appendix B.7
for t1=1:aantal_waarden_2
    sellshalfuureen((t2+1),3)=sellshalfuureen(t2,2);
    t2=t2+1;
end

DateVector3=datevec(sellshalfuureen(:,2));
DateVector3(:,6)=round(DateVector3(:,6));

DateVector3(:,7)=DateVector3(:,4).*3600+DateVector3(:,5).*60+DateVector3(:,6);

DateVector4=datevec(sellshalfuureen(:,3));
DateVector4(:,6)=round(DateVector4(:,6));

DateVector4(:,7)=DateVector4(:,4).*3600+DateVector4(:,5).*60+DateVector4(:,6);

sellshalfuureen(:,4)=DateVector3(:,7)-DateVector4(:,7);
sum_2=sum(sellshalfuureen(:,4));
sellshalfuureen(:,5)=sellshalfuureen(:,4)/sum_2;
sellshalfuureen(:,6)=sellshalfuureen(:,1).*sellshalfuureen(:,5);
end

if size(buyshalfuurtwee) ~= 0
    grootte_3=size(buyshalfuurtwee);
aantal_waarden_3=grootte_3(1)-1;

    buyshalfuurtwee(1,3)=buyshalfuuren((aantal_waarden_1+1),2);
    for t3=1:aantal_waarden_3
        buyshalfuurtwee((t3+1),3)=buyshalfuurtwee(t3,2);
        t3=t3+1;
    end

    DateVector5=datevec(buyshalfuurtwee(:,2));
    DateVector5(:,6)=round(DateVector5(:,6));

    DateVector5(:,7)=DateVector5(:,4).*3600+DateVector5(:,5).*60+DateVector5(:,6);

    DateVector6=datevec(buyshalfuurtwee(:,3));
    DateVector6(:,6)=round(DateVector6(:,6));

    DateVector6(:,7)=DateVector6(:,4).*3600+DateVector6(:,5).*60+DateVector6(:,6);

    buyshalfuurtwee(:,4)=DateVector5(:,7)-DateVector6(:,7);
    sum_3=sum(buyshalfuurtwee(:,4));
buyshalfuurtwee(:,5)=buyshalfuurtwee(:,4)/sum_3;
buyshalfuurtwee(:,6)=buyshalfuurtwee(:,1).*buyshalfuurtwee(:,5);
end

if size(sellshalfuurtwee) ~= 0
    grootte_4=size(sellshalfuurtwee);
aantal_waarden_4=grootte_4(1)-1;
sellshalfuurtwee(1,3)=sellshalfuureen((aantal_waarden_2+1),2);
for t4=1:aantal_waarden_4
    sellshalfuurtwee((t4+1),3)=sellshalfuurtwee(t4,2);
t4=t4+1;
end

DateVector7=datevec(sellshalfuurtwee(:,2));
DateVector7(:,6)=round(DateVector7(:,6));

DateVector7(:,7)=DateVector7(:,4).*3600+DateVector7(:,5).*60+DateVector7(:,6);

DateVector8=datevec(sellshalfuurtwee(:,3));
DateVector8(:,6)=round(DateVector8(:,6));

DateVector8(:,7)=DateVector8(:,4).*3600+DateVector8(:,5).*60+DateVector8(:,6);

sellshalfuurtwee(:,4)=DateVector7(:,7)-DateVector8(:,7);
sum_4=sum(sellshalfuurtwee(:,4));
sellshalfuurtwee(:,5)=sellshalfuurtwee(:,4)/sum_4;
sellshalfuurtwee(:,6)=sellshalfuurtwee(:,1).*sellshalfuurtwee(:,5);
end

if size(buyshalfuurdrie) ~= 0
    grootte_5=size(buyshalfuurdrie);
aantal_waarden_5=grootte_5(1)-1;

    buyshalfuurdrie(1,3)=buyshalfuurtwee((aantal_waarden_3+1),2);
    for t5=1:aantal_waarden_5
        buyshalfuurdrie((t5+1),3)=buyshalfuurdrie(t5,2);
t5=t5+1;
    end

    DateVector9=datevec(buyshalfuurdrie(:,2));
    DateVector9(:,6)=round(DateVector9(:,6));

    DateVector9(:,7)=DateVector9(:,4).*3600+DateVector9(:,5).*60+DateVector9(:,6);

    DateVector10=datevec(buyshalfuurdrie(:,3));
    DateVector10(:,6)=round(DateVector10(:,6));

    DateVector10(:,7)=DateVector10(:,4).*3600+DateVector10(:,5).*60+DateVector10(:,6);

    buyshalfuurdrie(:,4)=DateVector9(:,7)-DateVector10(:,7);
sum_5=sum(buyshalfuurdrie(:,4));
buyshalfuurdrie(:,5)=buyshalfuurdrie(:,4)/sum_5;
buyshalfuurdrie(:,6)=buyshalfuurdrie(:,1).*buyshalfuurdrie(:,5);
end

if size(sellshalfuurdrie) ~= 0
    grootte_6=size(sellshalfuurdrie);
aantal_waarden_6=grootte_6(1)-1;
sellshalfuurdrie(1,3)=sellshalfuurtwee((aantal_waarden_4+1),2);
for t6=1:aantal_waarden_6
    sellshalfuurdrie((t6+1),3)=sellshalfuurdrie(t6,2);
    t6=t6+1;
end

DateVector11=datevec(sellshalfuurdrie(:,2));
DateVector11(:,6)=round(DateVector11(:,6));

DateVector11(:,7)=DateVector11(:,4).*3600+DateVector11(:,5).*60+DateVector11(:,6);

DateVector12=datevec(sellshalfuurdrie(:,3));
DateVector12(:,6)=round(DateVector12(:,6));

DateVector12(:,7)=DateVector12(:,4).*3600+DateVector12(:,5).*60+DateVector12(:,6);

sellshalfuurdrie(:,4)=DateVector11(:,7)-DateVector12(:,7);
sum_6=sum(sellshalfuurdrie(:,4));
sellshalfuurdrie(:,5)=sellshalfuurdrie(:,4)/sum_6;
sellshalfuurdrie(:,6)=sellshalfuurdrie(:,1).*sellshalfuurdrie(:,5);
end

if size(buyshalfuurvier) ~= 0
    grootte_7=size(buyshalfuurvier);
aantal_waarden_7=grootte_7(1)-1;

    buyshalfuurvier(1,3)=buyshalfuurvier((aantal_waarden_5+1),2);
    for t7=1:aantal_waarden_7
        buyshalfuurvier((t7+1),3)=buyshalfuurvier(t7,2);
        t7=t7+1;
    end

    DateVector13=datevec(buyshalfuurvier(:,2));
    DateVector13(:,6)=round(DateVector13(:,6));

    DateVector13(:,7)=DateVector13(:,4).*3600+DateVector13(:,5).*60+DateVector13(:,6);

    DateVector14=datevec(buyshalfuurvier(:,3));
    DateVector14(:,6)=round(DateVector14(:,6));

    DateVector14(:,7)=DateVector14(:,4).*3600+DateVector14(:,5).*60+DateVector14(:,6);

    buyshalfuurvier(:,4)=DateVector13(:,7)-DateVector14(:,7);
    sum_7=sum(buyshalfuurvier(:,4));
    buyshalfuurvier(:,5)=buyshalfuurvier(:,4)/sum_7;
    buyshalfuurvier(:,6)=buyshalfuurvier(:,1).*buyshalfuurvier(:,5);
end

if size(sellshalfuurvier) ~= 0
    grootte_8=size(sellshalfuurvier);
aantal_waarden_8=grootte_8(1)-1;

Appendix B.10
sellshalfuurvier(1,3)=sellshalfuurdrie((aantal_waarden_6+1),2);
for t8=1:aantal_waarden_8
  sellshalfuurvier((t8+1),3)=sellshalfuurvier(t8,2);
t8=t8+1;
end

DateVector15=datevec(sellshalfuurvier(:,2));
DateVector15(:,6)=round(DateVector15(:,6));

DateVector15(:,7)=DateVector15(:,4).*3600+DateVector15(:,5).*60+DateVector15(:,6);

DateVector16=datevec(sellshalfuurvier(:,3));
DateVector16(:,6)=round(DateVector16(:,6));

DateVector16(:,7)=DateVector16(:,4).*3600+DateVector16(:,5).*60+DateVector16(:,6);

sellshalfuurvier(:,4)=DateVector15(:,7)-DateVector16(:,7);
sum_8=sum(sellshalfuurvier(:,4));
sellshalfuurvier(:,5)=sellshalfuurvier(:,4)/sum_8;
sellshalfuurvier(:,6)=sellshalfuurvier(:,1).*sellshalfuurvier(:,5);
end

if size(buyshalfuurvijf) ~= 0
  grootte_9=size(buyshalfuurvijf);
aantal_waarden_9=grootte_9(1)-1;

  buyshalfuurvijf(1,3)=buyshalfuurvier((aantal_waarden_7+1),2);
  for t9=1:aantal_waarden_9
    buyshalfuurvijf((t9+1),3)=buyshalfuurvijf(t9,2);
t9=t9+1;
  end

  DateVector17=datevec(buyshalfuurvijf(:,2));
  DateVector17(:,6)=round(DateVector17(:,6));

  DateVector17(:,7)=DateVector17(:,4).*3600+DateVector17(:,5).*60+DateVector17(:,6);

  DateVector18=datevec(buyshalfuurvijf(:,3));
  DateVector18(:,6)=round(DateVector18(:,6));

  DateVector18(:,7)=DateVector18(:,4).*3600+DateVector18(:,5).*60+DateVector18(:,6);

  buyshalfuurvijf(:,4)=DateVector17(:,7)-DateVector18(:,7);
sum_9=sum(buyshalfuurvijf(:,4));
buyshalfuurvijf(:,5)=buyshalfuurvijf(:,4)/sum_9;
buyshalfuurvijf(:,6)=buyshalfuurvijf(:,1).*buyshalfuurvijf(:,5);
end

if size(sellshalfuurvijf) ~= 0
  grootte_10=size(sellshalfuurvijf);

aantal_waarden_10=grootte_10(1)-1;

sellshalfuurvijf(1,3)=sellshalfuurvier((aantal_waarden_8+1),2);
for t10=1:aantal_waarden_10
  sellshalfuurvijf((t10+1),3)=sellshalfuurvijf(t10,2);
t10=t10+1;
end

DateVector19=datevec(sellshalfuurvijf(:,2));
DateVector19(:,6)=round(DateVector19(:,6));
DateVector19(:,7)=DateVector19(:,4).*3600+DateVector19(:,5).*60+DateVector19(:,6);

sellshalfuurvijf(:,4)=DateVector19(:,7)-DateVector20(:,7);
sum_10=sum(sellshalfuurvijf(:,4));
sellshalfuurvijf(:,5)=sellshalfuurvijf(:,4)/sum_10;
sellshalfuurvijf(:,6)=sellshalfuurvijf(:,1).*sellshalfuurvijf(:,5);
end

if size(buyshalfuurzes) ~= 0
  grootte_11=size(buyshalfuurzes);
aantal_waarden_11=grootte_11(1)-1;

  buyshalfuurzes(1,3)=buyshalfuurvijf((aantal_waarden_9+1),2);
  for t11=1:aantal_waarden_11
    buyshalfuurzes((t11+1),3)=buyshalfuurzes(t11,2);
t11=t11+1;
  end

DateVector21=datevec(buyshalfuurzes(:,2));
DateVector21(:,6)=round(DateVector21(:,6));

DateVector21(:,7)=DateVector21(:,4).*3600+DateVector21(:,5).*60+DateVector21(:,6);

DateVector22=datevec(buyshalfuurzes(:,3));
DateVector22(:,6)=round(DateVector22(:,6));

DateVector22(:,7)=DateVector22(:,4).*3600+DateVector22(:,5).*60+DateVector22(:,6);

buyshalfuurzes(:,4)=DateVector21(:,7)-DateVector22(:,7);
sum_11=sum(buyshalfuurzes(:,4));
buyshalfuurzes(:,5)=buyshalfuurzes(:,4)/sum_11;
buyshalfuurzes(:,6)=buyshalfuurzes(:,1).*buyshalfuurzes(:,5);
end

if size(sellshalfuurzes) ~= 0
  grootte_12=size(sellshalfuurzes);
aantal_waarden_12=geen_taal_waarden_12(1)-1;

sellshalfuurzes(1,3)=sellshalfuurvijf((aantal_waarden_10+1),2);
for t12=1:aantal_waarden_12
    sellshalfuurzes((t12+1),3)=sellshalfuurzes(t12,2);
t12=t12+1;
end

DateVector23=datevec(sellshalfuurzes(:,2));
DateVector23(:,6)=round(DateVector23(:,6));

DateVector23(:,7)=DateVector23(:,4).*3600+DateVector23(:,5).*60+DateVector23(:,6);

DateVector24=datevec(sellshalfuurzes(:,3));
DateVector24(:,6)=round(DateVector24(:,6));

DateVector24(:,7)=DateVector24(:,4).*3600+DateVector24(:,5).*60+DateVector24(:,6);

sellshalfuurzes(:,4)=DateVector23(:,7)-DateVector24(:,7);
sum_12=sum(sellshalfuurzes(:,4));
sellshalfuurzes(:,5)=sellshalfuurzes(:,4)/sum_12;
sellshalfuurzes(:,6)=sellshalfuurzes(:,1).*sellshalfuurzes(:,5);
end

if size(buyshalfuurzeven) ~= 0
    grootte_13=size(buyshalfuurzeven);
aantal_waarden_13=grootte_13(1)-1;

buyshalfuurzeven(1,3)=buyshalfuurzes((aantal_waarden_11+1),2);
for t13=1:aantal_waarden_13
    buyshalfuurzeven((t13+1),3)=buyshalfuurzeven(t13,2);
t13=t13+1;
end

DateVector25=datevec(buyshalfuurzeven(:,2));
DateVector25(:,6)=round(DateVector25(:,6));

DateVector25(:,7)=DateVector25(:,4).*3600+DateVector25(:,5).*60+DateVector25(:,6);

DateVector26=datevec(buyshalfuurzeven(:,3));
DateVector26(:,6)=round(DateVector26(:,6));

DateVector26(:,7)=DateVector26(:,4).*3600+DateVector26(:,5).*60+DateVector26(:,6);

buyshalfuurzeven(:,4)=DateVector25(:,7)-DateVector26(:,7);
sum_13=sum(buyshalfuurzeven(:,4));
buyshalfuurzeven(:,5)=buyshalfuurzeven(:,4)/sum_13;
buyshalfuurzeven(:,6)=buyshalfuurzeven(:,1).*buyshalfuurzeven(:,5);
end

if size(sellshalfuurzeven) ~= 0
    grootte_14=size(sellshalfuurzeven);
aantal_waarden_14=grootte_14(1)-1;

sellshalfuurzeven(1,3)=sellshalfuurzes((aantal_waarden_12+1),2);
for t14=1:aantal_waarden_14
    sellshalfuurzeven((t14+1),3)=sellshalfuurzeven(t14,2);
    t14=t14+1;
end

DateVector27=datevec(sellshalfuurzeven(:,2));
DateVector27(:,6)=round(DateVector27(:,6));

DateVector27(:,7)=DateVector27(:,4).*3600+DateVector27(:,5).*60+DateVector27(:,6);

DateVector28=datevec(sellshalfuurzeven(:,3));
DateVector28(:,6)=round(DateVector28(:,6));

DateVector28(:,7)=DateVector28(:,4).*3600+DateVector28(:,5).*60+DateVector28(:,6);

sellshalfuurzeven(:,4)=DateVector27(:,7)-DateVector28(:,7);
sum_14=sum(sellshalfuurzeven(:,4));
sellshalfuurzeven(:,5)=sellshalfuurzeven(:,4)/sum_14;
sellshalfuurzeven(:,6)=sellshalfuurzeven(:,1).*sellshalfuurzeven(:,5);

end

if size(buyshalfuuracht) ~= 0

    grootte_15=size(buyshalfuuracht);
    aantal_waarden_15=grootte_15(1)-1;

    buyshalfuuracht(1,3)=buyshalfuurzeven((aantal_waarden_13+1),2);
    for t15=1:aantal_waarden_15
        buyshalfuuracht((t15+1),3)=buyshalfuuracht(t15,2);
        t15=t15+1;
    end

    DateVector29=datevec(buyshalfuuracht(:,2));
    DateVector29(:,6)=round(DateVector29(:,6));

    DateVector29(:,7)=DateVector29(:,4).*3600+DateVector29(:,5).*60+DateVector29(:,6);

    DateVector30=datevec(buyshalfuuracht(:,3));
    DateVector30(:,6)=round(DateVector30(:,6));

    DateVector30(:,7)=DateVector30(:,4).*3600+DateVector30(:,5).*60+DateVector30(:,6);

    buyshalfuuracht(:,4)=DateVector29(:,7)-DateVector30(:,7);
    sum_15=sum(buyshalfuuracht(:,4));
    buyshalfuuracht(:,5)=buyshalfuuracht(:,4)/sum_15;
    buyshalfuuracht(:,6)=buyshalfuuracht(:,1).*buyshalfuuracht(:,5);
end

if size(sellshalfuuracht) ~= 0
grootte_16=size(sellshalfuuracht);
aantal_waarden_16=grootte_16(1)-1;

sellshalfuuracht(1,3)=sellshalfuurzeven((aantal_waarden_14+1),2);
for t16=1:aantal_waarden_16
    sellshalfuuracht((t16+1),3)=sellshalfuuracht(t16,2);
t16=t16+1;
end

DateVector31=datevec(sellshalfuuracht(:,2));
DateVector31(:,6)=round(DateVector31(:,6));

DateVector31(:,7)=DateVector31(:,4).*3600+DateVector31(:,5).*60+DateVector31(:,6);

DateVector32=datevec(sellshalfuuracht(:,3));
DateVector32(:,6)=round(DateVector32(:,6));

DateVector32(:,7)=DateVector32(:,4).*3600+DateVector32(:,5).*60+DateVector32(:,6);

sellshalfuuracht(:,4)=DateVector31(:,7)-DateVector32(:,7);
sum_16=sum(sellshalfuuracht(:,4));
sellshalfuuracht(:,5)=sellshalfuuracht(:,4)/sum_16;
sellshalfuuracht(:,6)=sellshalfuuracht(:,1).*sellshalfuuracht(:,5);
end

if size(buyshalfuurnegen) ~= 0
    grootte_17=size(buyshalfuurnegen);
aantal_waarden_17=grootte_17(1)-1;

    buyshalfuurnegen(1,3)=buyshalfuuracht((aantal_waarden_15+1),2);
    for t17=1:aantal_waarden_17
        buyshalfuurnegen((t17+1),3)=buyshalfuurnegen(t17,2);
t17=t17+1;
    end

    DateVector33=datevec(buyshalfuurnegen(:,2));
    DateVector33(:,6)=round(DateVector33(:,6));

    DateVector33(:,7)=DateVector33(:,4).*3600+DateVector33(:,5).*60+DateVector33(:,6);

    DateVector34=datevec(buyshalfuurnegen(:,3));
    DateVector34(:,6)=round(DateVector34(:,6));

    DateVector34(:,7)=DateVector34(:,4).*3600+DateVector34(:,5).*60+DateVector34(:,6);

    buyshalfuurnegen(:,4)=DateVector33(:,7)-DateVector34(:,7);
    sum_17=sum(buyshalfuurnegen(:,4));
    buyshalfuurnegen(:,5)=buyshalfuurnegen(:,4)/sum_17;
    buyshalfuurnegen(:,6)=buyshalfuurnegen(:,1).*buyshalfuurnegen(:,5);
end

if size(sellshalfuurnegen) ~= 0
grootte_18 = size(sellshalfuurnegen);
aantal_waarden_18 = grootte_18(1) - 1;

sellshalfuurnegen(1,3) = sellshalfuuracht((aantal_waarden_16 + 1), 2);
for t18 = 1:aantal_waarden_18
    sellshalfuurnegen((t18 + 1), 3) = sellshalfuurnegen(t18, 2);
t18 = t18 + 1;
end

DateVector35 = datevec(sellshalfuurnegen(:, 2));
DateVector35(:, 6) = round(DateVector35(:, 6));

DateVector35(:, 7) = DateVector35(:, 4) * 3600 + DateVector35(:, 5) * 60 + DateVector35(:, 6);

DateVector36 = datevec(sellshalfuurnegen(:, 3));
DateVector36(:, 6) = round(DateVector36(:, 6));

DateVector36(:, 7) = DateVector36(:, 4) * 3600 + DateVector36(:, 5) * 60 + DateVector36(:, 6);

sellshalfuurnegen(:, 4) = DateVector35(:, 7) - DateVector36(:, 7);
sum_18 = sum(sellshalfuurnegen(:, 4));
sellshalfuurnegen(:, 5) = sellshalfuurnegen(:, 4) / sum_18;
sellshalfuurnegen(:, 6) = sellshalfuurnegen(:, 1) .* sellshalfuurnegen(:, 5);
end

if size(buyshalfuurtien) ~= 0
    grootte_19 = size(buyshalfuurtien);
aantal_waarden_19 = grootte_19(1) - 1;

    buyshalfuurtien(1,3) = buyshalfuuracht((aantal_waarden_17 + 1), 2);
    for t19 = 1:aantal_waarden_19
        buyshalfuurtien((t19 + 1), 3) = buyshalfuurtien(t19, 2);
t19 = t19 + 1;
end

    DateVector37 = datevec(buyshalfuurtien(:, 2));
    DateVector37(:, 6) = round(DateVector37(:, 6));

    DateVector37(:, 7) = DateVector37(:, 4) * 3600 + DateVector37(:, 5) * 60 + DateVector37(:, 6);

    DateVector38 = datevec(buyshalfuurtien(:, 3));
    DateVector38(:, 6) = round(DateVector38(:, 6));

    DateVector38(:, 7) = DateVector38(:, 4) * 3600 + DateVector38(:, 5) * 60 + DateVector38(:, 6);

    buyshalfuurtien(:, 4) = DateVector37(:, 7) - DateVector38(:, 7);
    sum_19 = sum(buyshalfuurtien(:, 4));
    buyshalfuurtien(:, 5) = buyshalfuurtien(:, 4) / sum_19;
    buyshalfuurtien(:, 6) = buyshalfuurtien(:, 1) .* buyshalfuurtien(:, 5);
end

Appendix B.16
if size(sellshalfuurtien) ~= 0

grootte_20=size(sellshalfuurtien);
aantal_waarden_20=grootte_20(1)-1;

sellshalfuurtien(1,3)=sellshalfuurnegen((aantal_waarden_18+1),2);
for t20=1:aantal_waarden_20
    sellshalfuurtien((t20+1),3)=sellshalfuurtien(t20,2);
    t20=t20+1;
end

DateVector39=datevec(sellshalfuurtien(:,2));
DateVector39(:,6)=round(DateVector39(:,6));

DateVector39(:,7)=DateVector39(:,4).*3600+DateVector39(:,5).*60+DateVector39(:,6);

DateVector40=datevec(sellshalfuurtien(:,3));
DateVector40(:,6)=round(DateVector40(:,6));

DateVector40(:,7)=DateVector40(:,4).*3600+DateVector40(:,5).*60+DateVector40(:,6);

sellshalfuurtien(:,4)=DateVector39(:,7)-DateVector40(:,7);
sum_20=sum(sellshalfuurtien(:,4));
sellshalfuurtien(:,5)=sellshalfuurtien(:,4)/sum_20;
sellshalfuurtien(:,6)=sellshalfuurtien(:,1).*sellshalfuurtien(:,5);
end

y(aa,1)=dagen(tellerdagen);
y(aa,2)=starttimeday;
y(aa,3)=starttimeday+1*halfhour;
y(aa,4)=nanmean(buyshalfuureen(:,1));
y(aa,5)=nanmean(sellshalfuureen(:,1));
y(aa,7)=buyshalfuureen(a-1,1);
y(aa,8)=sellshalfuureen(b-1,1);
y(aa,10)=max(buyshalfuureen(:,1));
y(aa,11)=min(sellshalfuureen(:,1));
y(aa,13)=sum(buyshalfuureen(:,6));
y(aa,14)=sum(sellshalfuureen(:,6));
y(aa,16)=sum(buyshalfuureen(:,7))+sum(sellshalfuureen(:,7));
y(aa,17)=((sum(buyshalfuureen(:,1))+sum(sellshalfuureen(:,1)))/(aantal_waarden_1+aantal_waarden_2+2));
y(aa,20)=(aantal_waarden_1+aantal_waarden_2+2);

aa=aa+1;
y(aa,1)=dagen(tellerdagen);
y(aa,2)=starttimeday+1*halfhour;
y(aa,3)=starttimeday+2*halfhour;
y(aa,4)=nanmean(buyshalfuurtwee(:,1));
y(aa,5)=nanmean(sellshalfuurtwee(:,1));
y(aa,7)=buyshalfuurtwee(c-1,1);
y(aa,8)=sellshalfuurtwee(d-1,1);
y(aa,10)=max(buyshalfuurtwee(:,1));
y(aa,11)=min(sellshalfuurtwee(:,1));
y(aa,13)=sum(buyshalfuurtwee(:,6));
y(aa,14)=sum(sellshalfuurtwee(:,6));
y(aa,16)=sum(buyshalfuurtwee(:,7))+sum(sellshalfuurtwee(:,7));
\[ y(aa,17) = \frac{\text{sum(buyshalfuurtwee(:,1))} + \text{sum(sellshalfuurtwee(:,1))}}{\text{aantal_waarden}_3 + \text{aantal_waarden}_4 + 2}; \]
\[ y(aa,20) = (\text{aantal_waarden}_3 + \text{aantal_waarden}_4 + 2); \]
\[ aa = aa + 1; \]

\[ y(aa,1) = \text{dagen(tellerdagen)}; \]
\[ y(aa,2) = \text{starttimeday} + 2 \times \text{halfhour}; \]
\[ y(aa,3) = \text{starttimeday} + 3 \times \text{halfhour}; \]
\[ y(aa,4) = \text{nanmean(buyshalfuurdrie(:,1))}; \]
\[ y(aa,5) = \text{nanmean(sellshalfuurdrie(:,1))}; \]
\[ y(aa,7) = \text{buyshalfuurdrie}(e-1,1); \]
\[ y(aa,8) = \text{sellshalfuurdrie}(f-1,1); \]
\[ y(aa,10) = \text{max(buyshalfuurdrie(:,1))}; \]
\[ y(aa,11) = \text{min(sellshalfuurdrie(:,1))}; \]
\[ y(aa,13) = \text{sum(buyshalfuurdrie(:,6))}; \]
\[ y(aa,14) = \text{sum(sellshalfuurdrie(:,6))}; \]
\[ y(aa,16) = \text{sum(buyshalfuurdrie(:,7))} + \text{sum(sellshalfuurdrie(:,7))}; \]
\[ y(aa,17) = \frac{\text{sum(buyshalfuurdrie(:,1))} + \text{sum(sellshalfuurdrie(:,1))}}{\text{aantal_waarden}_5 + \text{aantal_waarden}_6 + 2}; \]
\[ y(aa,20) = (\text{aantal_waarden}_5 + \text{aantal_waarden}_6 + 2); \]
\[ aa = aa + 1; \]

\[ y(aa,1) = \text{dagen(tellerdagen)}; \]
\[ y(aa,2) = \text{starttimeday} + 3 \times \text{halfhour}; \]
\[ y(aa,3) = \text{starttimeday} + 4 \times \text{halfhour}; \]
\[ y(aa,4) = \text{nanmean(buyshalfuurvier(:,1))}; \]
\[ y(aa,5) = \text{nanmean(sellshalfuurvier(:,1))}; \]
\[ y(aa,7) = \text{buyshalfuurvier}(g-1,1); \]
\[ y(aa,8) = \text{sellshalfuurvier}(h-1,1); \]
\[ y(aa,10) = \text{max(buyshalfuurvier(:,1))}; \]
\[ y(aa,11) = \text{min(sellshalfuurvier(:,1))}; \]
\[ y(aa,13) = \text{sum(buyshalfuurvier(:,6))}; \]
\[ y(aa,14) = \text{sum(sellshalfuurvier(:,6))}; \]
\[ y(aa,16) = \text{sum(buyshalfuurvier(:,7))} + \text{sum(sellshalfuurvier(:,7))}; \]
\[ y(aa,17) = \frac{\text{sum(buyshalfuurvier(:,1))} + \text{sum(sellshalfuurvier(:,1))}}{\text{aantal_waarden}_7 + \text{aantal_waarden}_8 + 2}; \]
\[ y(aa,20) = (\text{aantal_waarden}_7 + \text{aantal_waarden}_8 + 2); \]
\[ aa = aa + 1; \]

\[ y(aa,1) = \text{dagen(tellerdagen)}; \]
\[ y(aa,2) = \text{starttimeday} + 4 \times \text{halfhour}; \]
\[ y(aa,3) = \text{starttimeday} + 5 \times \text{halfhour}; \]
\[ y(aa,4) = \text{nanmean(buyshalfuurvijf(:,1))}; \]
\[ y(aa,5) = \text{nanmean(sellshalfuurvijf(:,1))}; \]
\[ y(aa,7) = \text{buyshalfuurvijf}(l-1,1); \]
\[ y(aa,8) = \text{sellshalfuurvijf}(m-1,1); \]
\[ y(aa,10) = \text{max(buyshalfuurvijf(:,1))}; \]
\[ y(aa,11) = \text{min(sellshalfuurvijf(:,1))}; \]
\[ y(aa,13) = \text{sum(buyshalfuurvijf(:,6))}; \]
\[ y(aa,14) = \text{sum(sellshalfuurvijf(:,6))}; \]
\[ y(aa,16) = \text{sum(buyshalfuurvijf(:,7))} + \text{sum(sellshalfuurvijf(:,7))}; \]
\[ y(aa,17) = \frac{\text{sum(buyshalfuurvijf(:,1))} + \text{sum(sellshalfuurvijf(:,1))}}{\text{aantal_waarden}_9 + \text{aantal_waarden}_10 + 2}; \]
\[ y(aa,20) = (\text{aantal_waarden}_9 + \text{aantal_waarden}_10 + 2); \]
\[ aa = aa + 1; \]

\[ y(aa,1) = \text{dagen(tellerdagen)}; \]
\[ y(aa,2) = \text{starttimeday} + 5 \times \text{halfhour}; \]
\[ y(aa,3) = \text{starttimeday} + 6 \times \text{halfhour}; \]
\[ \text{if size(buyshalfuurzes)==0} \]
\[ y(aa,4) = \text{NaN}; \]

Appendix B.18
else
    y(aa,4)=nanmean(buyshalfuurzes(:,1));
end

if size(sellshalfuurzes)==0
    y(aa,5) = NaN;
else
    y(aa,5)=nanmean(sellshalfuurzes(:,1));
end
if size(buyshalfuurzes)==0
    y(aa,7) = NaN;
else
    y(aa,7)=buyshalfuurzes(n-1,1);
end

if size(sellshalfuurzes)==0
    y(aa,8) = NaN;
else
    y(aa,8)=sellshalfuurzes(o-1,1);
end
if size(buyshalfuurzes)==0
    y(aa,10) = NaN;
else
    y(aa,10)=max(buyshalfuurzes(:,1));
end

if size(sellshalfuurzes)==0
    y(aa,11) = NaN;
else
    y(aa,11)=min(sellshalfuurzes(:,1));
end
if size(buyshalfuurzes)==0
    y(aa,13) = NaN;
else
    y(aa,13)=sum(buyshalfuurzes(:,6));
end

if size(sellshalfuurzes)==0
    y(aa,14) = NaN;
else
    y(aa,14)=sum(sellshalfuurzes(:,6));
end
if size(sellshalfuurzes)==0
    y(aa,16) = NaN;
else
    y(aa,16)=sum(buyshalfuurzes(:,7))+sum(sellshalfuurzes(:,7));
end
if size(sellshalfuurzes)==0
    y(aa,17) = NaN;
else
    y(aa,17)=((sum(buyshalfuurzes(:,1))+sum(sellshalfuurzes(:,1)))/(aantal_waarden_11+aantal_waarden_12+2));
end
if size(sellshalfuurzes)==0
    y(aa,20) = NaN;
else
    y(aa,20)=(aantal_waarden_11+aantal_waarden_12+2);
end
aa=aa+1;
y(aa,1)=dagen(tellerdagen);
y(aa,2)=starttimeday+6*halfhour;
y(aa,3)=starttimeday+7*halfhour;
if size(buyshalfuurzeven)==0
  y(aa,4) = NaN;
else
  y(aa,4)=nanmean(buyshalfuurzeven(:,1));
end
if size(sellshalfuurzeven)==0
  y(aa,5) = NaN;
else
  y(aa,5)=nanmean(sellshalfuurzeven(:,1));
end
if size(buyshalfuurzeven)==0
  y(aa,7) = NaN;
else
  y(aa,7)=buyshalfuurzeven(p-1,1);
end
if size(sellshalfuurzeven)==0
  y(aa,8) = NaN;
else
  y(aa,8)=sellshalfuurzeven(q-1,1);
end
if size(buyshalfuurzeven)==0
  y(aa,10) = NaN;
else
  y(aa,10)=max(buyshalfuurzeven(:,1));
end
if size(sellshalfuurzeven)==0
  y(aa,11) = NaN;
else
  y(aa,11)=min(sellshalfuurzeven(:,1));
end
if size(buyshalfuurzeven)==0
  y(aa,13) = NaN;
else
  y(aa,13)=sum(buyshalfuurzeven(:,6));
end
if size(sellshalfuurzeven)==0
  y(aa,14) = NaN;
else
  y(aa,14)=sum(sellshalfuurzeven(:,6));
end
if size(sellshalfuurzeven)==0
  y(aa,16) = NaN;
else
  y(aa,16)=sum(buyshalfuurzeven(:,7))+sum(sellshalfuurzeven(:,7));
end
if size(sellshalfuurzeven)==0
  y(aa,17) = NaN;
else
  y(aa,17)=((sum(buyshalfuurzeven(:,1))+sum(sellshalfuurzeven(:,1)))/aantal_waarden_13+aantal_waarden_14+2));
end
if size(sellshalfuurzeven)==0
    y(aa,20) = NaN;
else
    y(aa,20)=(aantal_waarden_13+aantal_waarden_14+2);
end
aa=aa+1;

y(aa,1)=dagen(tellerdagen);
y(aa,2)=starttimeday+7*halfhour;
y(aa,3)=starttimeday+8*halfhour;
if size(buyshalfuuracht)==0
    y(aa,4) = NaN;
else
    y(aa,4)=nanmean(buyshalfuuracht(:,1));
end

if size(sellshalfuuracht)==0
    y(aa,5) = NaN;
else
    y(aa,5)=nanmean(sellshalfuuracht(:,1));
end
if size(buyshalfuuracht)==0
    y(aa,7) = NaN;
else
    y(aa,7)=buyshalfuuracht(r-1,1);
end

if size(sellshalfuuracht)==0
    y(aa,8) = NaN;
else
    y(aa,8)=sellshalfuuracht(s-1,1);
end
if size(buyshalfuuracht)==0
    y(aa,10) = NaN;
else
    y(aa,10)=max(buyshalfuuracht(:,1));
end

if size(sellshalfuuracht)==0
    y(aa,11) = NaN;
else
    y(aa,11)=min(sellshalfuuracht(:,1));
end
if size(buyshalfuuracht)==0
    y(aa,13) = NaN;
else
    y(aa,13)=sum(buyshalfuuracht(:,6));
end

if size(sellshalfuuracht)==0
    y(aa,14) = NaN;
else
    y(aa,14)=sum(sellshalfuuracht(:,6));
end
if size(sellshalfuuracht)==0
    y(aa,16) = NaN;
else
    y(aa,16)=sum(buyshalfuuracht(:,7))+sum(sellshalfuuracht(:,7));
end
if size(sellshalfuuracht)==0

y(aa,17) = NaN;

else
    y(aa,17) = ((sum(buyshalfuuracht(:,1)) + sum(sellshalfuuracht(:,1))) / (aantal_waarden_15 + aantal_waarden_16 + 2));
end

if size(sellshalfuuracht) == 0
    y(aa,20) = NaN;
else
    y(aa,20) = (aantal_waarden_15 + aantal_waarden_16 + 2);
end

aa = aa + 1;

y(aa,1) = dagen(tellerdagen);
y(aa,2) = starttimeday + 8 * halfhour;
y(aa,3) = starttimeday + 9 * halfhour;
if size(buyshalfuurnegen) == 0
    y(aa,4) = NaN;
else
    y(aa,4) = nanmean(buyshalfuurnegen(:,1));
end

if size(sellshalfuurnegen) == 0
    y(aa,5) = NaN;
else
    y(aa,5) = nanmean(sellshalfuurnegen(:,1));
end

if size(buyshalfuurnegen) == 0
    y(aa,7) = NaN;
else
    y(aa,7) = buyshalfuurnegen(t-1,1);
end

if size(sellshalfuurnegen) == 0
    y(aa,8) = NaN;
else
    y(aa,8) = sellshalfuurnegen(u-1,1);
end

if size(buyshalfuurzes) == 0
    y(aa,10) = NaN;
else
    y(aa,10) = max(buyshalfuurzes(:,1));
end

if size(sellshalfuurnegen) == 0
    y(aa,11) = NaN;
else
    y(aa,11) = min(sellshalfuurnegen(:,1));
end

if size(buyshalfuurnegen) == 0
    y(aa,13) = NaN;
else
    y(aa,13) = sum(buyshalfuurnegen(:,6));
end

if size(sellshalfuurnegen) == 0
    y(aa,14) = NaN;
else
    y(aa,14) = sum(sellshalfuurnegen(:,6));
end
if size(sellshalfuurnegen)==0
    y(aa,16) = NaN;
else
    y(aa,16)=sum(buyshalfuurnegen(:,7))+sum(sellshalfuurnegen(:,7));
end
if size(sellshalfuurnegen)==0
    y(aa,17) = NaN;
else
    y(aa,17)=((sum(buyshalfuurnegen(:,1))+sum(sellshalfuurnegen(:,1)))/(aantal_waarden_17+aantal_waarden_18+2));
end
if size(sellshalfuurnegen)==0
    y(aa,20) = NaN;
else
    y(aa,20)=(aantal_waarden_17+aantal_waarden_18+2);
end
aa=aa+1;

y(aa,1)=dagen(tellerdagen);
y(aa,2)=starttimeday+9*halfhour;
y(aa,3)=starttimeday+10*halfhour;
if size(buyshalfuurtien)==0
    y(aa,4) = NaN;
else
    y(aa,4)=nanmean(buyshalfuurtien(:,1));
end
if size(sellshalfuurtien)==0
    y(aa,5) = NaN;
else
    y(aa,5)=nanmean(sellshalfuurtien(:,1));
end
if size(buyshalfuurtien)==0
    y(aa,7) = NaN;
else
    y(aa,7)=buyshalfuurtien(v-1,1);
end
if size(sellshalfuurtien)==0
    y(aa,8) = NaN;
else
    y(aa,8)=sellshalfuurtien(w-1,1);
end
if size(buyshalfuurtien)==0
    y(aa,10) = NaN;
else
    y(aa,10)=max(buyshalfuurtien(:,1));
end
if size(sellshalfuurtien)==0
    y(aa,11) = NaN;
else
    y(aa,11)=min(sellshalfuurtien(:,1));
end
if size(buyshalfuurtien)==0
    y(aa,13) = NaN;
else
    y(aa,13)=sum(buyshalfuurtien(:,6));
end
if size(sellshalffuurten)==0
  y(aa,14) = NaN;
else
  y(aa,14)=sum(sellshalffuurten(:,6));
end
if size(sellshalffuurten)==0
  y(aa,16) = NaN;
else
  y(aa,16)=sum(buyshalffuurten(:,7))+sum(sellshalffuurten(:,7));
end
if size(sellshalffuurten)==0
  y(aa,17) = NaN;
else
  y(aa,17)=((sum(buyshalffuurten(:,1))+sum(sellshalffuurten(:,1)))/(aantal_wa
arden_19+aantal_waarden_20+2));
end
if size(sellshalffuurten)==0
  y(aa,20) = NaN;
else
  y(aa,20)=(aantal_waarden_19+aantal_waarden_20+2);
end
aa=aa+1;

a=1;
b=1;
c=1;
d=1;
e=1;
f=1;
g=1;
h=1;
l=1;
m=1;
n=1;
o=1;
p=1;
q=1;
r=1;
s=1;
t=1;
u=1;
v=1;
w=1;

t1=1;
t2=1;
t3=1;
t4=1;
t5=1;
t6=1;
t7=1;
t8=1;
t9=1;
t10=1;
t11=1;
t12=1;
t13=1;
t14=1;
t15=1;
t16=1;
t17=1;
t18=1;
t19=1;
t20=1;

buyshalfuureen=[];
sellshalfuureen=[];
buyshalfuurtwee=[];
sellshalfuurtwee=[];
buyshalfuurdrie=[];
sellshalfuurdrie=[];
buyshalfuurvier=[];
sellshalfuurvier=[];
buyshalfuurvijf=[];
sellshalfuurvijf=[];
buyshalfuurzes=[];
sellshalfuurzes=[];
buyshalfuurzeven=[];
sellshalfuurzeven=[];
buyshalfuuracht=[];
sellshalfuuracht=[];
buyshalfuurnegen=[];
sellshalfuurnegen=[];
buyshalfuurtien=[];
sellshalfuurtien=[];

DateVector1=[];
DateVector2=[];
DateVector3=[];
DateVector4=[];
DateVector5=[];
DateVector6=[];
DateVector7=[];
DateVector8=[];
DateVector9=[];
DateVector10=[];
DateVector11=[];
DateVector12=[];
DateVector13=[];
DateVector14=[];
DateVector15=[];
DateVector16=[];
DateVector17=[];
DateVector18=[];
DateVector19=[];
DateVector20=[];
DateVector21=[];
DateVector22=[];
DateVector23=[];
DateVector24=[];
DateVector25=[];
DateVector26=[];
DateVector27=[];
DateVector28=[];
DateVector29=[];
DateVector30=[];
DateVector31=[];
DateVector32=[];
DateVector33=[];
Appendix B.

DateVector34=[];
DateVector35=[];
DateVector36=[];
DateVector37=[];
DateVector38=[];
DateVector39=[];
DateVector40=[];

tellerdagen=tellerdagen+1;
end

y(:,6)=y(:,4)-y(:,5);
y(:,9)=y(:,7)-y(:,8);
y(:,12)=y(:,10)-y(:,11);
y(:,15)=y(:,13)-y(:,14);
y(:,18)=y(:,16).^(-1);
y(:,19)=y(:,17).^(-1);
end
Algorithm 2:

spreads_vol_prij_eur_rub_tod_2 = verwijdernegatievespreads(spreads_vol_prij_eur_rub_tod);

Description:
The b/a spreads that have a negative value get a zero value.

```matlab
function [ y ] = verwijdernegatievespreads( x )
groottex = size(x);
rowsx = groottex(1);
i = 1;
aa = 1;

for i = 1:rowsx
    y(aa,1) = x(i,1);
    y(aa,2) = x(i,2);
    y(aa,3) = x(i,3);
    y(aa,4) = x(i,4);
    y(aa,5) = x(i,5);
    if (x(5*rowsx+i)) < 0
        y(aa,6) = 0;
    else
        y(aa,6) = x(i,6);
    end
    y(aa,7) = x(i,7);
    y(aa,8) = x(i,8);
    if (x(8*rowsx+i)) < 0
        y(aa,9) = 0;
    else
        y(aa,9) = x(i,9);
    end
    y(aa,10) = x(i,10);
    y(aa,11) = x(i,11);
    if (x(11*rowsx+i)) < 0
        y(aa,12) = 0;
    else
        y(aa,12) = x(i,12);
    end
    y(aa,13) = x(i,13);
    y(aa,14) = x(i,14);
    if (x(14*rowsx+i)) < 0
        y(aa,15) = 0;
    else
        y(aa,15) = x(i,15);
    end
    y(aa,16) = x(i,16);
    y(aa,17) = x(i,17);
    y(aa,18) = x(i,18);
    y(aa,19) = x(i,19);
    y(aa,20) = x(i,20);
    aa = aa + 1;
end
i = i + 1;
end
```
Algorithm 3:

\[ \text{stochastictime1\_eur\_rub\_tod} = \text{stochastictime\_eur\_rub\_tod}(\text{intraday\_data\_2011\_eur\_rub\_tod}); \]

Description:
This algorithm calculates the stochastic time between trades according to method 1.

```matlab
function [ t ] = stochastictime_eur_rub_tod( x )
dagen=unique(x(:,1));
tussenwaarde=size(dagen);
aantaldagen=tussenwaarde(1);
rijen=size(x);
rowsx=rijen(1);

starttimeday=(datenum('30-\text{dec}-1899 10:00:00'})-datenum('30-\text{dec}-1899 00:00:00'));
halfhour=datenum('30-\text{dec}-1899 00:30:00')-datenum('30-\text{dec}-1899 00:00:00');

tellerdagen=1;
aa=1;
i=1;
askprices=[];
bidprices=[];
a=1;
b=1;
y=[];
DateVector1=[];
DateVector2=[];
DateVector3=[];
tellery=1;
teller1=1;
teller2=1;
teller5=1;
tellerz=1;
z=[];
w=[];
c=1;
d=1;
e=1;
f=1;
g=1;
h=1;
l=1;
m=1;
n=1;
k=1;
o=1;
p=1;
q=1;
r=1;
halfuureen=[];
halfuurtwee=[];
halfuurdrie=[];
halfuurvier=[];
halfuurdrievif=[];
halfuurzes=[];
```
halfuurzeven=[];
halfuuracht=[];
halfuurnegen=[];
halfuurtien=[];

for tellerdagen=1:aantaldagen
    for tellerx=i:rowsx
        if x(i)== dagen(tellerdagen)
            if x(5*rowsx+i)==1
                askprices(a,1)=x(1*rowsx+i);
                a=a+1;
            else
                bidprices(b,1)=x(1*rowsx+i);
                b=b+1;
            end
        end
        i=i+1;
    end

    DateVector1=datevec(askprices(:,1));
    DateVector1(:,6)=round(DateVector1(:,6));
    DateVector1(:,7)=DateVector1(:,4).*3600+DateVector1(:,5).*60+DateVector1(:,6);
    askprices(:,2)=DateVector1(:,7);

    DateVector2=datevec(bidprices(:,1));
    DateVector2(:,6)=round(DateVector2(:,6));
    DateVector2(:,7)=DateVector2(:,4).*3600+DateVector2(:,5).*60+DateVector2(:,6);
    bidprices(:,2)=DateVector2(:,7);

    i=1;
    for tellerx=i:rowsx
        if x(i)== dagen(tellerdagen)
            y(tellery,1)=x(rowsx+i);
            y(tellery,2)=x(rowsx*5+i);
            tellery=tellery+1;
        end
        i=i+1;
    end

    DateVector3=datevec(y(:,1));
    DateVector3(:,6)=round(DateVector3(:,6));
    DateVector3(:,7)=DateVector3(:,4).*3600+DateVector3(:,5).*60+DateVector3(:,6);
    y(:,3)=DateVector3(:,7);

    groottey=size(y);
    rowsy=groottey(1);

    askrijen=size(askprices);
    rowsask=askrijen(1);
    bidrijen=size(bidprices);
    rowsbid=bidrijen(1);
i=1;

for i=1:rowsy
    if y(rowsy+i)==1 && teller1 <= rowsbid
        while (y(2*rowsy+i) > bidprices(teller1,2) && teller1 < rowsbid)
            teller1=teller1+1;
            if y(2*rowsy+i)==y(2*rowsy+i-1) && teller1 < rowsbid &&
                y(1*rowsy+i)~=y(1*rowsy+i-1)
                    teller1=teller1+1;
                    if y(2*rowsy+i)==y(2*rowsy+i-2) && teller1 < rowsbid &&
                        y(1*rowsy+i)~=y(1*rowsy+i-2)
                            teller1=teller1+1;
                            if y(2*rowsy+i)==y(2*rowsy+i-3) && teller1 < rowsbid &&
                                y(1*rowsy+i)~=y(1*rowsy+i-3)
                                    teller1=teller1+1;
                                    if y(2*rowsy+i)==y(2*rowsy+i-4) && teller1 <
                                        rowsbid && y(1*rowsy+i)~=y(1*rowsy+i-4)
                                            teller1=teller1+1;
                                            if y(2*rowsy+i)==y(2*rowsy+i-5) && teller1 <
                                                rowsbid && y(1*rowsy+i)~=y(1*rowsy+i-5)
                                                    teller1=teller1+1;
                                                    if y(2*rowsy+i)==y(2*rowsy+i-6) &&
                                                        teller1 < rowsbid && y(1*rowsy+i)~=y(1*rowsy+i-6)
                                                            teller1=teller1+1;
                                                            if y(2*rowsy+i)==y(2*rowsy+i-7) &&
                                                                teller1 < rowsbid && y(1*rowsy+i)~=y(1*rowsy+i-7)
                                                                    teller1=teller1+1;
                                                                    if y(2*rowsy+i)==y(2*rowsy+i-8) &&
                                                                        teller1 < rowsbid && y(1*rowsy+i)~=y(1*rowsy+i-8)
                                                                            teller1=teller1+1;
                                                                            if y(2*rowsy+i)==y(2*rowsy+i-9) &&
                                                                                teller1 < rowsbid && y(1*rowsy+i)~=y(1*rowsy+i-9)
                                                                                    teller1=teller1+1;
                                                                                    if y(2*rowsy+i)==y(2*rowsy+i-10) &&
                                                                                        teller1 < rowsbid && y(1*rowsy+i)~=y(1*rowsy+i-10)
                                                                                            teller1=teller1+1;
                                                                                            end
                                                                        end
                                                                    end
                                                    end
                                            end
                                        end
                                    end
                                end
                            end
                        end
                    end
                end
            end
        end
    end
elseif y(rowsy+i)==0 && teller2 <= rowsask
    while (y(2*rowsy+i) < askprices(teller2,2) && teller2 < rowsask)
        teller2=teller2+1;
        if y(2*rowsy+i)==y(2*rowsy+i-1) && teller2 < rowsask &&
            y(1*rowsy+i)~=y(1*rowsy+i-1)
                teller2=teller2+1;
                if y(2*rowsy+i)==y(2*rowsy+i-2) && teller2 < rowsask &&
                    y(1*rowsy+i)~=y(1*rowsy+i-2)
                        teller2=teller2+1;
                        if y(2*rowsy+i)==y(2*rowsy+i-3) && teller2 < rowsask &&
                            y(1*rowsy+i)~=y(1*rowsy+i-3)
                                teller2=teller2+1;
                                if y(2*rowsy+i)==y(2*rowsy+i-4) && teller2 < rowsask &&
                                    y(1*rowsy+i)~=y(1*rowsy+i-4)
                                        teller2=teller2+1;
                                        if y(2*rowsy+i)==y(2*rowsy+i-5) && teller2 < rowsask &&
                                            y(1*rowsy+i)~=y(1*rowsy+i-5)
                                                teller2=teller2+1;
                                                if y(2*rowsy+i)==y(2*rowsy+i-6) &&
                                                    teller2 < rowsask && y(1*rowsy+i)~=y(1*rowsy+i-6)
                                                        teller2=teller2+1;
                                                        if y(2*rowsy+i)==y(2*rowsy+i-7) &&
                                                            teller2 < rowsask && y(1*rowsy+i)~=y(1*rowsy+i-7)
                                                                teller2=teller2+1;
                                                                if y(2*rowsy+i)==y(2*rowsy+i-8) &&
                                                                    teller2 < rowsask && y(1*rowsy+i)~=y(1*rowsy+i-8)
                                                                        teller2=teller2+1;
                                                                        if y(2*rowsy+i)==y(2*rowsy+i-9) &&
                                                                            teller2 < rowsask && y(1*rowsy+i)~=y(1*rowsy+i-9)
                                                                                teller2=teller2+1;
                                                                                if y(2*rowsy+i)==y(2*rowsy+i-10) &&
                                                                                    teller2 < rowsask && y(1*rowsy+i)~=y(1*rowsy+i-10)
                                                                                        teller2=teller2+1;
                                                                                        end
                                    end
                                end
                            end
                        end
                    end
                end
            end
        end
    end
end
z(tellerz,1)=y(i);
z(tellerz,2)=y(2*rowsy+i);
z(tellerz,3)=bidprices(teller1,2);
tellerz=tellerz+1;
elseif y(rowsy+i)==0 && teller2 <= rowsask
    while (y(2*rowsy+i) < askprices(teller2,2) && teller2 < rowsask)
        teller2=teller2+1;
        if y(2*rowsy+i)==y(2*rowsy+i-1) && teller2 < rowsask &&
            y(1*rowsy+i)~=y(1*rowsy+i-1)
                teller2=teller2+1;
                if y(2*rowsy+i)==y(2*rowsy+i-2) && teller2 < rowsask &&
                    y(1*rowsy+i)~=y(1*rowsy+i-2)
                        teller2=teller2+1;
                        if y(2*rowsy+i)==y(2*rowsy+i-3) && teller2 < rowsask &&
                            y(1*rowsy+i)~=y(1*rowsy+i-3)
                                teller2=teller2+1;
                                if y(2*rowsy+i)==y(2*rowsy+i-4) && teller2 < rowsask &&
                                    y(1*rowsy+i)~=y(1*rowsy+i-4)
                                        teller2=teller2+1;
                                        if y(2*rowsy+i)==y(2*rowsy+i-5) &&
                                            teller2 < rowsask && y(1*rowsy+i)~=y(1*rowsy+i-5)
                                                teller2=teller2+1;
                                                if y(2*rowsy+i)==y(2*rowsy+i-6) &&
                                                    teller2 < rowsask && y(1*rowsy+i)~=y(1*rowsy+i-6)
                                                        teller2=teller2+1;
                                                        if y(2*rowsy+i)==y(2*rowsy+i-7) &&
                                                            teller2 < rowsask && y(1*rowsy+i)~=y(1*rowsy+i-7)
                                                                teller2=teller2+1;
                                                                if y(2*rowsy+i)==y(2*rowsy+i-8) &&
                                                                    teller2 < rowsask && y(1*rowsy+i)~=y(1*rowsy+i-8)
                                                                        teller2=teller2+1;
                                                                        if y(2*rowsy+i)==y(2*rowsy+i-9) &&
                                                                            teller2 < rowsask && y(1*rowsy+i)~=y(1*rowsy+i-9)
                                                                                teller2=teller2+1;
                                                                                if y(2*rowsy+i)==y(2*rowsy+i-10) &&
                                                                                    teller2 < rowsask && y(1*rowsy+i)~=y(1*rowsy+i-10)
                                                                                        teller2=teller2+1;
                                                                                        end
                                    end
                                end
                            end
                        end
                    end
                end
            end
        end
    end
end
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if y(2*rowsy+i)==y(2*rowsy+i-3) && teller2 < rowsask && y(1*rowsy+i)==y(1*rowsy+i-3) 
teller2=teller2+1;
if y(2*rowsy+i)==y(2*rowsy+i-4) && teller2 < rowsask && y(1*rowsy+i)==y(1*rowsy+i-4) 
teller2=teller2+1;
if y(2*rowsy+i)==y(2*rowsy+i-5) && teller2 < rowsask && y(1*rowsy+i)==y(1*rowsy+i-5) 
teller2=teller2+1;
if y(2*rowsy+i)==y(2*rowsy+i-6) && teller2 < rowsask && y(1*rowsy+i)==y(1*rowsy+i-6) 
teller2=teller2+1;
if y(2*rowsy+i)==y(2*rowsy+i-7) && teller2 < rowsask && y(1*rowsy+i)==y(1*rowsy+i-7) 
teller2=teller2+1;
if y(2*rowsy+i)==y(2*rowsy+i-8) && teller2 < rowsask && y(1*rowsy+i)==y(1*rowsy+i-8) 
teller2=teller2+1;
if y(2*rowsy+i)==y(2*rowsy+i-9) && teller2 < rowsask && y(1*rowsy+i)==y(1*rowsy+i-9) 
teller2=teller2+1;
if y(2*rowsy+i)==y(2*rowsy+i-10) && teller2 < rowsask && y(1*rowsy+i)==y(1*rowsy+i-10) 
teller2=teller2+1;
end
end
end
end
end
z(tellerz,1)=y(i);
z(tellerz,2)=y(2*rowsy+i);
z(tellerz,3)=askprices(teller2,2);
tellerz=tellerz+1;
else
break
end
i=i+1;
end

z(:,4)=z(:,3)-z(:,2);
groottez=size(z);
rowsz=groottez(1);
i=1;

for i=1:rowsz
if z(i,4) >= 0
w(i,:)=z(i,:);
end
i=i+1;
end

groottw=size(w);
rowsw=groottw(1);
for teller5=1:rowsw
    if w(teller5,1) <= (dagen(tellerdagen)+starttimeday+halfhour)
        halfuureen(c,1)=w(teller5,4);
        c=c+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+2*halfhour)
        halfuurtwee(d,1)=w(teller5,4);
        d=d+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+3*halfhour)
        halfuurdrie(e,1)=w(teller5,4);
        e=e+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+4*halfhour)
        halfuurvier(f,1)=w(teller5,4);
        f=f+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+5*halfhour)
        halfuurvijf(g,1)=w(teller5,4);
        g=g+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+6*halfhour)
        halfuurstes(h,1)=w(teller5,4);
        h=h+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+7*halfhour)
        halfuurzeven(l,1)=w(teller5,4);
        l=l+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+8*halfhour)
        halfuurtacht(m,1)=w(teller5,4);
        m=m+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+9*halfhour)
        halfuurnegen(k,1)=w(teller5,4);
        k=k+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+10*halfhour)
        halfuurtien(n,1)=w(teller5,4);
        n=n+1;
    end
    teller5=teller5+1;
end

t(aa,1)=dagen(tellerdagen);
t(aa,2)=starttimeday;
t(aa,3)=starttimeday+halfhour;
if size(halfuureen)==0
    t(aa,4)=NaN;
else
    t(aa,4)=nanmean(halfuureen);
end
aa=aa+1;

t(aa,1)=dagen(tellerdagen);
t(aa,2)=starttimeday+halfhour;
t(aa,3)=starttimeday+2*halfhour;
if size(halfuurtwee)==0
    t(aa,4)=NaN;
else
    t(aa,4)=nanmean(halfuurtwee);
end
aa=aa+1;

t(aa,1)=dagen(tellerdagen);
t(aa,2)=starttimeday+2*halfhour;
t(aa,3)=starttimeday+3*halfhour;
if size(halfuurdrie)==0
t(aa,4)=NaN;
else
t(aa,4)=nanmean(halfuurdrie);
end
aa=aa+1;

t(aa,1)=dagen(tellerdagen);
t(aa,2)=starttimeday+3*halfhour;
t(aa,3)=starttimeday+4*halfhour;
if size(halfuurvier)==0
t(aa,4)=NaN;
else
t(aa,4)=nanmean(halfuurvier);
end
aa=aa+1;

t(aa,1)=dagen(tellerdagen);
t(aa,2)=starttimeday+4*halfhour;
t(aa,3)=starttimeday+5*halfhour;
if size(halfuurvijf)==0
t(aa,4)=NaN;
else
t(aa,4)=nanmean(halfuurvijf);
end
aa=aa+1;

t(aa,1)=dagen(tellerdagen);
t(aa,2)=starttimeday+5*halfhour;
t(aa,3)=starttimeday+6*halfhour;
if size(halfuurzes)==0
t(aa,4)=NaN;
else
t(aa,4)=nanmean(halfuurzes);
end
aa=aa+1;

t(aa,1)=dagen(tellerdagen);
t(aa,2)=starttimeday+6*halfhour;
t(aa,3)=starttimeday+7*halfhour;
if size(halfuurzeven)==0
t(aa,4)=NaN;
else
t(aa,4)=nanmean(halfuurzeven);
end
aa=aa+1;

t(aa,1)=dagen(tellerdagen);
t(aa,2)=starttimeday+7*halfhour;
t(aa,3)=starttimeday+8*halfhour;
if size(halfuuracht)==0
t(aa,4)=NaN;
else
t(aa,4)=nanmean(halfuuracht);
end
aa=aa+1;

t(aa,1)=dagen(tellerdagen);
t(aa,2)=starttimeday+8*halfhour;
t(aa,3)=starttimeday+9*halfhour;
if \( \text{size(halfuurnegen)} == 0 \)
\[ t(aa,4) = \text{NaN}; \]
else
\[ t(aa,4) = \text{nanmean(halfuurnegen)}; \]
end

\( aa = aa + 1; \)

\[ t(aa,1) = \text{dagen(tellerdagen)}; \]
\[ t(aa,2) = \text{starttimeday} + 9\times\text{halfhour}; \]
\[ t(aa,3) = \text{starttimeday} + 10\times\text{halfhour}; \]
if \( \text{size(halfuurtien)} == 0 \)
\[ t(aa,4) = \text{NaN}; \]
else
\[ t(aa,4) = \text{nanmean(halfuurtien)}; \]
end

\( aa = aa + 1; \)

\( i = 1; \)
\[ \text{askprices} = []; \]
\[ \text{bidprices} = []; \]
\( a = 1; \)
\( b = 1; \)
\( y = []; \)
\[ \text{DateVector1} = []; \]
\[ \text{DateVector2} = []; \]
\[ \text{DateVector3} = []; \]
\( \text{tellery} = 1; \)
\( \text{teller1} = 1; \)
\( \text{teller2} = 1; \)
\( \text{teller5} = 1; \)
\( \text{tellerz} = 1; \)
\( z = []; \)
\( w = []; \)
\( c = 1; \)
\( d = 1; \)
\( e = 1; \)
\( f = 1; \)
\( g = 1; \)
\( h = 1; \)
\( l = 1; \)
\( m = 1; \)
\( n = 1; \)
\( k = 1; \)
\( o = 1; \)
\( p = 1; \)
\( q = 1; \)
\( r = 1; \)
\[ \text{halfuureen} = []; \]
\[ \text{halfuurtwee} = []; \]
\[ \text{halfuurdrie} = []; \]
\[ \text{halfuurvier} = []; \]
\[ \text{halfuurvijf} = []; \]
\[ \text{halfuurzes} = []; \]
\[ \text{halfuurzeven} = []; \]
\[ \text{halfuuracht} = []; \]
\[ \text{halfuurnegen} = []; \]
\[ \text{halfuurtien} = []; \]

\( \text{tellerdagen} = \text{tellerdagen} + 1; \)
end

t(:,5)=sqrt(t(:,4));

end
**Algorithm 4:**

stochastictime2_eur_rub_tod = stochastictime2_eur_rub_tod(intraday_data_2011_eur_rub_tod);

**Description:**

This algorithm calculates the stochastic time between trades according to method 2.

```matlab
function [ z ] = stochastictime2_eur_rub_tod( x )

aa = 1;
i = 1;
groottex = size(x);
rowsx = groottex(1);

starttime = (datenum('30-dec-1899 10:00:00') - datenum('30-dec-1899 00:00:00'));
halfhour = datenum('30-dec-1899 00:30:00') - datenum('30-dec-1899 00:00:00');

dagen = unique(x(:,1));
tussenwaarde = size(dagen);
aantaldagen = tussenwaarde(1);
tellerdagen = 1;
tellery = 1;
teller1 = 1;
teller5 = 1;

c = 1;
d = 1;
e = 1;
f = 1;
g = 1;
h = 1;
l = 1;
m = 1;
n = 1;
k = 1;
o = 1;
p = 1;
q = 1;
r = 1;

halfuurzes = [];
halfuurzeven = [];

halfuuracht = [];
halfuurzehn = [];
halfuurtien = [];

for tellerdagen = 1:aantaldagen
    for tellerx = i:rowsx
        if x(i) == dagen(tellerdagen)
```

Appendix B.36
\begin{verbatim}
    y(tellery,1)=x(rowsx+i);
tellery=tellijer+1;
end
i=i+1;
end

DateVector=datavec(y(:,1));
DateVector(:,6)=round(DateVector(:,6));
DateVector(:,7)=DateVector(:,4).*3600+DateVector(:,5).*60+DateVector(:,6);

groottey=size(y);
rowsy=groottey(1);
rowsy_minus_1=rowsy-1;

for tellerdatevector=1:rowsy_minus_1;
    DateVector(tellerdatevector,8)=DateVector(tellerdatevector+1,7);
tellerdatevector=tellerdatevector+1;
end

DateVector(:,9)=DateVector(:,8)-DateVector(:,7);
y(:,2)=DateVector(:,9);

for teller1=1:rowsy_minus_1
    w(teller1,1)=y(teller1,1);
w(teller1,2)=y(teller1,2);
teller1=teller1+1;
end

groottew=size(w);
rowsw=groottew(1);

for teller5=1:rowsw
    if w(teller5,1) <= (dagen(tellerdagen)+starttimeday+halfhour)
        halfuureen(c,1)=w(teller5,2);
c=c+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+2*halfhour)
        halfuurtwee(d,1)=w(teller5,2);
d=d+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+3*halfhour)
        halfuurdrie(e,1)=w(teller5,2);
e=e+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+4*halfhour)
        halfuurvier(f,1)=w(teller5,2);
f=f+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+5*halfhour)
        halfuurvijf(g,1)=w(teller5,2);
g=g+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+6*halfhour)
        halfuurzes(h,1)=w(teller5,2);
h=h+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+7*halfhour)
        halfuurnegen(i,1)=w(teller5,2);
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+8*halfhour)
        halfuurnacht(m,1)=w(teller5,2);
m=m+1;
    elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+9*halfhour)
        halfuurnegen(k,1)=w(teller5,2);
k=k+1;
\end{verbatim}
elseif w(teller5,1) <= (dagen(tellerdagen)+starttimeday+10*halfhour)
    halfuurtien(n,1)=w(teller5,2);
    n=n+1;
end

teller5=teller5+1;
end

z(aa,1)=dagen(tellerdagen);
z(aa,2)=starttimeday;
z(aa,3)=starttimeday+halfhour;
if size(halfuureen)==0
    z(aa,4)=NaN;
else
    z(aa,4)=nanmean(halfuureen);
end
aa=aa+1;

z(aa,1)=dagen(tellerdagen);
z(aa,2)=starttimeday+halfhour;
z(aa,3)=starttimeday+2*halfhour;
if size(halfuurtwee)==0
    z(aa,4)=NaN;
else
    z(aa,4)=nanmean(halfuurtwee);
end
aa=aa+1;

z(aa,1)=dagen(tellerdagen);
z(aa,2)=starttimeday+2*halfhour;
z(aa,3)=starttimeday+3*halfhour;
if size(halfuurdrie)==0
    z(aa,4)=NaN;
else
    z(aa,4)=nanmean(halfuurdrie);
end
aa=aa+1;

z(aa,1)=dagen(tellerdagen);
z(aa,2)=starttimeday+3*halfhour;
z(aa,3)=starttimeday+4*halfhour;
if size(halfuurvier)==0
    z(aa,4)=NaN;
else
    z(aa,4)=nanmean(halfuurvier);
end
aa=aa+1;

z(aa,1)=dagen(tellerdagen);
z(aa,2)=starttimeday+4*halfhour;
z(aa,3)=starttimeday+5*halfhour;
if size(halfuurvijf)==0
    z(aa,4)=NaN;
else
    z(aa,4)=nanmean(halfuurvijf);
end
aa=aa+1;

z(aa,1)=dagen(tellerdagen);
z(aa,2)=starttimeday+5*halfhour;
z(aa,3)=starttimeday+6*halfhour;
if size(halfuurzes) == 0
    z(aa, 4) = NaN;
else
    z(aa, 4) = nanmean(halfuurzes);
end
aa = aa + 1;

z(aa, 1) = dagen(tellerdagen);
z(aa, 2) = starttimeday + 6 * halfhour;
z(aa, 3) = starttimeday + 7 * halfhour;
if size(halfuurzeven) == 0
    z(aa, 4) = NaN;
else
    z(aa, 4) = nanmean(halfuurzeven);
end
aa = aa + 1;

z(aa, 1) = dagen(tellerdagen);
z(aa, 2) = starttimeday + 7 * halfhour;
z(aa, 3) = starttimeday + 8 * halfhour;
if size(halfuuracht) == 0
    z(aa, 4) = NaN;
else
    z(aa, 4) = nanmean(halfuuracht);
end
aa = aa + 1;

z(aa, 1) = dagen(tellerdagen);
z(aa, 2) = starttimeday + 8 * halfhour;
z(aa, 3) = starttimeday + 9 * halfhour;
if size(halfuurnegen) == 0
    z(aa, 4) = NaN;
else
    z(aa, 4) = nanmean(halfuurnegen);
end
aa = aa + 1;

z(aa, 1) = dagen(tellerdagen);
z(aa, 2) = starttimeday + 9 * halfhour;
z(aa, 3) = starttimeday + 10 * halfhour;
if size(halfuurtien) == 0
    z(aa, 4) = NaN;
else
    z(aa, 4) = nanmean(halfuurtien);
end
aa = aa + 1;

y = [];
w = [];
DateVector = [];
tellery = 1;
teller1 = 1;
teller5 = 1;
i = 1;
halfuureen = [];
halfuurtwee = [];
halfuurdrie=[];
halfuurvier=[];
halfuurvijf=[];
halfuurzes=[];
halfuurzeven=[];
halfuuracht=[];
halfuurnegen=[];
halfuurrtien=[];
halfuurelf=[];
halfuurtwaalf=[];
halfuurdertien=[];
halfuurveertien=[];

c=1;
d=1;
e=1;
f=1;
g=1;
h=1;
l=1;
m=1;
n=1;
k=1;
o=1;
p=1;
q=1;
r=1;

tellerdagen=tellerdagen+1;

end

z(:,5)=sqrt(z(:,4));

end
Algorithm 5:

```
spreads_vol_price_comp_truerate_time_eur_rub_tod=competitie_exchangerate_stochastictime_AV_MM( data_2011_eur_rub_tod_corrected, spreads_vol_prijs_eur_rub_tod_2, stochastictime1_eur_rub_tod, stochastictime2_eur_rub_tod);
```

**Description:**

This algorithm calculates competition per half-hour according to our three methods and adds it to a file that contains the other variables that were already calculated. Furthermore, the just above calculated stochastic time between trades according to our 2 proposed methods are added. This algorithm also adds the total volume traded per day to the file.

```
function [ w ] = competitie_exchangerate_stochastictime_AV_MM( data, intraday_data, tijd1, tijd2 )

x=data;
y=intraday_data;
w=intraday_data;
grootte_x=size(x);
grootte_y=size(y);

aantal_rijen_x=grootte_x(1);
aantal_rijen_y=grootte_y(1);
dagen_x=unique(x);
dagen_y=unique(y);
tussenwaardex=size(dagen_x);
tussenwaardey=size(dagen_y);
aantal_dagen_x=tussenwaardex(1);
aantal_dagen_y=tussenwaardey(1);
tellerdagen_x=1;
tellerdagen_y=1;

i=1;
j=1;

aa=1;

for tellerdagen_y=1:aantal_dagen_y
    while y(i)==dagen_y(tellerdagen_y)
        for j=1:aantal_rijen_x
            if x(j)== dagen_y(tellerdagen_y)
                w(aa,21)=x(13*aantal_rijen_x+j);
                w(aa,22)=x(14*aantal_rijen_x+j);
                w(aa,23)=x(10*aantal_rijen_x+j);
                aa=aa+1;
            end
        end
        j=j+1;
    end
    i=i+1;
end
j=1;
tellerdagen_y=tellerdagen_y+1;
```
\begin{verbatim}
end

w(:,24)=(w(:,20)./w(:,21)).*w(:,22);
w(:,25)=(w(:,16)./w(:,23)).*w(:,22);

w(:,26)=((w(:,4)+w(:,5))/2);
w(:,27)=((w(:,10)+w(:,11))/2);
w(:,28)=1./w(:,26);
w(:,29)=1./w(:,27);

grootte_w=size(w);
rowsw=grootte_w(1);
tellerw=1;

for tellerw=1:rowsw;
    w(tellerw,30)=tijd1(tellerw,5);
    w(tellerw,31)=tijd2(tellerw,5);
    tellerw=tellerw+1;
end
\end{verbatim}
Algorithm 6:
intermezzo1=verwijderNaN_navolatiliteit(d_minus_ihp_eur_rub_tod);

Description:
Because there is a jump in the closing hours on May 16, 2011, there are some half-hours that have
gotten a NaN value because before May 16, 2011 no trading took place in these half-hours. These are
now deleted.

```
function [ y ] = verwijderNaN_voorvolatiliteit( x )

groottex=size(x);
rowsx=groottex(1);
i=1;
aa=1;
for i=1:rowsx
    if isnan(x(3*rowsx+i)) ~= 1
        y(aa,1)= x(i,1);
        y(aa,2)= x(i,2);
        y(aa,3)= x(i,3);
        y(aa,4)= x(i,4);
        y(aa,5)= x(i,5);
        y(aa,6)= x(i,6);
        y(aa,7)= x(i,7);
        y(aa,8)= x(i,8);
        y(aa,9)= x(i,9);
        y(aa,10)= x(i,10);
        y(aa,11)= x(i,11);
        y(aa,12)= x(i,12);
        y(aa,13)= x(i,13);
        y(aa,14)= x(i,14);
        y(aa,15)= x(i,15);
        y(aa,16)= x(i,16);
        y(aa,17)= x(i,17);
        y(aa,18)= x(i,18);
        y(aa,19)= x(i,19);
        y(aa,20)= x(i,20);
        y(aa,21)= x(i,21);
        y(aa,22)= x(i,22);
        y(aa,23)= x(i,23);
        y(aa,24)= x(i,24);
        y(aa,25)= x(i,25);
        y(aa,26)= x(i,26);
        y(aa,27)= x(i,27);
        y(aa,28)= x(i,28);
        y(aa,29)= x(i,29);
        y(aa,30)= x(i,30);
        y(aa,31)= x(i,31);
        aa=aa+1;
    end
    i=i+1;
end
end
```
Algorithm 7:

\[ d_{\text{minus ihp eur rub tod}} = \text{volatiliteit eur rub tod}(\text{intermezzo}); \]

Description:
This method calculates and adds the return volatility to the file with the other variables.

```matlab
function [ y ] = volatiliteit_eur_rub_tod( w )
grootte_w = size(w);
rowsw = grootte_w(1);

y = w;
y(1,32) = NaN;
y(1,33) = NaN;

tellerw = 2;

for tellerw = 2:rowsw
    y(tellerw,32) = log(w(25*rowsw+tellerw)) - log(w(25*rowsw+(tellerw-1)));
tellerw = tellerw + 1;
end

tellerw = 2;

for tellerw = 2:rowsw
    y(tellerw,33) = log(w(26*rowsw+tellerw)) - log(w(26*rowsw+(tellerw-1)));
tellerw = tellerw + 1;
end

y(1,32) = NaN;
y(1,33) = NaN;
y(1,34) = NaN;
y(1,35) = NaN;

tellerw = 6;
telleri = 2;

for tellerw = 6:rowsw
    y(tellerw,34) = std(y(telleri:tellerw,32));
tellerw = tellerw + 1;
telleri = telleri + 1;
end

tellerw = 6;
telleri = 2;

for tellerw = 6:rowsw
    y(tellerw,35) = std(y(telleri:tellerw,33));
tellerw = tellerw + 1;
telleri = telleri + 1;
end

y(1:5,34) = NaN;
y(1:5,35) = NaN;
y(1:5,36) = NaN;
y(1:5,37) = NaN;
```

Appendix B.44
\[ y(:,36) = \sqrt{5.95 \times 252} \cdot y(:,34); \]
\[ y(:,37) = \sqrt{5.95 \times 252} \cdot y(:,35); \]
Algorithm 8:
intermezzo1=verwijderNaN_navalatiliteit(d_minus_ihp_eur_rub_tod);

Description:
This method eliminates those first half-hours for which no volatility could be calculated.

function [ y ] = verwijderNaN_navalatiliteit( x )

groottex=size(x);
rowsx=groottex(1);
i=1;
aa=1;

for i=1:rowsx
    if isnan(x(36*rowsx+i)) ~= 1
        y(aa,1)= x(i,1);
y(aa,2)= x(i,2);
y(aa,3)= x(i,3);
y(aa,4)= x(i,4);
y(aa,5)= x(i,5);
y(aa,6)= x(i,6);
y(aa,7)= x(i,7);
y(aa,8)= x(i,8);
y(aa,9)= x(i,9);
y(aa,10)= x(i,10);
y(aa,11)= x(i,11);
y(aa,12)= x(i,12);
y(aa,13)= x(i,13);
y(aa,14)= x(i,14);
y(aa,15)= x(i,15);
y(aa,16)= x(i,16);
y(aa,17)= x(i,17);
y(aa,18)= x(i,18);
y(aa,19)= x(i,19);
y(aa,20)= x(i,20);
y(aa,21)= x(i,21);
y(aa,22)= x(i,22);
y(aa,23)= x(i,23);
y(aa,24)= x(i,24);
y(aa,25)= x(i,25);
y(aa,26)= x(i,26);
y(aa,27)= x(i,27);
y(aa,28)= x(i,28);
y(aa,29)= x(i,29);
y(aa,30)= x(i,30);
y(aa,31)= x(i,31);
y(aa,32)= x(i,32);
y(aa,33)= x(i,33);
y(aa,34)= x(i,34);
y(aa,35)= x(i,35);
y(aa,36)= x(i,36);
y(aa,37)= x(i,37);
aa=aa+1;
end
    i=i+1;
end
**Algorithm 9:**

\[ d_{eur\_rub\_tod\_LV\_WA} = \text{ihp\_eur\_rub\_tod}(\text{intermezzo1}); \]

**Description:**

This method calculates and adds the IHP.

```matlab
function [ y ] = ihp_eur_rub_tod( x )

y=x;

y(:,38)=y(:,26).*(2.*normcdf(0.5.*y(:,36).*sqrt(((y(:,30).^2)./(60*30*5.95*252)))-1);
y(:,39)=y(:,26).*(2.*normcdf(0.5.*y(:,36).*sqrt(((y(:,31).^2)./(60*30*5.95*252)))-1);
y(:,40)=y(:,27).*(2.*normcdf(0.5.*y(:,37).*sqrt(((y(:,30).^2)./(60*30*5.95*252)))-1);
y(:,41)=y(:,27).*(2.*normcdf(0.5.*y(:,37).*sqrt(((y(:,31).^2)./(60*30*5.95*252)))-1);

end
```
Algorithm 10:

\[
d_{\text{dagelijks}_\text{eur}_\text{rub}_\text{tod}_\text{AV}_\text{MM}} = \text{maakdagelijks}_\text{AV}_\text{MM}(d_{\text{eur}_\text{rub}_\text{tod}_\text{AV}_\text{MM}});
\]

**Description:**
This transforms the intraday data into its daily counterparts to be able to retrieve the summary statistics for the daily spread measures.

```matlab
function [ y ] = maakdagelijks_AV_MM( x )

verschillendagedagen = unique(x(:,1));
tussenwaarde1 = size(verschillendagedagen);
aantaldagen = tussenwaarde1(1);

grootex = size(x);
rowsx = grootex(1);
tabel = [];
tellerdagen = 1;
i = 1;
a = 1;
aa = 1;

for tellerdagen = 1:aantaldagen;
    for i = 1:rowsx
        if x(i) == verschillendagedagen(tellerdagen)
            tabel(a,1) = x(i,1);
tabel(a,2) = x(i,2);
tabel(a,3) = x(i,3);
tabel(a,4) = x(i,6);
tabel(a,5) = x(i,12);
tabel(a,6) = x(i,16);
tabel(a,7) = x(i,17);
tabel(a,8) = x(i,18);
tabel(a,9) = x(i,19);
tabel(a,10) = x(i,20);
tabel(a,11) = x(i,21);
tabel(a,12) = x(i,22);
tabel(a,13) = x(i,23);
tabel(a,14) = x(i,24);
tabel(a,15) = x(i,25);
tabel(a,16) = x(i,26);
tabel(a,17) = x(i,27);
tabel(a,18) = x(i,28);
tabel(a,19) = x(i,29);
tabel(a,20) = x(i,30);
tabel(a,21) = x(i,31);
tabel(a,22) = x(i,36);
tabel(a,23) = x(i,37);
tabel(a,24) = x(i,38);
tabel(a,25) = x(i,39);
tabel(a,26) = x(i,40);
tabel(a,27) = x(i,41);
        a = a+1;
    end
    i = i+1;
end
```

Appendix B.48
groottetabel = size(tabel);
aantalrijentabel = groottetabel(1);

tabel(:,28) = tabel(:,4).*tabel(:,6). / tabel(:,13));
tabel(:,29) = tabel(:,5).*tabel(:,6). / tabel(:,13));

y(aa,1) = verschillendedagen(tellerdagen);
y(aa,2) = (sum(tabel(:,4)) / aantalrijentabel);
y(aa,3) = (sum(tabel(:,5)) / aantalrijentabel);
y(aa,4) = sum(tabel(:,28));
y(aa,5) = sum(tabel(:,29));
y(aa,6) = mean(tabel(:,6));
y(aa,7) = mean(tabel(:,7));
y(aa,8) = mean(tabel(:,8));
y(aa,9) = mean(tabel(:,9));
y(aa,10) = mean(tabel(:,10));
y(aa,11) = mean(tabel(:,11));
y(aa,12) = mean(tabel(:,12));
y(aa,13) = mean(tabel(:,13));
y(aa,14) = mean(tabel(:,14));
y(aa,15) = mean(tabel(:,15));
y(aa,16) = mean(tabel(:,16));
y(aa,17) = mean(tabel(:,17));
y(aa,18) = mean(tabel(:,18));
y(aa,19) = mean(tabel(:,19));
y(aa,20) = mean(tabel(:,20));
y(aa,21) = mean(tabel(:,21));
y(aa,22) = mean(tabel(:,22));
y(aa,23) = mean(tabel(:,23));
y(aa,24) = mean(tabel(:,24));
y(aa,25) = mean(tabel(:,25));
y(aa,26) = mean(tabel(:,26));
y(aa,27) = mean(tabel(:,27));

aa = aa + 1;

tabel = [];
a = 1;
i = 1;
tellerdagen = tellerdagen + 1;
# Appendix C: Summary statistics spreads

## Summary of the descriptive statistics of the spread measures for the currencies RUB/EUR TOD and RUB/EUR TOM

The mean and quartile values for the different measures of the b/a spread

<table>
<thead>
<tr>
<th>Variable</th>
<th>RUB/EUR TOD</th>
<th></th>
<th></th>
<th></th>
<th>RUB/EUR TOM</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>25%</td>
<td>Median</td>
<td>75%</td>
<td>Mean</td>
<td>25%</td>
<td>Median</td>
<td>75%</td>
</tr>
<tr>
<td><strong>Daily spread measures (days = 100)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$EWQS_{LV}$</td>
<td>0.0065</td>
<td>0.0046</td>
<td>0.0062</td>
<td>0.0080</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$VWES_{LV}$</td>
<td>0.0063</td>
<td>0.0039</td>
<td>0.0063</td>
<td>0.0083</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$REWQS_{LV}$</td>
<td>0.000162</td>
<td>0.000114</td>
<td>0.000155</td>
<td>0.000200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$RVWES_{LV}$</td>
<td>0.000157</td>
<td>0.000099</td>
<td>0.000159</td>
<td>0.000207</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$EWQS_{AV}$</td>
<td>0.0045</td>
<td>0.0031</td>
<td>0.0043</td>
<td>0.0060</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$VWES_{AV}$</td>
<td>0.0043</td>
<td>0.0028</td>
<td>0.0041</td>
<td>0.0057</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$REWQS_{AV}$</td>
<td>0.000111</td>
<td>0.000077</td>
<td>0.000107</td>
<td>0.000150</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$RVWES_{AV}$</td>
<td>0.000108</td>
<td>0.000069</td>
<td>0.000103</td>
<td>0.000144</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$EWQS_{MM}$</td>
<td>0.0589</td>
<td>0.0472</td>
<td>0.0568</td>
<td>0.0681</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$VWES_{MM}$</td>
<td>0.0613</td>
<td>0.0483</td>
<td>0.0585</td>
<td>0.0716</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$REWQS_{MM}$</td>
<td>0.001467</td>
<td>0.001178</td>
<td>0.001405</td>
<td>0.001697</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$RVWES_{MM}$</td>
<td>0.001528</td>
<td>0.001206</td>
<td>0.001456</td>
<td>0.001788</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$EWQS_{COS}$</td>
<td>0.0029</td>
<td>0.0016</td>
<td>0.0028</td>
<td>0.0040</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$VWES_{COS}$</td>
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<td>0.0016</td>
<td>0.0027</td>
<td>0.0038</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$REWQS_{COS}$</td>
<td>0.000073</td>
<td>0.000040</td>
<td>0.000069</td>
<td>0.000099</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$RVWES_{COS}$</td>
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<td>0.000039</td>
<td>0.000067</td>
<td>0.000095</td>
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<tr>
<td>$EWQS_{CS10}$</td>
<td>0.0032</td>
<td>0.0017</td>
<td>0.0028</td>
<td>0.0043</td>
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<tr>
<td>$VWES_{CS10}$</td>
<td>0.0031</td>
<td>0.0018</td>
<td>0.0028</td>
<td>0.0043</td>
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<tr>
<td>$REWQS_{CS10}$</td>
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<td>0.000042</td>
<td>0.000071</td>
<td>0.000107</td>
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<tr>
<td>$RVWES_{CS10}$</td>
<td>0.000076</td>
<td>0.000044</td>
<td>0.000069</td>
<td>0.000107</td>
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</tr>
<tr>
<td>Intraday spread measures</td>
<td>(half-hours = 595)</td>
<td>(half-hours = 1451)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
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<tr>
<td>$SPR_{LV}$</td>
<td>0.0066</td>
<td>0.0000</td>
<td></td>
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<tr>
<td>$RSPR_{LV}$</td>
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<td>0.000000</td>
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<tr>
<td>$SPR_{AV}$</td>
<td>0.0046</td>
<td>0.0006</td>
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<tr>
<td>$RSPR_{AV}$</td>
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<td>$SPR_{MM}$</td>
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<td>0.0365</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$RSPR_{MM}$</td>
<td>0.001415</td>
<td>0.000907</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$SPR_{C_{55}}$</td>
<td>0.0030</td>
<td>0.0000</td>
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</tr>
<tr>
<td>$RSPR_{C_{55}}$</td>
<td>0.000075</td>
<td>0.000000</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$SPR_{C_{510}}$</td>
<td>0.0033</td>
<td>0.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$RSPR_{C_{510}}$</td>
<td>0.000082</td>
<td>0.000000</td>
<td></td>
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</tr>
</tbody>
</table>

$EWQS_X$ is the equal-weighted quoted b/a spread, with $X = \{LV, AV, MM, C_{55}, C_{510}\}$ being the method used for calculating the b/a spread. $VWES_X$ is the volume-weighted effective b/a spread, with $X$ being the method used for calculating the b/a spread. $REWQS_X$ and $RVWES_X$ are the equal-weighted quoted and volume-weighted effective b/a spreads divided by the true exchange rate respectively. Both with $X$ being the method used for calculating the b/a spread. $SPR_X$ is the quoted b/a spread, with $X$ being the method used for calculating the b/a spread. $RSPR_X$ is the quoted b/a spread divided by the true exchange rate and $X$ being the method used for calculating the b/a spread.

Table C-1: Summary of the descriptive statistics of the spread measures for the currencies RUB/EUR TOD and RUB/EUR TOM

Appendix C.2
## Summary of the descriptive statistics of the spread measures for the currencies RUB/USD TOD and RUB/USD TOM

The mean and quartile values for the different measures of the b/a spread

<table>
<thead>
<tr>
<th>Variable</th>
<th>RUB/USD TOD</th>
<th>RUB/USD TOM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>25%</td>
</tr>
<tr>
<td>Daily spread measures</td>
<td>(days = 99)</td>
<td></td>
</tr>
<tr>
<td>EWQSVL</td>
<td>0.0035</td>
<td>0.0021</td>
</tr>
<tr>
<td>VWESVL</td>
<td>0.0032</td>
<td>0.0021</td>
</tr>
<tr>
<td>REWQSVL</td>
<td>0.001122</td>
<td>0.000075</td>
</tr>
<tr>
<td>RWWESVL</td>
<td>0.001140</td>
<td>0.000070</td>
</tr>
<tr>
<td>EWQSAV</td>
<td>0.0021</td>
<td>0.0015</td>
</tr>
<tr>
<td>VWESA</td>
<td>0.0021</td>
<td>0.0014</td>
</tr>
<tr>
<td>REWQSA</td>
<td>0.000075</td>
<td>0.000051</td>
</tr>
<tr>
<td>RWWESA</td>
<td>0.000074</td>
<td>0.000049</td>
</tr>
<tr>
<td>EWQSMM</td>
<td>0.0397</td>
<td>0.0293</td>
</tr>
<tr>
<td>VWESMM</td>
<td>0.0450</td>
<td>0.0330</td>
</tr>
<tr>
<td>REWQSMM</td>
<td>0.001396</td>
<td>0.001032</td>
</tr>
<tr>
<td>RWWESMM</td>
<td>0.001580</td>
<td>0.001169</td>
</tr>
<tr>
<td>EWQSCS</td>
<td>0.0019</td>
<td>0.0012</td>
</tr>
<tr>
<td>VWESC</td>
<td>0.0018</td>
<td>0.0011</td>
</tr>
<tr>
<td>REWQSCS</td>
<td>0.000066</td>
<td>0.000041</td>
</tr>
<tr>
<td>RWWESCO</td>
<td>0.000062</td>
<td>0.000038</td>
</tr>
<tr>
<td>EWQCS10</td>
<td>0.0024</td>
<td>0.0015</td>
</tr>
<tr>
<td>VWESC10</td>
<td>0.0022</td>
<td>0.0014</td>
</tr>
<tr>
<td>REWQSCS10</td>
<td>0.000083</td>
<td>0.000053</td>
</tr>
<tr>
<td>RWWESCO10</td>
<td>0.000078</td>
<td>0.000047</td>
</tr>
<tr>
<td>Intraday spread measures</td>
<td>(half-hours = 995)</td>
<td></td>
</tr>
<tr>
<td>SPRLV</td>
<td>0.0035</td>
<td>0.0001</td>
</tr>
<tr>
<td>RSPIRVL</td>
<td>0.000122</td>
<td>0.000003</td>
</tr>
<tr>
<td>SPRAV</td>
<td>0.0021</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Appendix C.3
### Table C-2: Summary of the descriptive statistics of the spread measures for the currencies RUB/USD TOD and RUB/USD TOM

<table>
<thead>
<tr>
<th>Spread Measure</th>
<th>RSPR&lt;sub&gt;AV&lt;/sub&gt;</th>
<th>SPR&lt;sub&gt;MM&lt;/sub&gt;</th>
<th>RSPR&lt;sub&gt;MM&lt;/sub&gt;</th>
<th>SPR&lt;sub&gt;C&lt;sub&gt;0.05&lt;/sub&gt;&lt;/sub&gt;</th>
<th>RSPR&lt;sub&gt;C&lt;sub&gt;0.05&lt;/sub&gt;&lt;/sub&gt;</th>
<th>SPR&lt;sub&gt;C&lt;sub&gt;5.10&lt;/sub&gt;&lt;/sub&gt;</th>
<th>RSPR&lt;sub&gt;C&lt;sub&gt;5.10&lt;/sub&gt;&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.000075</td>
<td>0.000004</td>
<td>0.000056</td>
<td>0.000106</td>
<td>0.000058</td>
<td>0.000000</td>
<td>0.000043</td>
</tr>
<tr>
<td></td>
<td>0.0397</td>
<td>0.0190</td>
<td>0.0292</td>
<td>0.0469</td>
<td>0.0487</td>
<td>0.0214</td>
<td>0.0350</td>
</tr>
<tr>
<td></td>
<td>0.001392</td>
<td>0.000659</td>
<td>0.001006</td>
<td>0.001655</td>
<td>0.001709</td>
<td>0.000737</td>
<td>0.001237</td>
</tr>
<tr>
<td></td>
<td>0.0019</td>
<td>0.0000</td>
<td>0.0010</td>
<td>0.0025</td>
<td>0.0021</td>
<td>0.0000</td>
<td>0.0010</td>
</tr>
<tr>
<td></td>
<td>0.000066</td>
<td>0.000000</td>
<td>0.000035</td>
<td>0.000089</td>
<td>0.000076</td>
<td>0.000000</td>
<td>0.000036</td>
</tr>
<tr>
<td></td>
<td>0.0024</td>
<td>0.0000</td>
<td>0.0015</td>
<td>0.0030</td>
<td>0.0028</td>
<td>0.0000</td>
<td>0.0019</td>
</tr>
<tr>
<td></td>
<td>0.000083</td>
<td>0.000000</td>
<td>0.000054</td>
<td>0.000106</td>
<td>0.000098</td>
<td>0.000000</td>
<td>0.000064</td>
</tr>
</tbody>
</table>

**EWQ<sub>X</sub>S<sub>X</sub>** is the equal-weighted quoted b/a spread, with \( X = \{LV, AV, MM, C<sub>0.05</sub>, C<sub>5.10</sub>\} \) being the method used for calculating the b/a spread. **VWES<sub>X</sub>** is the volume-weighted effective b/a spread, with \( X \) being the method used for calculating the b/a spread. **REWQ<sub>X</sub>S<sub>X</sub>** and **RVWES<sub>X</sub>** are the equal-weighted quoted and volume-weighted effective b/a spreads divided by the true exchange rate respectively. Both with \( X \) being the method used for calculating the b/a spread. **SPR<sub>X</sub>** is the quoted b/a spread, with \( X \) being the method used for calculating the b/a spread. **RSPR<sub>X</sub>** is the quoted b/a spread divided by the true exchange rate and \( X \) being the method used for calculating the b/a spread.
### Appendix D: Summary statistics determinants

#### Summary of the descriptive statistics of the spread determinants for the currencies RUB/EUR TOD and RUB/EUR TOM.

The mean and quartile values for the different determinants of the b/a spread

<table>
<thead>
<tr>
<th></th>
<th>RUB/EUR TOD (half-hours = 595)</th>
<th>RUB/ EUR TOM (half-hours = 1451)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>25%</td>
</tr>
<tr>
<td>$T_{LV}$</td>
<td>40.1501</td>
<td>39.9103</td>
</tr>
<tr>
<td>$in v(T_{LV})$</td>
<td>0.0249</td>
<td>0.0247</td>
</tr>
<tr>
<td>$T_{AV}$</td>
<td>40.1502</td>
<td>39.9082</td>
</tr>
<tr>
<td>$in v(T_{AV})$</td>
<td>0.0249</td>
<td>0.0247</td>
</tr>
<tr>
<td>$T_{MM}$</td>
<td>40.1506</td>
<td>39.9081</td>
</tr>
<tr>
<td>$in v(T_{MM})$</td>
<td>0.0249</td>
<td>0.0247</td>
</tr>
<tr>
<td>$T_{c05}$</td>
<td>40.1489</td>
<td>39.9012</td>
</tr>
<tr>
<td>$in v(T_{c05})$</td>
<td>0.0249</td>
<td>0.0247</td>
</tr>
<tr>
<td>$T_{c510}$</td>
<td>40.1500</td>
<td>39.9084</td>
</tr>
<tr>
<td>$in v(T_{c510})$</td>
<td>0.0249</td>
<td>0.0247</td>
</tr>
<tr>
<td>$TV$</td>
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<td>12529500</td>
</tr>
<tr>
<td>$in v(TV)$</td>
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<td>4.30E-08</td>
</tr>
<tr>
<td>$C_D$</td>
<td>183.5042</td>
<td>170.0000</td>
</tr>
<tr>
<td>$\sigma_{LV}$</td>
<td>0.0560</td>
<td>0.0305</td>
</tr>
<tr>
<td>$\sigma_{AV}$</td>
<td>0.0527</td>
<td>0.0259</td>
</tr>
<tr>
<td>$\sigma_{MM}$</td>
<td>0.0525</td>
<td>0.0243</td>
</tr>
<tr>
<td>$\sigma_{c05}$</td>
<td>0.0589</td>
<td>0.0325</td>
</tr>
<tr>
<td>$\sigma_{c510}$</td>
<td>0.0586</td>
<td>0.0307</td>
</tr>
<tr>
<td>$\sqrt{t_1}$</td>
<td>8.7851</td>
<td>7.2443</td>
</tr>
<tr>
<td>$\sqrt{t_2}$</td>
<td>4.7688</td>
<td>4.0498</td>
</tr>
</tbody>
</table>

Appendix D.1
<table>
<thead>
<tr>
<th>$\text{IHP}_{LV,t_1}$</th>
<th>0.0046</th>
<th>0.0025</th>
<th>0.0037</th>
<th>0.0057</th>
<th>0.0043</th>
<th>0.0024</th>
<th>0.0035</th>
<th>0.0053</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{IHP}_{LV,t_1}$</td>
<td>0.0025</td>
<td>0.0014</td>
<td>0.0020</td>
<td>0.0032</td>
<td>0.0021</td>
<td>0.0012</td>
<td>0.0017</td>
<td>0.0026</td>
</tr>
<tr>
<td>$\text{IHP}_{AV,t_1}$</td>
<td>0.0043</td>
<td>0.0022</td>
<td>0.0034</td>
<td>0.0055</td>
<td>0.0035</td>
<td>0.0018</td>
<td>0.0029</td>
<td>0.0043</td>
</tr>
<tr>
<td>$\text{IHP}_{AV,t_1}$</td>
<td>0.0023</td>
<td>0.0012</td>
<td>0.0018</td>
<td>0.0031</td>
<td>0.0018</td>
<td>0.0010</td>
<td>0.0014</td>
<td>0.0022</td>
</tr>
<tr>
<td>$\text{IHP}_{MM,t_1}$</td>
<td>0.0043</td>
<td>0.0021</td>
<td>0.0033</td>
<td>0.0053</td>
<td>0.0038</td>
<td>0.0020</td>
<td>0.0030</td>
<td>0.0046</td>
</tr>
<tr>
<td>$\text{IHP}_{MM,t_1}$</td>
<td>0.0023</td>
<td>0.0011</td>
<td>0.0018</td>
<td>0.0030</td>
<td>0.0019</td>
<td>0.0010</td>
<td>0.0016</td>
<td>0.0024</td>
</tr>
<tr>
<td>$\text{IHP}<em>{C</em>{OS},t_1}$</td>
<td>0.0048</td>
<td>0.0028</td>
<td>0.0040</td>
<td>0.0060</td>
<td>0.0043</td>
<td>0.0024</td>
<td>0.0036</td>
<td>0.0054</td>
</tr>
<tr>
<td>$\text{IHP}<em>{C</em>{OS},t_2}$</td>
<td>0.0026</td>
<td>0.0015</td>
<td>0.0022</td>
<td>0.0034</td>
<td>0.0021</td>
<td>0.0012</td>
<td>0.0019</td>
<td>0.0027</td>
</tr>
<tr>
<td>$\text{IHP}<em>{C</em>{S10},t_1}$</td>
<td>0.0048</td>
<td>0.0026</td>
<td>0.0039</td>
<td>0.0062</td>
<td>0.0043</td>
<td>0.0024</td>
<td>0.0036</td>
<td>0.0052</td>
</tr>
<tr>
<td>$\text{IHP}<em>{C</em>{S10},t_2}$</td>
<td>0.0026</td>
<td>0.0014</td>
<td>0.0022</td>
<td>0.0034</td>
<td>0.0021</td>
<td>0.0012</td>
<td>0.0018</td>
<td>0.0027</td>
</tr>
</tbody>
</table>

$T_x$ is the true exchange rate, corresponding to the b/a spread calculated according to method $X=(LV, AV, MM, C_{OS}, C_{S10})$. $Inv(T_x)$ is the inverse of $T_x$. $C_Y$ is a measure for competition, with $Y=(D, T, V)$ being the method used. $\sigma_x$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{\tau}$ is the average square root of the number of seconds between trades according to method $Z=(1,2)$. $\text{IHP}_{X,t}$ is the inventory holding premium based on $T_x$, $\sigma_x$ and $\sqrt{\tau}$.

Table D-1: Summary of the descriptive statistics of the spread determinants for the currencies RUB/EUR TOD and RUB/EUR TOM
## Summary of the descriptive statistics of the spread determinants for the currencies RUB/USD TOD and RUB/USD TOM.

The mean and quartile values for the different determinants of the b/a spread:

<table>
<thead>
<tr>
<th></th>
<th>RUB/USD TOD (half-hours = 995)</th>
<th>RUB/USD TOM (half-hours = 1451)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>25%</td>
</tr>
<tr>
<td>$\text{inv}(T_{LV})$</td>
<td>0.0350</td>
<td>0.0342</td>
</tr>
<tr>
<td>$\text{inv}(T_{AV})$</td>
<td>0.0350</td>
<td>0.0342</td>
</tr>
<tr>
<td>$\text{inv}(T_{MM})$</td>
<td>0.0350</td>
<td>0.0342</td>
</tr>
<tr>
<td>$\text{inv}(T_{c5g})$</td>
<td>0.0350</td>
<td>0.0342</td>
</tr>
<tr>
<td>$\text{inv}(T_{c510})$</td>
<td>0.0350</td>
<td>0.0342</td>
</tr>
<tr>
<td>$TV$</td>
<td>113985988</td>
<td>64729750</td>
</tr>
<tr>
<td>$\text{inv}(TV)$</td>
<td>1.30E-08</td>
<td>6.55E-09</td>
</tr>
<tr>
<td>$C_D$</td>
<td>268.2060</td>
<td>263.0000</td>
</tr>
<tr>
<td>$\sigma_{LV}$</td>
<td>0.0607</td>
<td>0.0260</td>
</tr>
<tr>
<td>$\sigma_{AV}$</td>
<td>0.0554</td>
<td>0.0216</td>
</tr>
<tr>
<td>$\sigma_{MM}$</td>
<td>0.0590</td>
<td>0.0252</td>
</tr>
<tr>
<td>$\sigma_{c5g}$</td>
<td>0.0613</td>
<td>0.0264</td>
</tr>
<tr>
<td>$\sigma_{c510}$</td>
<td>0.0631</td>
<td>0.0280</td>
</tr>
<tr>
<td>$\sqrt{T_{1}}$</td>
<td>6.6311</td>
<td>5.1411</td>
</tr>
<tr>
<td>$\sqrt{T_{2}}$</td>
<td>3.1197</td>
<td>2.3878</td>
</tr>
<tr>
<td>$IHP_{LV,t_1}$</td>
<td>0.0019</td>
<td>0.0010</td>
</tr>
<tr>
<td>$IHP_{LV,t_1}$</td>
<td>0.0009</td>
<td>0.0005</td>
</tr>
<tr>
<td>$IHP_{AV,t_1}$</td>
<td>0.0017</td>
<td>0.0008</td>
</tr>
</tbody>
</table>

Appendix D.3
| $IHP_{AV,t_1}$ | 0.0008 | 0.0004 | 0.0006 | 0.0010 | 0.0006 | 0.0003 | 0.0004 | 0.0007 |
| $IHP_{MM,t_1}$ | 0.0019 | 0.0009 | 0.0015 | 0.0025 | 0.0015 | 0.0008 | 0.0012 | 0.0019 |
| $IHP_{MM,t_2}$ | 0.0009 | 0.0004 | 0.0007 | 0.0011 | 0.0007 | 0.0004 | 0.0006 | 0.0009 |
| $IHP_{C_{0.5},t_1}$ | 0.0020 | 0.0010 | 0.0016 | 0.0024 | 0.0014 | 0.0007 | 0.0011 | 0.0018 |
| $IHP_{C_{0.5},t_2}$ | 0.0009 | 0.0005 | 0.0007 | 0.0011 | 0.0007 | 0.0003 | 0.0005 | 0.0009 |
| $IHP_{C_{5.10},t_1}$ | 0.0020 | 0.0011 | 0.0016 | 0.0025 | 0.0014 | 0.0007 | 0.0011 | 0.0017 |
| $IHP_{C_{5.10},t_2}$ | 0.0009 | 0.0005 | 0.0008 | 0.0012 | 0.0006 | 0.0003 | 0.0005 | 0.0008 |

$T_X$ is the true exchange rate, corresponding to the b/a spread calculated according to method $X=[LV, AV, MM, C_{0.5}, C_{5.10}]$. $\text{Inv}(T_X)$ is the inverse of $T_X$. $C_Y$ is a measure for competition, with $Y=[D, T, V]$ being the method used. $\alpha_X$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{\tau_Z}$ is the average square root of the number of seconds between trades according to method $Z=[1, 2]$. $IHP_{X,t_Z}$ is the inventory holding premium based on $T_X$, $\alpha_X$ and $\sqrt{\tau_Z}$.

Table D-2: Summary of descriptive statistics of the spread determinants for the currencies RUB/USD TOD and RUB/USD TOM

Appendix D.4
## Appendix E: Correlation tables

### Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the LV method

Summary of the correlations between the variables used for the regressions

<table>
<thead>
<tr>
<th></th>
<th>SPR&lt;sub&gt;LV&lt;/sub&gt;</th>
<th>RSP&lt;sub&gt;LV&lt;/sub&gt;</th>
<th>T&lt;sub&gt;LV&lt;/sub&gt;</th>
<th>inv(&lt;i&gt;T&lt;sub&gt;LV&lt;/sub&gt;&lt;/i&gt;)</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C&lt;sub&gt;D&lt;/sub&gt;</th>
<th>C&lt;sub&gt;T&lt;/sub&gt;</th>
<th>C&lt;sub&gt;V&lt;/sub&gt;</th>
<th>σ&lt;sub&gt;LV&lt;/sub&gt;</th>
<th>√&lt;i&gt;τ&lt;/i&gt;&lt;sub&gt;1&lt;/sub&gt;</th>
<th>√&lt;i&gt;τ&lt;/i&gt;&lt;sub&gt;2&lt;/sub&gt;</th>
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<td>RSP&lt;sub&gt;LV&lt;/sub&gt;</td>
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<td>-0.0945</td>
<td>-0.0343</td>
<td>0.0361</td>
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<tr>
<td>inv(TV)</td>
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<td>-0.6609</td>
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<td>-0.0282</td>
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<td>0.1732</td>
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<td>-0.2333</td>
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<td>-0.0524</td>
<td>0.0032</td>
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</table>

SPR<sub>LV</sub> is the b/a spread calculated according to the LV method. RSP<sub>LV</sub> is the relative spread, which is equal to the SPR<sub>LV</sub> divided by the true exchange rate. T<sub>LV</sub> is the true exchange rate. Inv(<i>T<sub>LV</sub></i>) is the inverse of T<sub>LV</sub>. TV is the total volume traded per half-hour. Inv(TV) is the inverse of TV. C<sub>D</sub> is a measure for competition, with Y={D,T,V} being the corresponding method being used. σ<sub>LV</sub> is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. √<i>τ</i><sub>1</sub> is the average square root of the number of seconds between trades according to method Z={1,2}. IHP<sub>L,V,T</sub> is the inventory holding premium based on SPR<sub>LV</sub>, σ<sub>LV</sub> and √<i>τ</i><sub>2</sub>.

Table E-1: Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the LV method
### Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the AV method

Summary of the correlations between the variables used for the regressions

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<th>RSPR &lt;sub&gt;AV&lt;/sub&gt;</th>
<th>T &lt;sub&gt;AV&lt;/sub&gt;</th>
<th>inv(T &lt;sub&gt;AV&lt;/sub&gt;)</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C &lt;sub&gt;D&lt;/sub&gt;</th>
<th>C &lt;sub&gt;T&lt;/sub&gt;</th>
<th>C &lt;sub&gt;V&lt;/sub&gt;</th>
<th>σ &lt;sub&gt;AV&lt;/sub&gt;</th>
<th>√&lt;sup&gt;τ&lt;/sup&gt;₁</th>
<th>√&lt;sup&gt;τ&lt;/sup&gt;₂</th>
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<td>RSPR &lt;sub&gt;AV&lt;/sub&gt;</td>
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<td>inv(TV)</td>
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<td>σ &lt;sub&gt;AV&lt;/sub&gt;</td>
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<tr>
<td>√&lt;sup&gt;τ&lt;/sup&gt;₁</td>
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<td>0.0141</td>
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<td>-0.5397</td>
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<td>0.2327</td>
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<td>-0.5529</td>
<td>-0.2489</td>
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<tr>
<td>√&lt;sup&gt;τ&lt;/sup&gt;₂</td>
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</tr>
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<td>-0.0996</td>
<td>-0.0507</td>
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SPR<sub>AV</sub> is the b/a spread calculated according to the AV method. RSPR<sub>AV</sub> is the relative spread, which is equal to the SPR<sub>AV</sub> divided by the true exchange rate. T<sub>AV</sub> is the true exchange rate. inv(T<sub>AV</sub>) is the inverse of T<sub>AV</sub>. TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. C<sub>V</sub> is a measure for competition, with Y={D,T,V} being the corresponding method being used. σ<sub>AV</sub> is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. 1<sub>τ</sub> is the average square root of the number of seconds between trades according to method z={1,2}. IHP<sub>AV,t₁</sub> is the inventory holding premium based on SPR<sub>AV</sub>, σ<sub>AV</sub> and 1<sub>τ</sub>.

Table E-2: Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the AV method
**Summary of the correlations between the variables used for regressions**

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<th>RSPR&lt;sub&gt;MM&lt;/sub&gt;</th>
<th>T&lt;sub&gt;MM&lt;/sub&gt;</th>
<th>inv(T&lt;sub&gt;MM&lt;/sub&gt;)</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C&lt;sub&gt;D&lt;/sub&gt;</th>
<th>C&lt;sub&gt;T&lt;/sub&gt;</th>
<th>C&lt;sub&gt;V&lt;/sub&gt;</th>
<th>σ&lt;sub&gt;MM&lt;/sub&gt;</th>
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<td>-0.6730</td>
<td>-0.2608</td>
<td>0.7625</td>
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</tr>
<tr>
<td>IHP&lt;sub&gt;MM,t&lt;sub&gt;1&lt;/sub&gt;&lt;/sub&gt;</td>
<td>0.2157</td>
<td>0.2168</td>
<td>-0.0562</td>
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<td>-0.1096</td>
<td>-0.3259</td>
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<td>0.1018</td>
<td>0.9508</td>
<td>-0.0076</td>
<td>-0.0995</td>
</tr>
<tr>
<td>IHP&lt;sub&gt;MM,t&lt;sub&gt;2&lt;/sub&gt;&lt;/sub&gt;</td>
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<td>0.0693</td>
<td>0.0729</td>
<td>-0.1144</td>
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<td>0.0913</td>
<td>0.9701</td>
<td>-0.1151</td>
<td>-0.0699</td>
</tr>
</tbody>
</table>

SPR<sub>MM</sub> is the b/a spread calculated according to the MM method. RSPR<sub>MM</sub> is the relative spread, which is equal to the SPR<sub>MM</sub> divided by the true exchange rate. T<sub>MM</sub> is the true exchange rate. inv(T<sub>MM</sub>) is the inverse of T<sub>MM</sub>. TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. C<sub>V</sub> is a measure for competition, with Y={D,T,V} being the corresponding method being used. σ<sub>MM</sub> is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. √τ<sub>i</sub> is the average square root of the number of seconds between trades according to method Z={1,2}. IHP<sub>MM,t<sub>i</sub></sub> is the inventory holding premium based on SPR<sub>MM</sub>, σ<sub>MM</sub> and √τ<sub>i</sub>.

Table E-3: Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the MM method.

Appendix E.3
### Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the \( C_{05} \) method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>( SPR_{C_{05}} )</th>
<th>( RSPR_{C_{05}} )</th>
<th>( T_{C_{05}} )</th>
<th>( inv(T_{C_{05}}) )</th>
<th>( TV )</th>
<th>( inv(TV) )</th>
<th>( C_D )</th>
<th>( C_T )</th>
<th>( C_V )</th>
<th>( \sigma_{C_{05}} )</th>
<th>( \sqrt{\hat{t}_1} )</th>
<th>( \sqrt{\hat{t}_2} )</th>
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<tbody>
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<td>( SPR_{C_{05}} )</td>
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</tr>
<tr>
<td>( RSPR_{C_{05}} )</td>
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<td>1.0000</td>
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<tr>
<td>( T_{C_{05}} )</td>
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</tr>
<tr>
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<tr>
<td>( TV )</td>
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<td>-0.0998</td>
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</tr>
<tr>
<td>( inv(TV) )</td>
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<td>0.1662</td>
<td>0.0346</td>
<td>-0.0357</td>
<td>-0.6609</td>
<td>1.0000</td>
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<tr>
<td>( C_D )</td>
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<td>0.1032</td>
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<tr>
<td>( C_T )</td>
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<td>-0.1377</td>
<td>-0.0584</td>
<td>0.0605</td>
<td>0.7159</td>
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<td>-0.3388</td>
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</tr>
<tr>
<td>( C_V )</td>
<td>-0.1271</td>
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<td>( \sigma_{C_{05}} )</td>
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<tr>
<td>( \sqrt{\hat{t}_1} )</td>
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<td>-0.5397</td>
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<td>0.2270</td>
<td>-0.8407</td>
<td>-0.6730</td>
<td>-0.2473</td>
<td>0.7625</td>
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</tr>
<tr>
<td>( IHP_{C_{05},t_1} )</td>
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<td>0.0801</td>
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<td>0.1270</td>
<td>0.0387</td>
<td>-0.0727</td>
<td>-0.2958</td>
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<td>0.0487</td>
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<td>0.0781</td>
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<td>-0.0713</td>
<td>0.0006</td>
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</table>

\( SPR_{C_{05}} \) is the b/a spread calculated according to the \( C_{05} \) method. \( RSPR_{C_{05}} \) is the relative spread, which is equal to the \( SPR_{C_{05}} \) divided by the true exchange rate. \( T_{C_{05}} \) is the true exchange rate. \( inv(T_{C_{05}}) \) is the inverse of \( T_{C_{05}} \). \( TV \) is the total volume traded per half-hour. \( inv(TV) \) is the inverse of \( TV \). \( C_D \) is a measure for competition, with \( Y=\{D,T,V\} \) being the corresponding method being used. \( \sigma_{C_{05}} \) is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. \( \sqrt{\hat{t}_2} \) is the average square root of the number of seconds between trades according to method \( Z=\{1,2\} \). \( IHP_{C_{05},t} \) is the inventory holding premium based on \( SPR_{C_{05}}, \sigma_{C_{05}} \) and \( \sqrt{\hat{t}_2} \).

Table E-4: Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the \( C_{05} \) method

Appendix E.4
Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the $C_{S10}$ method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>$SPR_{C_{S10}}$</th>
<th>$RSPR_{C_{S10}}$</th>
<th>$T_{C_{S10}}$</th>
<th>$inv(T_{C_{S10}})$</th>
<th>$TV$</th>
<th>$inv(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{C_{S10}}$</th>
<th>$\sqrt{\bar{t}_1}$</th>
<th>$\sqrt{\bar{t}_2}$</th>
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<tbody>
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</tr>
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<td>1.0000</td>
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<td>$T_{C_{S10}}$</td>
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<td>$inv(T_{C_{S10}})$</td>
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</tr>
<tr>
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<tr>
<td>$inv(TV)$</td>
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<td>-0.6609</td>
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</tr>
<tr>
<td>$C_D$</td>
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<td>-0.1450</td>
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<td>-0.0995</td>
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<td>$C_V$</td>
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<td>-0.6645</td>
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<td>-0.2325</td>
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<td>0.0228</td>
<td>-0.6581</td>
<td>0.7397</td>
<td>0.2270</td>
<td>-0.8407</td>
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<td>$IHP_{C_{S10}\tau_1}$</td>
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</table>

$SPR_{C_{S10}}$ is the b/a spread calculated according to the $C_{S10}$ method. $RSPR_{C_{S10}}$ is the relative spread, which is equal to the $SPR_{C_{S10}}$ divided by the true exchange rate. $T_{C_{S10}}$ is the true exchange rate. $inv(T_{C_{S10}})$ is the inverse of $T_{C_{S10}}$. $TV$ is the total volume traded per half-hour. $inv(TV)$ is the inverse of $TV$. $C_T$ is a measure for competition, with $Y=(D,T,V)$ being the corresponding method being used. $\sigma_{C_{S10}}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{\bar{t}_1}$ is the average square root of the number of seconds between trades according to method $Z=(1,2)$. $IHP_{C_{S10}\tau_1}$ is the inventory holding premium based on $SPR_{C_{S10}}$, $\sigma_{C_{S10}}$, and $\sqrt{\bar{t}_2}$. $IHP_{C_{S10}\tau_2}$ is the inventory holding premium based on $SPR_{C_{S10}}$, $\sigma_{C_{S10}}$, and $\sqrt{\bar{t}_2}$.

Table E-5: Pearson correlation table for RUB/EUR TOD with the b/a spread calculated according to the $C_{S10}$ method
### Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the LV method

Summary of the correlations between the variables used for regressions

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<th>RSPR_{LV}</th>
<th>T_{LV}</th>
<th>inv(T_{LV})</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C_D</th>
<th>C_T</th>
<th>C_V</th>
<th>\sigma_{LV}</th>
<th>\sqrt{t_1}</th>
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<td>0.1400</td>
<td>0.2328</td>
</tr>
</tbody>
</table>

SPR_{LV} is the b/a spread calculated according to the LV method. RSPR_{LV} is the relative spread, which is equal to the SPR_{LV} divided by the true exchange rate. T_{LV} is the true exchange rate. inv(T_{LV}) is the inverse of T_{LV}. TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. C_Y is a measure for competition, with Y={D,T,V} being the corresponding method being used. \sigma_{LV} is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. \sqrt{t_1} is the average square root of the number of seconds between trades according to method Z=(1,2). IHP_{LV,t} is the inventory holding premium based on SPR_{LV}, \sigma_{LV} and \sqrt{t_i}.

Table E-6: Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the LV method
### Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the AV method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>SPR$_{AV}$</th>
<th>RSPR$_{AV}$</th>
<th>T$_{AV}$</th>
<th>inv(T$_{AV}$)</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C$_{D}$</th>
<th>C$_{T}$</th>
<th>C$_{V}$</th>
<th>$\sigma_{AV}$</th>
<th>$\sqrt{t_1}$</th>
<th>$\sqrt{t_2}$</th>
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<tbody>
<tr>
<td>SPR$_{AV}$</td>
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<td>RSPR$_{AV}$</td>
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<td>T$_{AV}$</td>
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</tr>
<tr>
<td>inv(T$_{AV}$)</td>
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</tr>
<tr>
<td>TV</td>
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<td></td>
</tr>
<tr>
<td>inv(TV)</td>
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<td>-0.1154</td>
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<tr>
<td>C$_{D}$</td>
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<td>-0.1904</td>
<td>0.1922</td>
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</tr>
<tr>
<td>C$_{T}$</td>
<td>0.0453</td>
<td>0.0455</td>
<td>-0.0527</td>
<td>0.0530</td>
<td>0.4970</td>
<td>-0.4587</td>
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</tr>
<tr>
<td>C$_{V}$</td>
<td>0.1177</td>
<td>0.1178</td>
<td>-0.0242</td>
<td>0.0243</td>
<td>0.9218</td>
<td>-0.6106</td>
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<td>0.5625</td>
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<tr>
<td>$\sigma_{AV}$</td>
<td>-0.0365</td>
<td>-0.0362</td>
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<td>0.0940</td>
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<td>$\sqrt{t_1}$</td>
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<td>0.5867</td>
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<td>-0.5009</td>
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</tr>
<tr>
<td>IHP$_{AV,t_1}$</td>
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<td>-0.0047</td>
<td>-0.0731</td>
<td>0.0731</td>
<td>-0.0242</td>
<td>-0.0293</td>
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<td>0.9237</td>
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<td>IHP$_{AV,t_2}$</td>
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<td>-0.0703</td>
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<td>0.9359</td>
<td>0.1442</td>
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</tr>
</tbody>
</table>

**SPR$_{AV}$** is the b/a spread calculated according to the AV method. **RSPR$_{AV}$** is the relative spread, which is equal to the SPR$_{AV}$ divided by the true exchange rate. **T$_{AV}$** is the true exchange rate. **inv(T$_{AV}$)** is the inverse of T$_{AV}$. **TV** is the total volume traded per half-hour. **inv(TV)** is the inverse of TV. **C$_{V}$** is a measure for competition, with $Y$={D,T,V} being the corresponding method being used. **$\sigma_{AV}$** is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. **$\sqrt{t_1}$** is the average square root of the number of seconds between trades according to method $Z$=(1,2). **IHP$_{AV,t_1}$** is the inventory holding premium based on SPR$_{AV}$, $\sigma_{AV}$ and **$\sqrt{t_2}$**.

Table E-7: Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to to the AV method
## Appendix E.8

### Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the MM method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>SPR(_{MM})</th>
<th>RSPR(_{MM})</th>
<th>T(_{MM})</th>
<th>inv(T(_{MM}))</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C(_D)</th>
<th>C(_T)</th>
<th>C(_V)</th>
<th>(\sigma_{MM})</th>
<th>(\sqrt{\bar{t}_1})</th>
<th>(\sqrt{\bar{t}_2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPR(_{MM})</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
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<td>RSPR(_{MM})</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>T(_{MM})</td>
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<tr>
<td>inv(T(_{MM}))</td>
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<td></td>
</tr>
<tr>
<td>inv(TV)</td>
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<td>-0.1125</td>
<td>-0.5716</td>
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</tr>
<tr>
<td>C(_D)</td>
<td>0.1781</td>
<td>0.1801</td>
<td>-0.1894</td>
<td>0.1912</td>
<td>0.2151</td>
<td>-0.2082</td>
<td>1.0000</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>C(_T)</td>
<td>0.3052</td>
<td>0.3048</td>
<td>-0.0489</td>
<td>0.0493</td>
<td>0.4970</td>
<td>-0.4587</td>
<td>0.1525</td>
<td>1.0000</td>
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<tr>
<td>C(_V)</td>
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<td>0.9218</td>
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<td>0.5625</td>
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<tr>
<td>(\sigma_{MM})</td>
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<tr>
<td>(\sqrt{\bar{t}_1})</td>
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<td>-0.2419</td>
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<td>-0.0520</td>
<td>-0.3372</td>
<td>0.3893</td>
<td>-0.2578</td>
<td>-0.4576</td>
<td>-0.3312</td>
<td>-0.0339</td>
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<tr>
<td>(\sqrt{\bar{t}_2})</td>
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<td>-0.3044</td>
<td>0.0927</td>
<td>-0.0937</td>
<td>-0.4895</td>
<td>0.5867</td>
<td>-0.2172</td>
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<td>-0.5009</td>
<td>-0.0788</td>
<td>0.5848</td>
<td>1.0000</td>
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<tr>
<td>(IHP_{MM,t_1})</td>
<td>0.0736</td>
<td>0.0748</td>
<td>-0.0964</td>
<td>0.0961</td>
<td>-0.0166</td>
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<td>0.0886</td>
<td>-0.1305</td>
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<td>0.9250</td>
<td>0.2813</td>
<td>0.0957</td>
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<tr>
<td>(IHP_{MM,t_2})</td>
<td>0.0740</td>
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<td>-0.0937</td>
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<td>-0.1050</td>
<td>0.9360</td>
<td>0.1406</td>
<td>0.2152</td>
</tr>
</tbody>
</table>

- SPR\(_{MM}\) is the b/a spread calculated according to the MM method. RSPR\(_{MM}\) is the relative spread, which is equal to the SPR\(_{MM}\) divided by the true exchange rate. T\(_{MM}\) is the true exchange rate. inv(T\(_{MM}\)) is the inverse of T\(_{MM}\). TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. C\(_V\) is a measure for competition, with Y\(=\{D,T,V\}\) being the corresponding method being used. \(\sigma_{MM}\) is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. \(\sqrt{\bar{t}_1}\) is the average square root of the number of seconds between trades according to method Z\(=\{1,2\}\). \(IHP_{MM,t}\) is the inventory holding premium based on SPR\(_{MM}\), \(\sigma_{MM}\) and \(\sqrt{\bar{t}_2}\).

Table E-8: Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the MM method
### Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the $C_{05}$ method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>$SPR_{C_{05}}$</th>
<th>$RSPR_{C_{05}}$</th>
<th>$T_{C_{05}}$</th>
<th>$inv(T_{C_{05}})$</th>
<th>$TV$</th>
<th>$inv(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{C_{05}}$</th>
<th>$\sqrt{\hat{t}_1}$</th>
<th>$\sqrt{\hat{t}_2}$</th>
</tr>
</thead>
<tbody>
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<td>$SPR_{C_{05}}$</td>
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<td>$RSPR_{C_{05}}$</td>
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</tr>
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<td>$inv(TV)$</td>
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<tr>
<td>$C_D$</td>
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</tr>
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<td>$C_V$</td>
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</tr>
<tr>
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<td>-0.1005</td>
<td>-0.4895</td>
<td>0.5867</td>
<td>-0.2172</td>
<td>-0.8007</td>
<td>-0.5009</td>
<td>-0.1037</td>
<td>0.5848</td>
<td>1.0000</td>
</tr>
<tr>
<td>$IH_{C_{05}T_1}$</td>
<td>0.0082</td>
<td>0.0085</td>
<td>-0.0994</td>
<td>0.0991</td>
<td>-0.0501</td>
<td>0.0049</td>
<td>0.0673</td>
<td>-0.1285</td>
<td>-0.0691</td>
<td>0.9043</td>
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</tr>
<tr>
<td>$IH_{C_{05}T_2}$</td>
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<td>0.9126</td>
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</tr>
</tbody>
</table>

$SPR_{C_{05}}$ is the b/a spread calculated according to the $C_{05}$ method. $RSPR_{C_{05}}$ is the relative spread, which is equal to the $SPR_{C_{05}}$ divided by the true exchange rate. $T_{C_{05}}$ is the true exchange rate. $inv(T_{C_{05}})$ is the inverse of $T_{C_{05}}$. $TV$ is the total volume traded per half-hour. $inv(TV)$ is the inverse of $TV$. $C_D$ is a measure for competition, with $Y = \{D,T,V\}$ being the corresponding method being used. $\sigma_{C_{05}}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{\hat{t}_1}$ and $\sqrt{\hat{t}_2}$ are the average square root of the number of seconds between trades according to method $Z = \{1,2\}$. $IH_{C_{05}T_1}$ is the inventory holding premium based on $SPR_{C_{05}}$, $\sigma_{C_{05}}$, and $\sqrt{\hat{t}_2}$.

Table E-9: Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the $C_{05}$ method
Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the $C_{S10}$ method

Summary of the correlations between the variables used for regressions

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<th>$SPR_{C_{S10}}$</th>
<th>$RSPR_{C_{S10}}$</th>
<th>$T_{C_{S10}}$</th>
<th>$\text{inv}(T_{C_{S10}})$</th>
<th>$TV$</th>
<th>$\text{inv}(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{C_{S10}}$</th>
<th>$\sqrt{\bar{t}}_1$</th>
<th>$\sqrt{\bar{t}}_2$</th>
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</thead>
<tbody>
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<tr>
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<td>0.0830</td>
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<td>0.0605</td>
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$SPR_{C_{S10}}$ is the b/a spread calculated according to the $C_{S10}$ method. $RSPR_{C_{S10}}$ is the relative spread, which is equal to the $SPR_{C_{S10}}$ divided by the true exchange rate. $T_{C_{S10}}$ is the true exchange rate. $\text{inv}(T_{C_{S10}})$ is the inverse of $T_{C_{S10}}$. $TV$ is the total volume traded per half-hour. $\text{inv}(TV)$ is the inverse of $TV$. $C_Y$ is a measure for competition, with $Y=(D,T,V)$ being the corresponding method being used. $\sigma_{C_{S10}}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{\bar{t}}_1$ is the average square root of the number of seconds between trades according to method $Z=(1,2)$. $\text{IHP}_{C_{S10}^{*,1}}$ is the inventory holding premium based on $SPR_{C_{S10}}$, $\sigma_{C_{S10}}$, and $\sqrt{\bar{t}}_2$.

Table E-10: Pearson correlation table for RUB/EUR TOM with the b/a spread calculated according to the $C_{S10}$ method

Appendix E.10
### Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the LV method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>$\text{SPR}_{LV}$</th>
<th>$\text{RSPR}_{LV}$</th>
<th>$\text{T}_{LV}$</th>
<th>$\text{inv}(\text{T}_{LV})$</th>
<th>$\text{TV}$</th>
<th>$\text{inv}(\text{TV})$</th>
<th>$\text{C}_D$</th>
<th>$\text{C}_T$</th>
<th>$\text{C}_V$</th>
<th>$\sigma_{LV}$</th>
<th>$\sqrt{t_1}$</th>
<th>$\sqrt{t_2}$</th>
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<td>$\text{inv}(\text{TV})$</td>
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<tr>
<td>$\sigma_{LV}$</td>
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$\text{SPR}_{LV}$ is the b/a spread calculated according to the LV method. $\text{RSPR}_{LV}$ is the relative spread, which is equal to the $\text{SPR}_{LV}$ divided by the true exchange rate. $T_{LV}$ is the true exchange rate. $\text{inv}(T_{LV})$ is the inverse of $T_{LV}$. $TV$ is the total volume traded per half-hour. $\text{inv}(TV)$ is the inverse of $TV$. $C_Y$ is a measure for competition, with $Y=D,T,V$ being the corresponding method being used. $\sigma_{LV}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{t_1}$ is the average square root of the number of seconds between trades according to method $Z=1,2$. $\text{IHP}_{LV,t_1}$ is the inventory holding premium based on $\text{SPR}_{LV}$, $\sigma_{LV}$ and $\sqrt{t_2}$.
### Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the AV method

Summary of the correlations between the variables used for regressions

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<th>RSPR\textsubscript{AV}</th>
<th>T\textsubscript{AV}</th>
<th>inv(T\textsubscript{AV})</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C\textsubscript{D}</th>
<th>C\textsubscript{T}</th>
<th>C\textsubscript{V}</th>
<th>σ\textsubscript{AV}</th>
<th>√t\textsubscript{1}</th>
<th>√t\textsubscript{2}</th>
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</tbody>
</table>

\(SPR\textsubscript{AV}\) is the b/a spread calculated according to the AV method. \(RSPR\textsubscript{AV}\) is the relative spread, which is equal to the \(SPR\textsubscript{AV}\) divided by the true exchange rate. \(T\textsubscript{AV}\) is the true exchange rate. \(Inv(T\textsubscript{AV})\) is the inverse of \(T\textsubscript{AV}\). \(TV\) is the total volume traded per half-hour. \(Inv(TV)\) is the inverse of \(TV\). \(C\textsubscript{V}\) is a measure for competition, with \(Y=\{D,T,V\}\) being the corresponding method being used. \(\sigma\textsubscript{AV}\) is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. \(\sqrt{t}\) is the average square root of the number of seconds between trades according to method \(Z=\{1,2\}\). \(IHP\textsubscript{AV,t1}\) is the inventory holding premium based on \(SPR\textsubscript{AV}, \sigma\textsubscript{AV}\) and \(\sqrt{t}\).

Table E-12: Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the AV method
# Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the MM method

Summary of the correlations between the variables used for regressions

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<th>$TV$</th>
<th>$\text{inv}(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{MM}$</th>
<th>$\sqrt{t_1}$</th>
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<tr>
<td>$\text{inv}(TV)$</td>
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<tr>
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<td>0.0906</td>
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<td>-0.3184</td>
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</tr>
<tr>
<td>$\sqrt{t_1}$</td>
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<td>-0.0104</td>
<td>-0.6638</td>
<td>0.5604</td>
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<td>$IH_{MM,t_1}$</td>
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<td>0.0403</td>
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<td>0.0922</td>
<td>0.2843</td>
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<td>0.9528</td>
<td>-0.2744</td>
<td>-0.2689</td>
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</tbody>
</table>

$SPR_{MM}$ is the b/a spread calculated according to the MM method. $RSPR_{MM}$ is the relative spread, which is equal to the $SPR_{MM}$ divided by the true exchange rate. $T_{MM}$ is the true exchange rate. $\text{inv}(T_{MM})$ is the inverse of $T_{MM}$. $TV$ is the total volume traded per half-hour. $\text{inv}(TV)$ is the inverse of $TV$. $C_V$ is a measure for competition, with $Y=(D,T,V)$ being the corresponding method being used. $\sigma_{MM}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{t_1}$ is the average square root of the number of seconds between trades according to method $Z=(1,2)$. $IH_{MM,t_1}$ is the inventory holding premium based on $SPR_{MM}$, $\sigma_{MM}$ and $\sqrt{t_2}$.

Table E-13: Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the MM method
<table>
<thead>
<tr>
<th></th>
<th>SPR_{C_{05}}</th>
<th>RSPR_{C_{05}}</th>
<th>T_{C_{05}}</th>
<th>inv(T_{C_{05}})</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C_D</th>
<th>C_T</th>
<th>C_V</th>
<th>σ_{C_{05}}</th>
<th>√t_1</th>
<th>√t_2</th>
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<td>SPR_{C_{05}}</td>
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<tr>
<td>RSPR_{C_{05}}</td>
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<tr>
<td>T_{C_{05}}</td>
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<tr>
<td>inv(T_{C_{05}})</td>
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<tr>
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<tr>
<td>inv(TV)</td>
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<td>0.1162</td>
<td>-0.1166</td>
<td>-0.5716</td>
<td>1.0000</td>
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<tr>
<td>C_D</td>
<td>-0.0036</td>
<td>-0.0026</td>
<td>-0.1911</td>
<td>0.1929</td>
<td>0.2151</td>
<td>-0.2082</td>
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<td>C_T</td>
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<tr>
<td>C_V</td>
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<td>σ_{C_{05}}</td>
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<td>-0.1547</td>
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<td>0.0816</td>
<td>-0.1351</td>
<td>0.1636</td>
<td>0.0495</td>
<td>0.0521</td>
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<tr>
<td>√t_1</td>
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<td>-0.3372</td>
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<td>-0.4576</td>
<td>-0.3312</td>
<td>-0.0490</td>
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<td>√t_2</td>
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<td>-0.1005</td>
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<td>0.5867</td>
<td>-0.2172</td>
<td>-0.8007</td>
<td>-0.5009</td>
<td>-0.1037</td>
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<tr>
<td>IHP_{C_{05},t_1}</td>
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<td>-0.0501</td>
<td>0.0049</td>
<td>0.0673</td>
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<td>-0.0691</td>
<td>0.9043</td>
<td>0.3212</td>
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<td>-0.1064</td>
<td>0.0712</td>
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<td>-0.1349</td>
<td>0.9126</td>
<td>0.1651</td>
<td>0.2595</td>
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</table>

SPR_{C_{05}} is the b/a spread calculated according to the C_{05} method. RSPR_{C_{05}} is the relative spread, which is equal to the SPR_{C_{05}} divided by the true exchange rate. T_{C_{05}} is the true exchange rate. inv(T_{C_{05}}) is the inverse of T_{C_{05}}. TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. C_T is a measure for competition, with Y={D,T,V} being the corresponding method being used. σ_{C_{05}} is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. √t_1 is the average square root of the number of seconds between trades according to method Z={1,2}. IHP_{C_{05},t_2} is the inventory holding premium based on SPR_{C_{05}}, σ_{C_{05}} and √t_2.

Table E-14: Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the C_{05} method.

Appendix E.14
### Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the $C_{S10}$ method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>$SPR_{C_{S10}}$</th>
<th>$RSPR_{C_{S10}}$</th>
<th>$T_{C_{S10}}$</th>
<th>$inv(T_{C_{S10}})$</th>
<th>$TV$</th>
<th>$inv(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{C_{S10}}$</th>
<th>$\sqrt{\tau_1}$</th>
<th>$\sqrt{\tau_2}$</th>
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<td>$RSPR_{C_{S10}}$</td>
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<td>1.0000</td>
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<tr>
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<tr>
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<td>-0.9999</td>
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<tr>
<td>$TV$</td>
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<td>0.1157</td>
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<tr>
<td>$inv(TV)$</td>
<td>-0.0345</td>
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<td>-0.5716</td>
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<tr>
<td>$C_D$</td>
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<td>0.1931</td>
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<tr>
<td>$C_T$</td>
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<td>0.5867</td>
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<td>-0.5009</td>
<td>-0.0938</td>
<td>0.5848</td>
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<tr>
<td>$IHP_{C_{S10}^f_1}$</td>
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<td>0.0204</td>
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<td>-0.1192</td>
<td>0.9203</td>
<td>0.1631</td>
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</table>

$SPR_{C_{S10}}$ is the b/a spread calculated according to the $C_{S10}$ method. $RSPR_{C_{S10}}$ is the relative spread, which is equal to the $SPR_{C_{S10}}$ divided by the true exchange rate. $T_{C_{S10}}$ is the true exchange rate. $inv(T_{C_{S10}})$ is the inverse of $T_{C_{S10}}$. $TV$ is the total volume traded per half-hour. $inv(TV)$ is the inverse of $TV$. $C_Y$ is a measure for competition, with $Y=$($D,T,V$) being the corresponding method being used. $\sigma_{C_{S10}}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{\tau_1}$ is the average square root of the number of seconds between trades according to method $Z=$($1,2$). $IHP_{C_{S10}^f_1}$ is the inventory holding premium based on $SPR_{C_{S10}}$, $\sigma_{C_{S10}}$, and $\sqrt{\tau_2}$.

Table E-15: Pearson correlation table for RUB/USD TOD with the b/a spread calculated according to the $C_{S10}$ method.
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<th>( \text{RSPR}_{LV} )</th>
<th>( T_{LV} )</th>
<th>( \text{inv}(T_{LV}) )</th>
<th>( TV )</th>
<th>( \text{inv}(TV) )</th>
<th>( C_D )</th>
<th>( C_T )</th>
<th>( C_V )</th>
<th>( \sigma_{LV} )</th>
<th>( \sqrt{t_1} )</th>
<th>( \sqrt{t_2} )</th>
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<td></td>
</tr>
<tr>
<td>( \sigma_{LV} )</td>
<td>0.0178</td>
<td>0.0198</td>
<td>-0.1726</td>
<td>0.1742</td>
<td>0.3832</td>
<td>-0.3282</td>
<td>0.1231</td>
<td>0.3235</td>
<td>0.2782</td>
<td>1.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \sqrt{t_1} )</td>
<td>0.0206</td>
<td>0.0194</td>
<td>0.1094</td>
<td>-0.1125</td>
<td>-0.6491</td>
<td>0.6782</td>
<td>-0.0877</td>
<td>-0.6114</td>
<td>-0.5903</td>
<td>-0.3346</td>
<td>1.0000</td>
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</tr>
<tr>
<td>( \sqrt{t_2} )</td>
<td>0.0194</td>
<td>0.0192</td>
<td>0.0444</td>
<td>-0.0473</td>
<td>-0.7008</td>
<td>0.7474</td>
<td>-0.0470</td>
<td>-0.8059</td>
<td>-0.6598</td>
<td>-0.3789</td>
<td>0.7592</td>
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</tr>
<tr>
<td>( IHP_{LV,t_1} )</td>
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<td>0.1174</td>
<td>0.1843</td>
<td>-0.1880</td>
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<td>0.1440</td>
<td>0.1065</td>
<td>0.9318</td>
<td>-0.0756</td>
<td>-0.1921</td>
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<tr>
<td>( IHP_{LV,t_2} )</td>
<td>0.0299</td>
<td>0.0315</td>
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<td>0.1402</td>
<td>0.2000</td>
<td>-0.1950</td>
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<td>0.1088</td>
<td>0.9502</td>
<td>-0.1751</td>
<td>-0.1603</td>
</tr>
</tbody>
</table>

\( \text{SPR}_{LV} \) is the b/a spread calculated according to the \( LV \) method. \( \text{RSPR}_{LV} \) is the relative spread, which is equal to \( \text{SPR}_{LV} \) divided by the true exchange rate. \( T_{LV} \) is the true exchange rate. \( \text{inv}(T_{LV}) \) is the inverse of \( T_{LV} \). \( TV \) is the total volume traded per half-hour. \( \text{inv}(TV) \) is the inverse of \( TV \). \( C_D \) is a measure for competition, with \( Y=\{D,T,V\} \) being the corresponding method being used. \( \sigma_{LV} \) is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. \( \sqrt{t_1} \) is the average square root of the number of seconds between trades according to method \( Z=\{1,2\} \). \( IHP_{LV,t_1} \) is the inventory holding premium based on \( \text{SPR}_{LV}, \sigma_{LV} \) and \( \sqrt{t_2} \).

Table E-16: Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the \( LV \) method

Appendix E.16
**Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the AV method**

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>$SPR_{AV}$</th>
<th>$RSPR_{AV}$</th>
<th>$T_{AV}$</th>
<th>$\text{inv}(T_{AV})$</th>
<th>$TV$</th>
<th>$\text{inv}(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{AV}$</th>
<th>$\sqrt{t_1}$</th>
<th>$\sqrt{t_2}$</th>
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<td>$SPR_{AV}$</td>
<td>1.0000</td>
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<tr>
<td>$RSPR_{AV}$</td>
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</tr>
<tr>
<td>$T_{AV}$</td>
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<td></td>
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<td>$\text{inv}(T_{AV})$</td>
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</tr>
<tr>
<td>$TV$</td>
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<td>0.0033</td>
<td>-0.1416</td>
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<tr>
<td>$\text{inv}(TV)$</td>
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<td>0.0416</td>
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<td>-0.0979</td>
<td>-0.7214</td>
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<tr>
<td>$C_D$</td>
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<td>0.0031</td>
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<td>0.0463</td>
<td>0.1090</td>
<td>-0.0900</td>
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<tr>
<td>$C_T$</td>
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<td>-0.0007</td>
<td>-0.0071</td>
<td>0.0063</td>
<td>0.6770</td>
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<td>0.1053</td>
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<tr>
<td>$C_V$</td>
<td>0.0033</td>
<td>0.0047</td>
<td>-0.0075</td>
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<td>0.8445</td>
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<td>0.8039</td>
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<tr>
<td>$\sigma_{AV}$</td>
<td>-0.0687</td>
<td>-0.0649</td>
<td>-0.1413</td>
<td>0.1422</td>
<td>0.3642</td>
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<tr>
<td>$\sqrt{t_1}$</td>
<td>0.0232</td>
<td>0.0213</td>
<td>0.1078</td>
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<td>-0.6491</td>
<td>0.6782</td>
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<td>-0.8059</td>
<td>-0.6598</td>
<td>-0.3564</td>
<td>0.7592</td>
<td>1.0000</td>
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<tr>
<td>$IHP_{AV,t_1}$</td>
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<td>0.0902</td>
<td>0.1796</td>
<td>-0.1773</td>
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<td>0.1568</td>
<td>0.1160</td>
<td>0.9400</td>
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<td>-0.1835</td>
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<td>$IHP_{AV,t_2}$</td>
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<td>0.1967</td>
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<td>0.1319</td>
<td>0.1206</td>
<td>0.9587</td>
<td>-0.1649</td>
<td>-0.1585</td>
</tr>
</tbody>
</table>

$SPR_{AV}$ is the b/a spread calculated according to the AV method. $RSPR_{AV}$ is the relative spread, which is equal to the $SPR_{AV}$ divided by the true exchange rate. $T_{AV}$ is the true exchange rate. $\text{inv}(T_{AV})$ is the inverse of $T_{AV}$. $TV$ is the total volume traded per half-hour. $\text{inv}(TV)$ is the inverse of $TV$. $C_V$ is a measure for competition, with $Y=\{D,T,V\}$ being the corresponding method being used. $\sigma_{AV}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{t_1}$ is the average square root of the number of seconds between trades according to method $Z=\{1,2\}$. $IHP_{AV,t}$ is the inventory holding premium based on $SPR_{AV}$, $\sigma_{AV}$ and $\sqrt{t_2}$.

Table E-17: Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the AV method
### Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the MM method

Summary of the correlations between the variables used for regressions

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<tr>
<th></th>
<th>SPR&lt;sub&gt;MM&lt;/sub&gt;</th>
<th>RSPR&lt;sub&gt;MM&lt;/sub&gt;</th>
<th>T&lt;sub&gt;MM&lt;/sub&gt;</th>
<th>inv(T&lt;sub&gt;MM&lt;/sub&gt;)</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C&lt;sub&gt;D&lt;/sub&gt;</th>
<th>C&lt;sub&gt;T&lt;/sub&gt;</th>
<th>C&lt;sub&gt;V&lt;/sub&gt;</th>
<th>σ&lt;sub&gt;MM&lt;/sub&gt;</th>
<th>√t&lt;sub&gt;1&lt;/sub&gt;</th>
<th>√t&lt;sub&gt;2&lt;/sub&gt;</th>
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</thead>
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<tr>
<td>RSPR&lt;sub&gt;MM&lt;/sub&gt;</td>
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<td>T&lt;sub&gt;MM&lt;/sub&gt;</td>
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<td>inv(T&lt;sub&gt;MM&lt;/sub&gt;)</td>
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<tr>
<td>inv(TV)</td>
<td>-0.3616</td>
<td>-0.3617</td>
<td>0.0957</td>
<td>-0.0975</td>
<td>-0.7214</td>
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<td>C&lt;sub&gt;T&lt;/sub&gt;</td>
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<td>-0.6114</td>
<td>-0.5903</td>
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<td>√t&lt;sub&gt;2&lt;/sub&gt;</td>
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<td>-0.3228</td>
<td>0.7592</td>
<td>1.0000</td>
</tr>
<tr>
<td>IHP&lt;sub&gt;MM,t&lt;sub&gt;1&lt;/sub&gt;&lt;/sub&gt;</td>
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<td>0.9412</td>
<td>-0.1107</td>
<td>-0.0725</td>
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</tbody>
</table>

SPR<sub>MM</sub> is the b/a spread calculated according to the MM method. RSPR<sub>MM</sub> is the relative spread, which is equal to the SPR<sub>MM</sub> divided by the true exchange rate. T<sub>MM</sub> is the true exchange rate. inv(T<sub>MM</sub>) is the inverse of T<sub>MM</sub>. TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. C<sub>v</sub> is a measure for competition, with Y=(D,T,V) being the corresponding method being used. σ<sub>MM</sub> is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. √t<sub>1</sub> is the average square root of the number of seconds between trades according to method Z=(1,2). IHP<sub>MM,t<sub>1</sub></sub> is the inventory holding premium based on SPR<sub>MM</sub>, σ<sub>MM</sub> and √t<sub>2</sub>.

Table E-18: Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the MM method
### Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the C₀₅ method

Summary of the correlations between the variables used for regressions

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<th>SPR$<em>{C</em>{05}}$</th>
<th>RSPR$<em>{C</em>{05}}$</th>
<th>T$<em>{C</em>{05}}$</th>
<th>inv(T$<em>{C</em>{05}}$)</th>
<th>TV</th>
<th>inv(TV)</th>
<th>C₀</th>
<th>C₉</th>
<th>Cᵥ</th>
<th>σ$<em>{C</em>{05}}$</th>
<th>$\sqrt{\bar{e}_1}$</th>
<th>$\sqrt{\bar{e}_2}$</th>
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<tr>
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<td>-0.1086</td>
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<td>-0.6491</td>
<td>0.6782</td>
<td>-0.0877</td>
<td>-0.6114</td>
<td>-0.5903</td>
<td>-0.3197</td>
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</tr>
<tr>
<td>$\sqrt{\bar{e}_2}$</td>
<td>-0.0338</td>
<td>-0.0340</td>
<td>0.0439</td>
<td>-0.0469</td>
<td>-0.7008</td>
<td>0.7474</td>
<td>-0.0470</td>
<td>-0.8059</td>
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<td>-0.3497</td>
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<td>IHP$<em>{C</em>{05},t_1}$</td>
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<td>0.0133</td>
<td>-0.1361</td>
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<td>0.0893</td>
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<td>IHP$<em>{C</em>{05},t_2}$</td>
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<td>0.9495</td>
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</table>

SPR$_{C_{05}}$ is the b/a spread calculated according to the C₀₅ method. RSPR$_{C_{05}}$ is the relative spread, which is equal to the SPR$_{C_{05}}$ divided by the true exchange rate. T$_{C_{05}}$ is the true exchange rate. inv(T$_{C_{05}}$) is the inverse of T$_{C_{05}}$. TV is the total volume traded per half-hour. inv(TV) is the inverse of TV. C₀ is a measure for competition, with Y={D,T,V} being the corresponding method being used. σ$_{C_{05}}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{\bar{e}_1}$ and $\sqrt{\bar{e}_2}$ are the average square root of the number of seconds between trades according to method Z={1,2}. IHP$_{C_{05},t_1}$ is the inventory holding premium based on SPR$_{C_{05}}$, σ$_{C_{05}}$, and $\sqrt{\bar{e}_2}$.

Table E-19: Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the C₀₅ method
### Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the $C_{510}$ method

Summary of the correlations between the variables used for regressions

<table>
<thead>
<tr>
<th></th>
<th>$SPR_{C_{510}}$</th>
<th>$RSPR_{C_{510}}$</th>
<th>$T_{C_{510}}$</th>
<th>$\text{inv}(T_{C_{510}})$</th>
<th>$TV$</th>
<th>$\text{inv}(TV)$</th>
<th>$C_D$</th>
<th>$C_T$</th>
<th>$C_V$</th>
<th>$\sigma_{C_{510}}$</th>
<th>$\sqrt{\bar{e}_1}$</th>
<th>$\sqrt{\bar{e}_2}$</th>
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</tr>
<tr>
<td>$\text{inv}(TV)$</td>
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<td>-0.0444</td>
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</tr>
<tr>
<td>$C_D$</td>
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<td>-0.0509</td>
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<td>$C_T$</td>
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<td>$C_V$</td>
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<td>$\sigma_{C_{510}}$</td>
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<td>-0.6114</td>
<td>-0.5903</td>
<td>-0.3121</td>
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</tr>
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<td>-0.7008</td>
<td>0.7474</td>
<td>-0.0470</td>
<td>-0.8059</td>
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<td>-0.3473</td>
<td>0.7592</td>
<td>1.0000</td>
</tr>
<tr>
<td>$IH_{C_{510}}_{\frac{t_1}{2}}$</td>
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<td>0.0470</td>
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<td>0.1085</td>
<td>0.1555</td>
<td>-0.1486</td>
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<td>0.1325</td>
<td>0.0995</td>
<td>0.9339</td>
<td>-0.0485</td>
<td>-0.1525</td>
</tr>
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<td>$IH_{C_{510}}_{\frac{t_2}{2}}$</td>
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<td>0.1686</td>
<td>-0.1534</td>
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<td>0.1010</td>
<td>0.9499</td>
<td>-0.1449</td>
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</tr>
</tbody>
</table>

$SPR_{C_{510}}$ is the b/a spread calculated according to the $C_{510}$ method. $RSPR_{C_{510}}$ is the relative spread, which is equal to the $SPR_{C_{510}}$ divided by the true exchange rate. $T_{C_{510}}$ is the true exchange rate. $\text{inv}(T_{C_{510}})$ is the inverse of $T_{C_{510}}$. $TV$ is the total volume traded per half-hour. $\text{inv}(TV)$ is the inverse of $TV$. $C_V$ is a measure for competition, with $Y=(D,T,V)$ being the corresponding method being used. $\sigma_{C_{510}}$ is the annualized return volatility of the exchange rate computed over the most recent 5 trading half-hours prior to the estimated half-hour. $\sqrt{\bar{e}_1}$ is the average square root of the number of seconds between trades according to method $Z=(1,2)$. $IH_{C_{510}}_{\frac{t_1}{2}}$ is the inventory holding premium based on $SPR_{C_{510}}, \sigma_{C_{510}}$ and $\sqrt{\bar{e}_2}$.

Table E-20: Pearson correlation table for RUB/USD TOM with the b/a spread calculated according to the $C_{510}$ method
Appendix F: Regression results

F.1. Absolute regression results

Regression results for $SPR_{LV}$
Regression results for $SPR_{LV_i} = \alpha_0 + \alpha_1 inv(TV)_i + \alpha_2 C_T_i + \alpha_3 IHP_{LV,i,t_i} + \epsilon_i$

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
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</table>

$SPR_{LV}$ is the b/a spread calculated according to the $LV$ method. $inv(TV)$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{LV,i,t_i}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{LV}$, the annualized return volatility $\sigma_{LV}$ and the average of the square root of the time between trades $\sqrt{T_i}$.

***Indicates significance at the 1% level; **Indicates significance at the 5% level; *Indicates significance at the 10% level

Table F-1: Regression results for $SPR_{LV}$
### Regression results for $SPR_{MM}$

Regression results for $SPR_{MM,t} = \alpha_0 + \alpha_1 \text{inv}(TV)_t + \alpha_2 C_T + \alpha_3 IHP_{MM,t} + \epsilon_t$

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
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<tr>
<td>$SPR_{MM}$</td>
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**$SPR_{MM}$** is the b/a spread calculated according to the MM method. $\text{inv}(TV)$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{MM,t}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{MM}$, the annualized return volatility $\sigma_{MM}$ and the average of the square root of the time between trades $\sqrt{T_i}$.

***Indicates significance at the 1% level
**Indicates significance at the 5% level
*Indicates significance at the 10% level

Table F.2: Regression results for $SPR_{MM}$
### Regression results for $SPR_{AV}$

Regression results for $SPR_{AV} = \alpha_0 + \alpha_1 inv(TV) + \alpha_2 C_T + \alpha_3 IHP_{AV,1} + \varepsilon$

<table>
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<tr>
<th>Independent variable</th>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
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</thead>
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<td>6.39***</td>
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$SPR_{AV}$ is the b/a spread calculated according to the $AV$ method. $inv(TV)$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{AV,1}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{AV}$, the annualized return volatility $\sigma_{AV}$ and the average of the square root of the time between trades $\sqrt{T}$.

***Indicates significance at the 1% level
**Indicates significance at the 5% level
*Indicates significance at the 10% level

Table F-3: Regression results for $SPR_{AV}$
Regression results for $SPR_{C_{05}}$

Regression results for $SPR_{C_{05i}} = \alpha_0 + \alpha_1 inv(TV)_i + \alpha_2 C_{T_i} + \alpha_3 IHP_{C_{05t_1}} + \varepsilon_i$

<table>
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<th>Independent variable $SPR_{C_{05}}$</th>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
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<th>$\alpha_1$</th>
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$SPR_{C_{05}}$ is the b/a spread calculated according to the $C_{05}$ method. $inv(TV)$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{C_{05t_1}}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{C_{05}}$, the annualized return volatility $\sigma_{C_{05}}$, and the average of the square root of the time between trades $\sqrt{T_1}$.

***Indicates significance at the 1% level

**Indicates significance at the 5% level

*Indicates significance at the 10% level

Table F-4: Regression results for $SPR_{C_{05}}$
Regression results for $SPR_{cs10}$

Regression results for $SPR_{cs10} = \alpha_0 + \alpha_1 inv(TV)_i + \alpha_2 C_T + \alpha_3 IHP_{cs10,t} + \varepsilon_i$

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</tbody>
</table>

$SPR_{cs10}$ is the b/a spread calculated according to the $C_{s10}$ method. $Inv(TV)$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{cs10,t}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{cs10}$, the annualized return volatility $\sigma_{cs10}$, and the average of the square root of the time between trades $\sqrt{T_T}$.

***Indicates significance at the 1% level
**Indicates significance at the 5% level
*Indicates significance at the 10% level

Table F-5: Regression results for $SPR_{cs10}$

Appendix F.5
F.2. Relative regression results

<table>
<thead>
<tr>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>$\alpha_0$</th>
<th>$\alpha_1$</th>
<th>$\alpha_2$</th>
<th>$\alpha_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR/RUB TOD</td>
<td>595</td>
<td>0.062857</td>
<td>0.001927</td>
<td>5,538.978</td>
<td>-0.000029</td>
<td>0.044703</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>2.19**</td>
<td>0.92</td>
<td>-1.80*</td>
<td>1.40</td>
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<tr>
<td>EUR/RUB TOM</td>
<td>1451</td>
<td>0.002545</td>
<td>0.002963</td>
<td>-2,794.801</td>
<td>-0.000033</td>
<td>-0.008273</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>6.24***</td>
<td>-1.56</td>
<td>-1.43</td>
<td>-0.18</td>
</tr>
<tr>
<td>USD/RUB TOD</td>
<td>995</td>
<td>0.033987</td>
<td>0.001433</td>
<td>6,825.285</td>
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<td>-0.014241</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>8.97***</td>
<td>1.84*</td>
<td>-3.47***</td>
<td>-0.55</td>
</tr>
<tr>
<td>USD/RUB TOM</td>
<td>1451</td>
<td>0.018233</td>
<td>0.001001</td>
<td>37,826.34</td>
<td>0.000005</td>
<td>-0.108996</td>
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<td>6.14***</td>
<td>3.07***</td>
<td>0.80</td>
<td>-2.91***</td>
</tr>
</tbody>
</table>

This table presents the regression results of the relative b/a spread of $S_{PRWA}/T_{WA}$. $S_{PRWA}$ is the quoted b/a spread calculated according to the WA method. $Inv(TV)$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHP_{WA,t}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{WA}$, the annualized return volatility $\sigma_{WA}$ and the average of the square root of the time between trades $\sqrt{T_t}$. $T_{WA}$ is the true exchange rate by which all variables are scaled i.e. here the midpoint between the bid and ask price.

***Indicates significance at the 1% level
**Indicates significance at the 5% level
*Indicates significance at the 10% level
<table>
<thead>
<tr>
<th>Currency pair</th>
<th>Observations</th>
<th>$R^2$</th>
<th>Coefficient estimates and t-ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR/RUB TOD</td>
<td>595</td>
<td>0.048333</td>
<td>$\alpha_0$: -0.001280, $\alpha_1$: 16745.62, $\alpha_2$: 0.000063, $\alpha_3$: 0.207791</td>
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<tr>
<td>EUR/RUB TOM</td>
<td>1451</td>
<td>0.002126</td>
<td>$\alpha_0$: 1.49, $\alpha_1$: 0.97, $\alpha_2$: 0.55</td>
</tr>
<tr>
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<td>$\alpha_0$: -0.000118, $\alpha_1$: 24077.99, $\alpha_2$: 0.000043, $\alpha_3$: -0.051904</td>
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<tr>
<td>USD/RUB TOM</td>
<td>1451</td>
<td>0.015488</td>
<td>$\alpha_0$: 0.37, $\alpha_1$: -0.36, $\alpha_2$: 3.81***, $\alpha_3$: -0.19</td>
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</tbody>
</table>

This table presents the regression results of the relative b/a spread of $SPRC_{C_0}$. $SPRC_{C_0}$ is the quoted b/a spread calculated according to the $C_0$ method. $lnv(TV)$ is the inverse of the volume traded. $C_T$ is a competition measure that uses the number of dealers of each trading day weighed with the number of trades per half-hour as a proxy for competition for each half-hour within that trading day. $IHPC_{C_0,t_1}$ is the inventory holding premium that is calculated based on the true exchange rate $T_{C_0}$, the annualized return volatility $\sigma_{C_0}$ and the average of the square root of the time between trades $\sqrt{T_1}$. $T_{C_0}$ is the true exchange rate by which all variables are scaled i.e. here the midpoint between the bid and ask price.

***Indicates significance at the 1% level  
**Indicates significance at the 5% level  
*Indicates significance at the 10% level
Appendix G: Intraday patterns

G.1. B/a spread intraday patterns

Figure G-1: Boxplot of the W/A b/a spread for RUB/EUR TOD

Figure G-2: Boxplot of the W/A b/a spread for RUB/EUR TOM
Figure G-3: Boxplot of the W/A b/a spread for RUB/USD TOD

Figure G-4: Boxplot of the W/A b/a spread for RUB/USD TOM

Appendix G.2
Figure G-5: Boxplot of the $C_0$ b/a spread for RUB/EUR TOD

Figure G-6: Boxplot of the $C_0$ b/a spread for RUB/EUR TOM

Figure G-7: Boxplot of the $C_0$ b/a spread for RUB/USD TOD
G.2. Volatility intraday patterns

Figure G-8: Boxplot of the C_o b/a spread for RUB/USD TOM

Figure G-9: Boxplot of the annualized return volatility for RUB/EUR TOD, with the true exchange rate determined according to the WA method
Figure G-10: Boxplot of the annualized return volatility for RUB/EUR TOM, with the true exchange rate determined according to the W/A method.

Figure G-11: Boxplot of the annualized return volatility for RUB/USD TOD, with the true exchange rate determined according to the W/A method.
Figure G.12: Boxplot of the annualized return volatility for RUB/USD TOM, with the true exchange rate determined according to the WA method.

Figure G.13: Boxplot of the annualized return volatility for RUB/EUR TOD, with the true exchange rate determined according to the $C_0$ method.
Appendix G.

Figure G-14: Boxplot of the annualized return volatility for RUB/EUR TOM, with the true exchange rate determined according to the $C_9$ method.

Figure G-15: Boxplot of the annualized return volatility for RUB/USD TOD, with the true exchange rate determined according to the $C_9$ method.

Appendix G.7
Figure G-16: Boxplot of the annualized return volatility for RUB/USD TOM, with the true exchange rate determined according to the $C_n$ method.
Appendix H: Transcript interview

This is the transcript of the interview with respondent H, being denoted as ‘respondent’ in the transcript. The questions were sent to the respondent before the interview took place.

Interviewer: I think you’ve had a chance to look the questions over a bit?
Respondent: Yes, I have been able to look them over. I even looked up the study by Bollen, Smith and Whaley. I must say, it looks very interesting, but I can tell you two things right away. I am completely unfamiliar with the foreign exchange markets – I have no idea how they work. I know a bit about exchange rates and I have some idea of how they are formed, but no more than that. Secondly, the markets where I have really worked a lot and where I have experience are the markets in less liquid shares. That is on the one hand as a market-maker but also just as a trader, that is, a trader in the sense of executing client orders as well as a trader who takes positions for a brokerage firm, for instance – I have done both of those things. So that is an answer to your first question.
The size of the spread is a very interesting thing, and the more scientific explanation you are trying to research was somewhat familiar to me, but ultimately it were the practical aspects that prevailed insofar as they influenced my job, let’s say. And there it seems to me – but that was quite a while ago now – that the number of participants was a very important component. This means the traders who deal in a particular share and the number of investors who were would-be buyers or sellers at a given moment. And a second point that appears to be an important factor that determines the size of the spread seems to me to be the free float – namely, the number of available shares that can be traded, let us say. In other words, those that are not in the hands of large institutional clients because they are sitting on them and never buy or sell them. So you have to set those aside and then the free float is the number of shares that are still available to be traded. This is perhaps less important on the foreign exchange market because there you have no limit. Money can always be created and that money can always be converted into another currency. With shares, this was a bit different, and that was sometimes a major limitation on account of which the spread tended to be much wider, since there were fewer shares in circulation. The short exposure – I don’t know if you... you have probably come across this before – in other words the number of shares that were shorted, that is, sold without the owner actually possessing them. That in turn has a direct impact on the free float – i.e. on the number of shares actually available for trading. In my job, the size of the spread – and this is a third factor – is also sometimes limited by the market authorities. Market authorities were sometimes sharply criticized if the spread was too wide for certain shares.
Interviewer: Yes, I did once read something about that being the case on stock markets as well.
Respondent: So the markets that were completely unwilling to accept negative criticism imposed maximum spreads on market-makers, or even liquidity providers, as they were called. And thus that is a maximum spread that is also present in the market. But what actually seems to me to be the most important factor, to some extent, is the drift. I don't know if you know this term. That is the tendency for an instrument to rise or fall in value.

Interviewer: Sort of the volatility, then?

Respondent: It is different from volatility, it is more the momentum. The share can have a strong momentum to increase at a given moment or it may have a weak momentum. How can I explain this better? When in the past Lernout & Hauspie showed very good results – whether there was a basis for these or not, let us leave that aside for now – then the drift tended sharply upwards. Then the sellers went away and it became very difficult to buy shares on the market, thereby immediately driving the spread way up. Thus if the drift is more stable, then you have people who at a given point want both to sell, because they need money or whatever, and more people who want to buy because it may be a good time to hold on to them. This drift seems to me to have been a very important factor, certainly in less liquid markets which is ultimately where I was trading. Those are the four factors that I remember from practical experience, let us say.

The third question, the determinants such as those in that study – I have little experience with them, so I can say little about them. I think that these are researched mainly by people who are writing a thesis on the topic, and I find it interesting in itself whether the market authorities that keep wondering why the heck the spread is so wide on certain instruments at a certain times. Those are the moments that are being investigated. There is apparently a great deal of literature about this, but let’s say that I don’t know more than that about this topic. I can understand the components and I am... I agree of course that those are important elements in determining the spread of a given instrument at a given moment. But no more than that. Certainly not about the scientific basis and the modelling of those things. I have not been involved with those matters at all. What I wanted to interject, and that has a bit to do with the drift I was talking about, is that if you have a bid-ask spread at a given moment, then the source of that bid-ask and its change over time is very interesting in order to see what the drift is like. The number of times that it is traded on the bid side or the ask side gives you an indication whether it is more the buyers or the sellers who are lining up for a given instrument. And that we did do. That is, we kept statistics and that showed – almost in real time - how the market stood on that day: whether trading was taking place in one or another market (bid or ask). Were there people – traders, in other words – who interposed themselves between the bid and the ask, and thereby narrowed the spread? Or were there people who withdrew from the order book, if you can put it that way? And ultimately, the dynamic in the order
book gives you a sense of the dynamic in the spread and gives you an idea of where that share is going at a particular time. And that was indeed done, not only by the people for whom I worked, but most traders analysed very carefully where the pressure lay: on buying or on selling. What are traders doing? Are they pulling back or adding orders at a given price level? Thus the order book is a very important component in the study of the spread. And I don’t find that as much in the modelling of it – but that may come back again in another way; I’ll leave that to you to research.

Interviewer: May I interrupt to ask a question? For example, if on a given day a lot of purchases are made, what do you do with that information? What do you do if there are a lot of purchases?

Respondent: Well, then you have two situations. Either you have a lot of those shares in your inventory holding, as it’s called, and then you are comfortable, because you can sell that during the day or over a number of days, at times when you have market demand and you can position yourself, that’s more a gut feeling, eh, in my experience. So OK, I have ten thousand shares in Lernout and they are showing good results. Well, I’ll try to sell a thousand shares at this level, thousand at a higher level, and so forth. There is not much time to do a lot of calculating about how much my heating and lighting costs. Traders think more about how can I earn some money quickly with the position I have or how do I build up a position that can help me make money in the near future. And so that is actually the exercise we did. And if our stock inventory was completely gone, then that was because we thought that it may have gone up too high too fast. And that from then on it would perhaps go down. Otherwise, you try to keep a minimum inventory so that you never end up with the problem of selling more than you own. That is something of the dynamic that is linked to the drift, in the end. And I think the inventory holding and inventory management is likely a very important component in the spread, but also in the way that traders behave in a given market. Have you ever had a chance to spend some time in a market room?

Interviewer: No, not yet, and that is why I decided to try to get a few people on the phone who can tell me more about it. I read a text by Lyons that pointed to that difference, that there is a big difference between the theory and the market and how people there actually think.

Respondent: I think so too – as I was reading the study by Bollen, Smith and Whaley – OK, that’s great, eh, to go and research that, but I found it a little unrealistic compared to what I experienced on the floor. And there are interesting components there, but I had the impression that the marginal aspects – the type of market, the type of participants present on the market at a given time, make the model less useful for explaining one thing or another. Maybe that’s a personal perspective. Certainly if we are talking about less liquid shares. I think that perhaps the model is a bit more complex if you want to make it absolutely clear.

Question 5, do you think it probable that if supply increases, the spread widens? I would say the opposite. If traders have a large inventory, and let us assume that they all do, then the competition...
to turn them into liquid assets at a given moment will intensify. And thus they will begin to compete more sharply with each other to unload the shares on the market. And I would be tempted to say that that will tend to narrow the spread rather than widen it. Once again, from my limited experience as a stock trader. And once again, depending on the drift – on the momentum – of the share. If there is a very strong drift at that moment, then that is perhaps less applicable because the traders can hold on to their position for a bit longer because there is sufficient liquidity in the market to be able to sell the shares at a given price. If there is less demand for the shares, then they will be in greater competition with each other to sell the shares at a certain moment. Another important point is also, but that is perhaps less applicable to foreign exchange markets, that at certain moments, and I’m thinking for instance of after September 11th – those in charge of market rooms have said for instance that tonight we are closing out all positions. So then the inventory holding – well, it is set to zero at a specific point in time. And that likely also influences the spread because you get many more shares in circulation at a given peak moment. And so the competition between traders to sell the shares is also much greater. And I am inclined to say that this has a narrowing effect. Thus there are other specific times when you can explain narrower spreads in another way. That is, for instance, a moment when positions are reduced after terrorist attacks or after great uncertainty following national crises, but you could also observe other moments. If for instance a company suddenly issues a profit warning so that confidence among traders is lacking, then the traders could also say: I don’t believe that company any longer, I can no longer go by what they say, so I’ll reduce my inventory completely. So that is also an element.

Question 6. I think that as traders we all assume that the people we deal with are always or almost always better informed, I think certainly in the case of shares. As a trader you try to monitor the activity on the market, but for the trader it is more important to know where the market is going than why the market is going up or down. And in my opinion that also has to do with gut feeling. Ultimately, you can be a very good stock analyst, who can explain perfectly well why the results of a company are good, better or worse than expected. The market perceives it in its own way. It could be, for example, that the market expects good results for the Bekaert share and that in the run-up to the publication of the press release on the results they have all built up an inventory. And then at the moment when the press release on the results is published, the market is more likely to be selling, although the results more or less meet expectations, let us say. At that point the market will perhaps fall slightly because to some extent people will have anticipated the facts that were to be published. In a sense the market has a life of its own and perhaps the spread does as well. I find it difficult that the information, and whether one has superior information or not – certainly when it comes to shares – I had the impression that once again the drift, the momentum of the share and the way the traders perceive it were more important than just the superior information itself. Superior

Appendix H.4
information – you still need to have good timing. Naturally, if you are an insider, then that’s a bit different. That is probably an extreme form of superior information. But here, too, you need the right timing. People say sometimes that the market is always right. It could be that you are wrong for a long time, even with inside information, because the market interprets that information in a completely different way than you do. Therefore it is not always black and white, even better informed people sometimes lose money because the entire market is against them. Sometimes it is also said that the market is your friend, meaning that you had better follow the market, that you should go along with the herd rather than try to outsmart the market and do the opposite. That is certainly true.

Question 7. I think that traders today have all possible information available to them. There are hedge fund traders who have set up gigantic strategic machines to distil information from the trends on the financial markets and I think people have gone very far with that. Those people are scientists who may have set up such models with the intention of making money in this way. I think that traders who want to do that have sufficient information. So I don’t think that a trader can ever plead that he had too little information, on the contrary. I think that the difficulty for traders lies ultimately in getting the correct information and knowing how that information will later be interpreted by the market.

Question 8. Does it seem likely that if the fixed costs increase, the spread widens? In theory yes, but in practice, once again, as a trader you have your inventory and the point is to make it profitable, and that means that it has to have a particular turnover rate. You can reduce your inventory once a day, and build it up again, and hopefully you will have generated profit in doing so. You can do that two or three times. That turnover rate will generate a result at the end of the day that is perfectly measurable and with that you will pay certain costs. But it is not the case that if you buy 50 shares in Bekaert, you will immediately weigh those 50 shares at a certain cost price that you have for your salary, and God knows what, heating and lighting, to which you can attach a certain price. You will simply sell those 50 shares as favourably as possible depending on your sense of the way the market will go. And if you think the market will continue to go up, you may buy 50 more and keep the 50 until the next day. On the other hand, if you buy those 50 shares at 50 euros and they fall to 45 euros, you may then sell them at 45 because you think the market will fall to 40 or 35. The cost side of the lighting and heating seems to me not to be a good measure for the spread in this case. I find it a bit unrealistic to go into this discussion, as ultimately the aim of a trader – I am now speaking only of traders, not investors – is to maximise profits. If you look at the other participants, namely long-term investors, they don’t need to take the cost aspect quite so much into account. So that does not reflect my experience. I find it even a bit unrealistic. I think that the turnover or the quantity of shares available for trading and the other factors should carry much more weight than the traders’
fixed costs. I have never seen traders take that into account. I think that they are more concerned about where the market is going and how I can maximise my profits and then you can decide whether that is enough to carry those costs. And in any case it is a very competitive market. If you do not earn enough for the brokerage firm you are working for, then you generally won’t stay long. Either you are a good trader and you bring in profits, or they see that you are not bringing in enough and then you fly out the door or they put you in the back office or in another job. But they don’t look systematically at the fixed costs for each position you take. I don’t think that is an important element.

Question 9. Increased competition, for sure. So the more traders, investors and hedge funds look at a particular instrument, the narrower the spread will be. I am convinced of that.

Question 10. What can constitute the largest share. I think – but that is perhaps less applicable to foreign exchange markets – transferable financial instruments, the free float as we have said. That is certainly based on the number of participants. Those may be traders, or market-makers, or hedge funds, or institutionals, or private investors. I think that they are the major determinants of the spread.

Question 11. Do you think that dealers who give quotes take these determinants into account? I think so. And there we get back to the drift again. I think that too, but the drift is a consequence of that, in my opinion. But I think that they certainly do take that into account.

Question 12. Would you as a party postpone your transaction because of the spread? Maybe not. We have certainly had the experience in the past that if the spreads were too wide, that was very bad publicity. And even for the company behind it – if we are talking about shares – it looked very bad for a company, and I would take for example Lernout & Hauspie or Innogenetics in the past, if the spread grew too wide then we sometimes got very angry phone calls from the financial directors of the companies that we were not doing our job properly because the spread was too wide. So that is something important in itself. It is an aspect of the company’s PR. A company that can base itself on an efficient market in their shares, they can be proud of that. Then that is also a sales argument at their investment meeting, and so on. But this must already be very high to prevent a party from buying or selling. It must be very inefficient as a market for that to be used as an argument not to do so. It must be very bad before it stops you doing something. But certainly if you have a 10% spread, the share must go up by 10% before you will make a profit and that is obviously not efficient.

I don’t know if I have been very useful. I think that your paper is more about foreign exchange markets. I would advise you to go to a big bank – for it is mainly the big banks that manage the markets – such as ING for instance, and try to get in there to spend a few hours talking to a trader on the foreign exchange markets, the euro-dollar exchange market strikes me as an interesting example. To be able to look over his shoulder, as it were, for a while.
Interviewer: Are they likely to allow that, then?

Respondent: Well, I think that that is certainly interesting for them too, to come into contact with someone who is interested in this. And who knows, they may be hiring in that sector later. You should just see how you can sell it. I have worked on the market for ING myself, and they regularly had interns as well as students there. People who were writing their thesis. They could easily spend a few hours following the trading. That is done, most certainly.

Interviewer: May I ask a few supplementary questions?

Respondent: Of course.

Interviewer: For example, what I have often wondered, did you ever notice at certain moments that the spread noticeably changes behaviour after certain events or something?

Respondent: Yes. Certainly. As I was saying, for instance after September 11th. So before what was happening there sank in, that order book was completely emptied out because people couldn’t see what the impact of that event would be on securities. And then you suddenly had a widening of the spread. You can also weigh up the spread – certainly with shares – against what volume you can do on the spread. For example, if you have 100 shares on the bid and 100 on the ask, then that is a very different spread than having 10,000 on the bid and another 10,000 on the ask. The volume that you can trade on the bid-ask seems to me to be an important parameter as well. And emptying out the order book, that is, I mean to say that the volume that can be sold and bought on the bid and on the ask gets a bit smaller, and the spread – you can have a very narrow spread – but you can perhaps trade marginally on that but that may give a false impression of the true spread. I don’t know if I am making myself clear?

Interviewer: Yes, it’s clear.

Respondent: And it may be that the spread remains the same after certain events, but that the volume that can be traded on the spread is a bit lower. And these are things that you have to see in practice. The way in which the order book is filled and the way the spread is determined or comes about is fascinating. No one looks closely at that when they read the share prices in the paper. I’m sure of that.

Interviewer: And has it ever happened that the spread moved in a certain direction without you being able to identify the cause? Without you knowing why it moved in one or other direction?

Respondent: No, I think that it was always the logical consequence of a number of events or very exceptional moments, and then you had the flash-crash on the markets – on NASDAQ, I think, where suddenly someone pushed the wrong button and suddenly wanted to buy or sell a large number, whether by mistake or not. But then afterwards you always have an explanation for it. Someone made a mistake and mistakes do happen. Even on stock markets. But there is always a logical explanation.
**Interviewer:** You were active on the stock market, and so the changes in the spread, were there certain times of the day when the average stood at the highest or the lowest point?

**Respondent:** You can imagine that traders also go for lunch. And it is not unusual for trading to be a little lighter around midday than in the afternoons or the mornings, for instance. Another example – and when the trading is lighter, it can happen that the spread is either smaller – going back to what I just said – and that therefore a lower volume can be used on the spread, or the spread simply widens. Both are possible. So around midday that can happen. Another moment, for example, is when important figures are published, either in Europe in the morning or in the United States, which is generally around 2:00-2:30 p.m., in the hours before or the half-hour before everyone generally waits a little until the figures come out and during that waiting period it is not unusual for the spread to widen and the volume to decrease somewhat.

**Interviewer:** I have two more questions. Are there actually certain banks, hedge funds or so on, that follow market making strategies without in fact being recognised as market-makers by the regulator?

**Respondent:** Yes. I am convinced of that. You certainly have people who have designed models and who have direct access to certain markets, certain stock markets, and who submit their orders via a brokerage firm and who are sometimes simultaneously present on the bid side and the ask side, without holding a license as a trader. So that does happen, yes, certainly.

**Interviewer:** Finally, do you think that market making is a profitable activity?

**Respondent:** That is an excellent question. I think that depends on the financial instrument and on all the parameters that we have just discussed. You know, there are Belgian shares for which liquidity providers were brought in. And it is an open secret that these liquidity providers – which are none other than market-makers, and that they are paid precisely because it is very difficult to develop a profitable activity as a market-maker in these illiquid shares without taking extravagant risks. I would say, depending on the financial instrument it can be easier or more difficult to generate profits. But in more liquid shares, such as NASDAQ shares, for example, where a great many client orders go through the hands of the market-maker, it is much easier to sell at the ask price and to buy at the bid price. There you have a highly profitable activity right away. With less liquid shares, where the drift is always unilateral - it is either sharply rising or sharply falling – you need a bit of luck to have a good inventory at just the right moment or on the contrary, to have no inventory when the share is falling. It is very hard to say, it has to do with the type of instrument, with the volatility, with the drift, with the volume available for trading, and so on and so forth. Even the number of share analysts who track a given security is an important component. The analysis reports that are published are often read by institutional investors who then follow up such a report and place a buy or sell order and then will in fact determine the liquidity. And therefore the spread as well. That is a lot of information.
all at once. If you would like to ask more specific questions later, I will in any case be a very interested reader.

Interviewer: Thank you very much and if I do have any more questions, I'll send them in an email or I’ll phone you back.