ITC 1/46
Journal of Information Technology and Control
Vol. 46 / No. 1 / 2017
pp. 70-85
DOI 10.5755/j01.itc.46.1.15413


Atomic Order Execution Tactics in Futures Markets: A Simulation Study Using Real World Market Data

Received 2016/06/28 | Accepted after revision 2017/02/28

http://dx.doi.org/10.5755/j01.itc.46.1.15413

# Atomic Order Execution Tactics in Futures Markets: A Simulation Study Using Real World Market Data

**Aistis Raudys, Saulius Blažiūnas, Linas Žvirblis**
Vilnius University, Faculty of Mathematics and Informatics
Naugarduko st. 24, LT-03225 Vilnius, Lithuania

**Darius Plikynas**
Vilnius University, Institute of Mathematics and Informatics,
Akademijos st. 4, LT-08663 Vilnius, Lithuania

**Corresponding author:** aistis@raudys.com

This research investigates a better way than using instant market orders to execute buy or sell orders in the futures markets. Every trader faces an execution cost arising from the difference in observed price and executed price. The goal of this paper is to optimise and reduce the cost of orders execution. 35 most liquid futures, over 1 billion ticks of real market data, and 20000 simulated orders per future are investigated. For most futures, our proposed methods have given significantly better order execution costs than executing with a widely used execution method – market orders. The improvement is obtained over large number of trades and may not hold for individual orders. This can be achieved by placing a limit order of the desired price, and waiting for a definite amount of time, and converting the order to a market order if it was not filled in time. For some futures, even better results can be obtained by improving limit order price by one or two ticks. The proposed order execution method can be attractive for any futures market practitioners whose orders are small or medium size.

**KEYWORDS:** algorithmic execution, atomic orders, order execution tactics, limit order, slippage, trading costs.

## Introduction

In the past two decades, quantitative trading has evolved rapidly. Such terms as electronic algorithmic trading (AT) or high frequency trading (HFT) are now universally known and used. One of the biggest drivers of such a trading evolution has been rapid technological development. As computers became faster, so did the trading. Now trading success depends on quick and precise trade execution. To trade more frequently, traders have to create their own trading execution methods. In the industry, these methods are often referred to as '*algos*'.

Trading costs can have a tremendous impact on trading results for some trading strategies. In more frequent trading cases, transaction costs can add up to 50% of fund performance [10]. Masteika and Rutkauskas [9] showed a strict control on order execution slippage is necessary. In their paper, a profitable futures portfolio becomes unprofitable if orders are executed with 8 ticks slippage. Trading costs are not only a problem for traders, but for the entire microstructure of the market. To cover increased trading costs, investors will trade more rarely and try to hold their positions longer. This will reduce trading volumes and decrease market liquidity (see [6]). See [8] and [14] for thorough article on the mechanics of AT and HFT and a useful overview of the terminology of the topic.

Execution costs consist of two parts: fixed costs such as broker commissions that cannot be avoided (though can be negotiated lower) and variable costs such as opportunity costs, market impact costs, price movement risks and others. Opportunity cost is the cost of unfulfilled trade. Market impact cost is the price of liquidity in the market while price movement risks represent the difference between final price and pre–trade (desired) price (the price for which trader wants to buy or sell an asset). This second part includes market liquidity (bid–ask spread) and price volatility risks (see [3]). Variable costs can be reduced by developing, optimising, and applying trade execution algorithms [5].

Our aim is to see how much costs of trade could decrease by using various combinations of waiting for the right opportunity and sacrificing rapidity of order filling. We empirically analyse execution costs of simulated trades using most popular and most liquid futures tick data. This study could be a foundation for building more sophisticated practical models of trade executing and also as a guideline for practitioners trying to reduce trading costs.

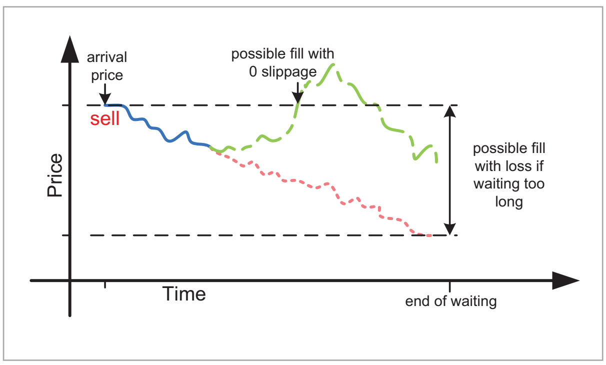
We think our study of atomic order execution would interest a broader audience than large order execution studies would. The number of smaller traders is far greater than large institutional traders.

## Literature review

The main tool for efficient trading is an optimal execution strategy based on combination of rules and order types. There are two main types of orders: market and limit. Market orders provide traders with the possibility to trade instantaneously at the best price currently available in the market. This way the trader takes liquidity from the market. In contrast, limit orders get the desired price by sacrificing instantaneous execution and any assurance the order will be executed in time. These orders provide liquidity to the market. Using these orders, trading venues offer a wide range of derived order types (such as limit–if–touched, market–to–limit, etc.) For more information on different types of orders and their properties see [8] and [6].

The potential of using these hybrid orders depend on the trading venues. We do not want to depend on such restrictions so we analyse execution possibilities us-

**Figure 1**
Two possible scenarios of execution of a limit order to sell



ing always available types of orders: limit and market.

To reduce order execution costs, the trader can use combinations of market and limit order rules. The trader must decide how long he or she can wait for the order to execute and how much the real price of an asset can differ from the goal price. Figure 1 illustrates two possible scenarios for a sell limit order. If the price moves like the curved dashed line, the limit order to sell would be filled with zero slippage. Otherwise, in the case of the dotted line, the trader would incur a loss equal to the price difference between straight dashed lines.

It is also important to take into account the size of the trade to be executed. The problem of the execution of large orders is well known and much analysed in scientific literature. We will not delve into the large order execution problem as this is not our goal. For a good source of information on large order execution problem, see [6].

Most research on this problem is theoretical (see [5] or [1]). Either that, or it concentrated on one market (see [7]). In past years, Algrem has published a series of articles in this field. Almgren and Criss [1] constructed a theoretical framework for large orders where they modelled prices as a discrete arithmetic random walk. They defined an efficient frontier for optimal trading strategies that solve the constrained optimisation problem. For given parameters, this problem can be solved by using various numerical methods. They also analysed possible impacts of future events on prices by incorporating drift and serial correlation. For the extensions of this paper, see [2] and a newer paper [4] in which Almgren analysed less liquid securities. We recommend a list of additional reading material on this topic in Yingsaeree's [14] dissertation. Here the author tries to model the probability of limit order execution given a specified trading horizon and proposes a new framework for order placement decisions based on the trade-off between the increase in profit from the better execution price and the risk of non-execution that utilise the developed execution probability model to balance this trade-off. It is also important in portfolio rebalancing where anticipated portfolio improvement may not be worth the transaction costs [13].

Raudys and Matkėnaitė's paper [12] appears to be the only one analysing exclusively data from futures markets and possible execution strategies in them. The authors used 1 tick as a spread between bid and ask. Data show that using 1 tick is not the best evaluation of a bid/ask spread. In our paper, we are going to use estimations of bid/ask spread for every future analysed. This should give us more realistic simulations results. In addition, Raudys and Matkėnaitė considered a limit order filled only if market price crossed limit price. Simulations in this paper covers more realistic scenarios when limit order is also filled after a certain amount of contracts are filled in that limit price. In other words, it is not necessary to cross the limit order for it to be filled.

## Mathematical methods, models and simulation methodology

The aim of this paper is to analyse several execution methods that combine market and limit orders, desired price, and waiting time. We do not seek to optimise individual orders; we seek to reduce slippage on average, across many trades. As a benchmark we have chosen to trade by market orders as soon as the order arrives. We compare execution prices using price at the moment the order arrived. This comparison method is also known as implementation shortfall.

We make some assumptions in our analysis. This is unavoidable as to test our models would be too expensive in actual trading. In our simulation, we assume that:

1. The order (both market and limit) arrives at the market on the next data tick after it is generated (triggered). The market order is filled on the next tick after being generated. The reason why this assumption is necessary is because it includes market impact. The market might react to trade by moving bid and ask. The next trade shows if and where either bid or ask moved to after last trade before generation time. This means that the next trade should be used as price in which we would have filled our order, even if this order fill would have happened before the next trade (next tick).
2. If we execute by market order, besides the difference between market price and the price the order was generated, we incur additional slippage unique for each future and time of the day. We calculate this slippage for every minute as half of the aver-

age of difference between bid and ask prices. This assumption pertains to the difference between whether the order is to buy or sell. The problem is that we do not know from tick data whether best bid or best ask was filled. Since we are interested in the average, then we can assume that in the complete period we analyse, half of the trades were filled on best bid and half on best ask.

3 Limit order is always filled when the market price crosses the limit order price. If historically there was a fill at a better price (from our point of view) than our limit order, then our limit order would have been filled first because our offered price was better (from market point of view).

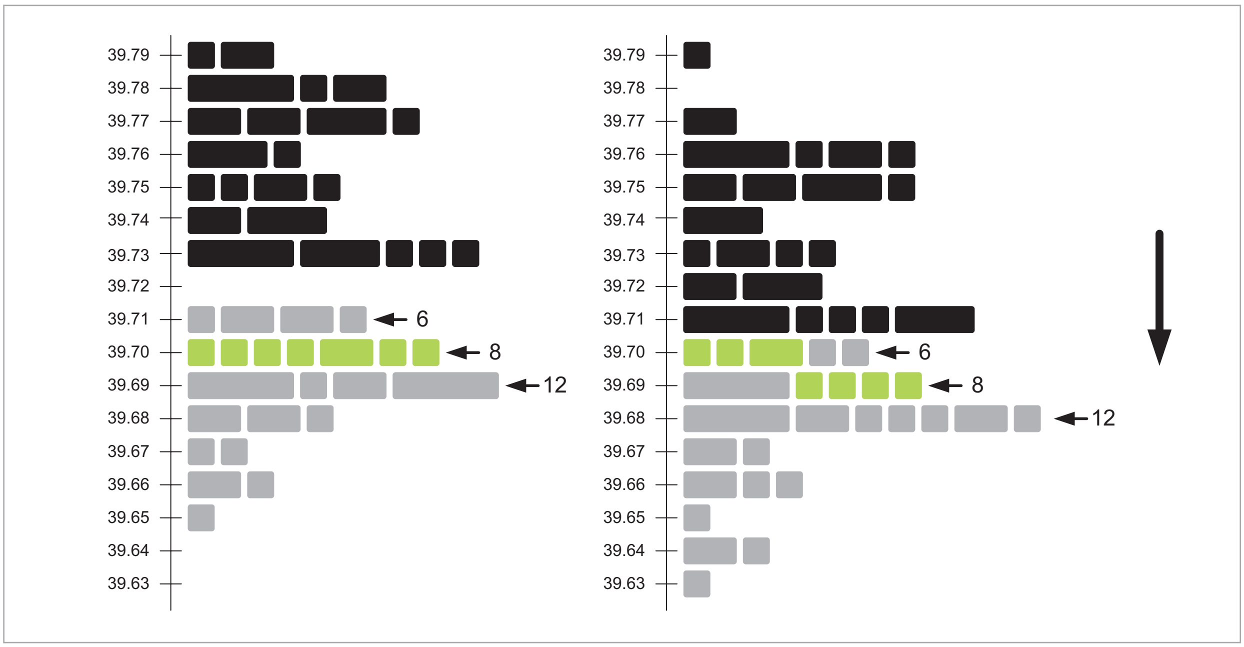
4 Limit order is also filled when the volume accumulated on the price level that holds our limit order surpasses that minute's historical average bid/ask. To calculate average bid/ask, only contracts on the best bid/ask price are used. For example, if our limit order was sent in a minute in which there were six contracts on best bid and ask on average, then our limit order will be filled when 6+1 contracts are filled on that price. This assumption holds even if we make limit order not on the best market bid/ask. This means that, for example, if we make our buy limit order at a price 2 ticks lower than the current best bid price, we will still count this order as filled if 6+1 trades are filled. An example in Figure 2 demonstrates why this assumption is sound.

5 The execution price of filled limit order is equal to the limit order price even if the market price triggering the execution of the limit order was much better. If a trade's price crossed our limit order's price, then we assume that our limit order would have been filled instead of that historical trade. A situation like this shows the market was willing to fill our limit order even at a better price than we wanted.

6 Limit order is converted (if not filled before) to market order and filled on the last historic tick if

**Figure 2**

Market matrix example. This represents a typical situation in a market. Assume that we make a buy limit order at a price 39.70 (8 limit orders are already placed at this price – as shown in the picture on the left), so our order is 9'th. After a few seconds, the best bid/ask moves lower and most of the limit orders are replaced by lower price (picture on the right). Now only 6 buy limit orders are at the price of 39.70. This example shows that, in average, it would make the same amount of trades filled as in best bid/ask for order to be filled even if a limit order is made on a different price, because most of the limit orders are replaced by lower price. This assumption holds on average, but it is not true in every situation



the trading session is about to end or be halted irrespective of the limit execution tactic. When the session ends or is halted, then the limit order is cancelled. In next trading session, a new limit order should be placed. The new session's open price can diverge greatly from the last price. To avoid this, we convert limit orders to market orders just before trading stops for all execution methods.

7 As we execute only atomic orders, we also assume no market impact. In this paper we do not address the large order execution problem. We address atomic order execution that will be interesting to smaller investors.

We made these assumptions by consulting practitioners and we think that they reflect reality in the best possible way using the market data available to us.

Variables which are used in equations are as follows:

- $N$ is the number of all simulated orders,
- $i$ corresponds to order number: $i \in \{1,2,\ldots,N\}$,
- $t$ is duration of limit order being held,
- $j$ corresponds to tick's number: $j \in \{0,1,\ldots,n_i\}$. For limit order $i$, $j = 0$ is the $i$'th order's arrival time tick, $j = 1$ is the $i$'th order's first tick after arrival time tick, and so on. $n_i$ is $i$'th order's last tick which does not surpass time $t$,
- $p_j^{C(i)}$ is the current price of a futures contract at the $i$'th order's $j$'th tick,
- $p^{G(i)}$ is the generated price of the $i$'th order,
- $p^{L(i)}$ is the limit order price of the $i$'th order,
- $v_j^{(i)}$ is the trades volume at the $i$'th order's $j$'th tick at the $i$'th order's limit order price level $p^{L(i)}$,
- $CO^{(i)}$ is the average amount of contracts on the moment of the $i$'th order arrival (at $j=0$ tick), offered as limit orders on best bid/ask prices from historical data,
- $1_{dir}^{(i)} = \begin{cases} 1 & if\ buy\ order \\ -1, & if\ sell\ order \end{cases}$ as direction of the $i$'th order, i.e. buy or sell. If the order is to buy, then its direction is equal to 1, if it is to sell, then direction is equal to −1,
- $P_E(t)$ and $P_{NE}(t)$ are thee probabilities that limit whether the order is executed ($E$) and, respectively, not executed ($NE$) in time horizon $t$,
- $\Delta p$ are the additional costs arising from the spread between bid and ask prices (comes from the second assumption).

The abovementioned probabilities can be expressed as:

$$P_E(t) = Pr\{TTF \le t\} = \frac{\sum_{i=1}^{N} 1_{(TTF_i \le t)}}{N}. \quad (1)$$

$$P_{NE}(t) = 1 - P_E(t) = 1 - \frac{\sum_{i=1}^{N} 1_{(TTF_i \le t)}}{}. \quad (2)$$

Here $TTF$ stands for Time–To–Fill and means time in which the limit order is filled and $N$ denotes the number of all placed limit orders (every limit order is placed and held for the time horizon $t$). Symbol $1_{(TTF_i \le t)}$ denotes all orders filled in time $t$. For example, suppose there are 5 limit orders in total ($N$ =5). Those orders would be filled by limit order after 5, 7, 25, 150, and 300 seconds ($TTF$ times). If $t$ =50, then the chance that the orders are executed in the first 50 seconds is 60% ($P_E(50) = \frac{3}{5} = 0.6$), if $t$ =160, then 80% ($P_E(50) = \frac{4}{5} = 0.8$). The longer the waiting time, the higher the probability of filling the limit order will be.

This definition has been previously used by several authors (see [14, 11]). We consider that if the $i$'th limit order at the price $p^{L(i)}$ is unfulfilled in time $t$, then it is instantaneously cancelled and switched to a market order, which is then filled at the first tick after time $t$ (for the $i$'th order it is $n_i$+1 tick) and the fill price is equal to $p_{n_i+1}^{C(i)}$. In such case, the total cost, when the limit is converted to market, is equal to:

$$TC^{LM^{(i)}} = \left(p_{n_i+1}^{C(i)} - p^{G(i)}\right) \cdot 1_{dir}^{(i)} + \Delta p. \quad (3)$$

Then the total cost of one trade can be defined as:

$$TC^{(i)} = \begin{cases} 0, & \text{when the limit order is filled} \\ TC^{LM(i)}, & \text{when the limit order is not filled and converted to the market order.} \end{cases} \quad (4)$$

To simplify Eq. (4), we do not include volume of limit orders and volume of fills in the market. In our calculations, we take into account market volume because of our fourth assumption. Equations used for calculations are presented in the next section.

We can now define the average cost of trading by limit orders, and then, switching to market ones, as:

$$TC = \frac{\sum_{i=1}^{N} TC^{(i)}}{N}. \tag{5}$$

Eq. (5) is valid if we assume that limit price $p^L$ is always equal to desired price $p^G$, so that the execution costs are zero if the limit order is executed. The other possible case is when the trader chooses to place the limit order price $p^L$ on different price level than the arrival price, seeking for negative execution costs. This tactic will be discussed in the next section. Moreover, this equation does not take into account market volumes.

In the remainder of our work, we try to empirically estimate probability $P_E(t)$ and average trade costs arising from unfulfilled limit orders. We do this by simulating trades and executing them using various combinations of $t$ and $p^L$.

We now formalize our analysed execution methods.

### Vanilla market order (*M*)

Vanilla market order execution is the simplest way of trading – by market orders. The order is sent to the market instantaneously, but because of the time it takes it to reach the market and because of spread between bid and ask prices, slippage occurs.

The cost of such trade can be expressed with the formula:

$$TC_M^{(i)} = \left(p_1^{C(i)} - p^{G(i)}\right) \cdot 1_{dir}^{(i)} + \Delta p. \tag{6}$$

According to the first assumption, the market order is filled on the next tick after the trade is generated. If we assume that an order arrived at tick 0, then the price by which it was filled is equal to $p_1^C + \Delta p$. In addition, $p^{G(i)}$ is the same as $p_0^C$. For our experiment, we have a general form:

$$TC_M^{(i)} = \left(p_1^{C(i)} - p_0^{C(i)}\right) \cdot 1_{dir}^{(i)} + \Delta p. \tag{7}$$

We have chosen this method as our benchmark.

### Hold limit order for *t* seconds and if not filled in *t* seconds, then change to market (*LM*)

This type of order execution combines both trading by market and limit orders. First, the limit order of the desired price is sent to the market (desired price is equal to the last filled trade price $p^G$). This order is held for $t$ seconds and if it is not filled in that time, it is cancelled and instantaneously changed to the market order.

In longer time periods, the price of futures moves with bigger amplitude, so it is possible that by waiting longer the trader would get the price better or worse than by trading instantaneously. This method is based on the idea that increased costs of more diverged prices of market orders (market price $p^C$ might move away from $p^G$ after $t$ seconds) may be outweighed by the benefits from filled limit trades. The question is for how long the limit order should be active to get an optimal cost reduction and whether such an execution method can reduce the trading costs. The trade cost of the order is calculated by Eq. (8):

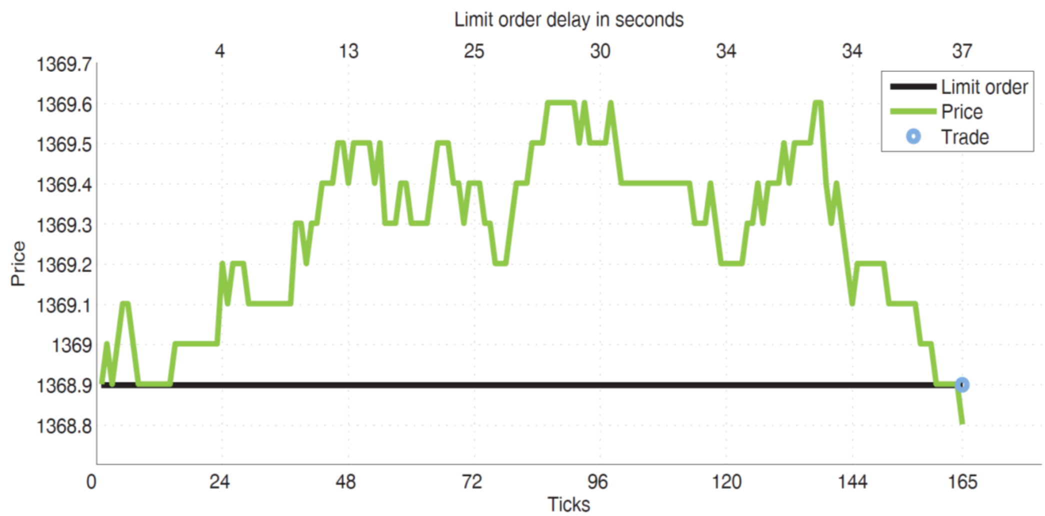
$$TC_{LM}^{(i)} = \begin{cases} 0, & when\ \ \exists y \in \{1, \dots, n_i\}: \\ & \left(p^{G(i)} - p_y^{C(i)}\right) \cdot 1_{dir}^{(i)} > 0 \\ & or\ \sum_{k \le y} v_k^{(i)} \ge CO^{(i)} + 1 \\ \left(p_{n_i+1}^{C(i)} - p_0^{C(i)}\right) \cdot & when\ \ \forall y \in \{1, \dots, n_i\}: \\ \cdot\, 1_{dir}^{(i)} + \Delta p, & \left(p^{G(i)} - p_y^{C(i)}\right) \cdot 1_{dir}^{(i)} \le 0 \\ & and\ \sum_{k \le y} v_k^{(i)} < CO^{(i)} + 1. \end{cases} \tag{8}$$

The $i$'th limit order is filled when the market price crosses our desired price or when the volume on the desired price level accumulates to more or equal to the average historical contracts ($CO^{(i)}$) plus one offered as limit orders on best bid/ask prices. So $v_k^{(i)}$ refers only to volume on a specific price level.The trading costs of filled limit trades would always be 0 because of our assumption that the execution price of the filled limit order is equal to the limit order price, even if the market price triggering the execution of the limit order was much better. Figure 3 shows an example of successful *LM* trade. Figure 4 offers an example of an unfilled *LM* trade.

The average execution costs of the *LM* method, when

**Figure 3**

Successfully executed *LM* trade. A buy limit order of gold future contract is placed on 1368.9 price level and is valid for $t = 100$ seconds. At first, the price runs away. However, later it comes back and the order is executed 37 seconds after it was placed, so we get 0 slippage. The tick data contains several price changes during the same second, therefore, the top $X$-axis in seconds is not consistent




the order is active for $t$ seconds, would be an average of the trade cost defined in Eq. (8).

**Place limit order at *k* ticks better price and if not filled in *t* seconds, then changes to market (*k* = 1, 2, 3, 4, 5 ticks) (*LBM*)**

The third execution method, *LBM*, is an extension of the previous one – *LM* method. *LBM1* is used for *LBM* with 1 tick better limit price, *LBM2* for *LMB* with 2 ticks better limit price and so on. *LMB* is based on the idea that in longer periods the amplitude of price movement is bigger and so it is possible to get a better price for the order than the generated price if the trader is patient enough.

The limit price of order $p^L$ in this case is not equal to generated price $p^G$ or $p_0^{\,C}$, which is market price at order generation time. In this method, $p^L$ is changed by $k$ number of ticks:

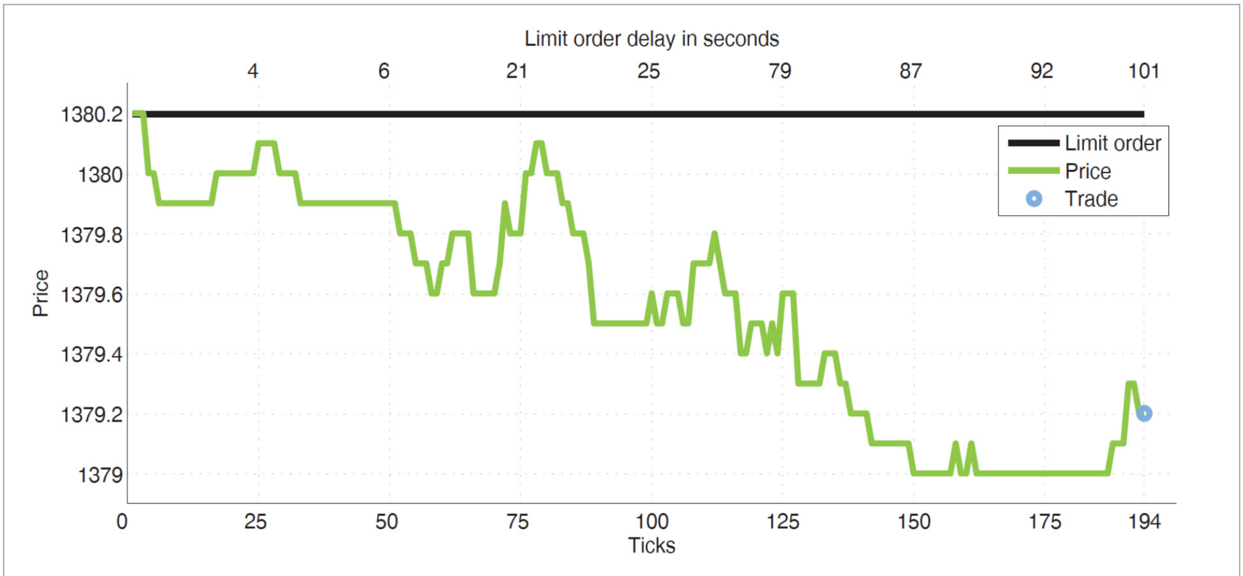
$$p^L = p^G - k \cdot tick\_value \cdot 1_{dir}. \tag{9}$$

In Eq. (9), the limit price is changed depending on $k$ (number of ticks), tick value, and $1_{dir}$ (direction of an order). Therefore, if $k$ was 3 and the order was a sell order, then the limit sell order price would be increased by 3 ticks from market price $p^G$. The trading cost of such an execution in the case of an unfulfilled limit order is still equal to $TC^{LM}$ as defined in Eq. (3). However, in the event of a successfully filled limit order, we get the profit equal to $k$ ticks. Hence, a cost of such execution mechanism is equal to:

$$TC_{LM}^{(i)} = \begin{cases} 0, & when\ \exists y \in \{1,\dots,n_i\}: \\ & \left(p^{G(i)} - p_y^{C(i)}\right) \cdot 1_{dir}^{(i)} > 0 \\ & or \sum_{k \le y} v_k^{(i)} \ge CO^{(i)} + 1 \\ \left(p_{n_i+1}^{C(i)} - p_0^{C(i)}\right) \cdot & when\ \forall y \in \{1,\dots,n_i\}: \\ \cdot 1_{dir}^{(i)} + \Delta p, & \left(p^{G(i)} - p_y^{C(i)}\right) \cdot 1_{dir}^{(i)} \le 0 \\ & and \sum_{k \le y} v_k^{(i)} < CO^{(i)} + 1. \end{cases} \tag{10}$$

**Figure 4**

Not filled *LM* trade of gold future. The sell order is placed on price level 1380.2 and is valid for $t$=100 seconds. We see this time the price diverges from our order and after 100 seconds our limit order is changed to market. The slippage is 10 ticks plus additional costs $\Delta p$




Note that $v_k^{(i)}$ refers only to volume on a specific price level (limit order's price level). The average execution costs of the *LBM* method, when order is active for $t$ seconds, would be an average of all trade's cost:

$$TC_{LBM} = \frac{\sum_{i=1}^{N} TC_{LBM}^{(i)}}{N}. \tag{11}$$

The limit order is filled when the market price moves lower than the limit price (when the order is to buy), or higher than the limit price (when the order is to sell). The limit order is also filled when the fourth assumption is satisfied. This method differs from the *LM* method in the probability that the limit order will be filled. Intuitively, the fill probability of the limit order with a better price is less or equal to the probability that an order with a worse limit price will be filled. This means that the average price of such an executing method is worsened by the probability of fulfilling by limit order, but is improved by profits from filled limits.

### Place limit order at *k* ticks better price and if not filled in *t* seconds plus random *x* seconds, then changes to market (*LBM+*)

This method is basically the same as *LBM*, except for the time of when the limit order is active. The potential risk with constant validities of limit orders is predictability. If someone (like HFT) in the market would notice such trading, he or she could try to manipulate the price for which market order is executed. In order to reduce such risk, the limit orders should have slightly different validities, so we suggest using a bit of randomness in trading in real life. The results of this method should be the same as *LBM* because random $x$ seconds do not make a significant impact on the simulation results if $x$ is small enough.

### The sample data description

For the real world, 35 most liquid (at the time of writing) futures contracts from US and EU electronic trading futures exchanges were used. Time series data were obtained from *TradeStation Securities*. Table 1 presents a list of futures with the abbreviations used in this paper. Both, commodity futures and financial futures were analysed.

Typically, a futures contract has an expiry date. Continuous historical prices of futures contracts are concatenated from multiple futures contracts and adjusted. Adjustments are necessary to get prices that are continuous and without any jumps in value. Tick data used in our study are adjusted.

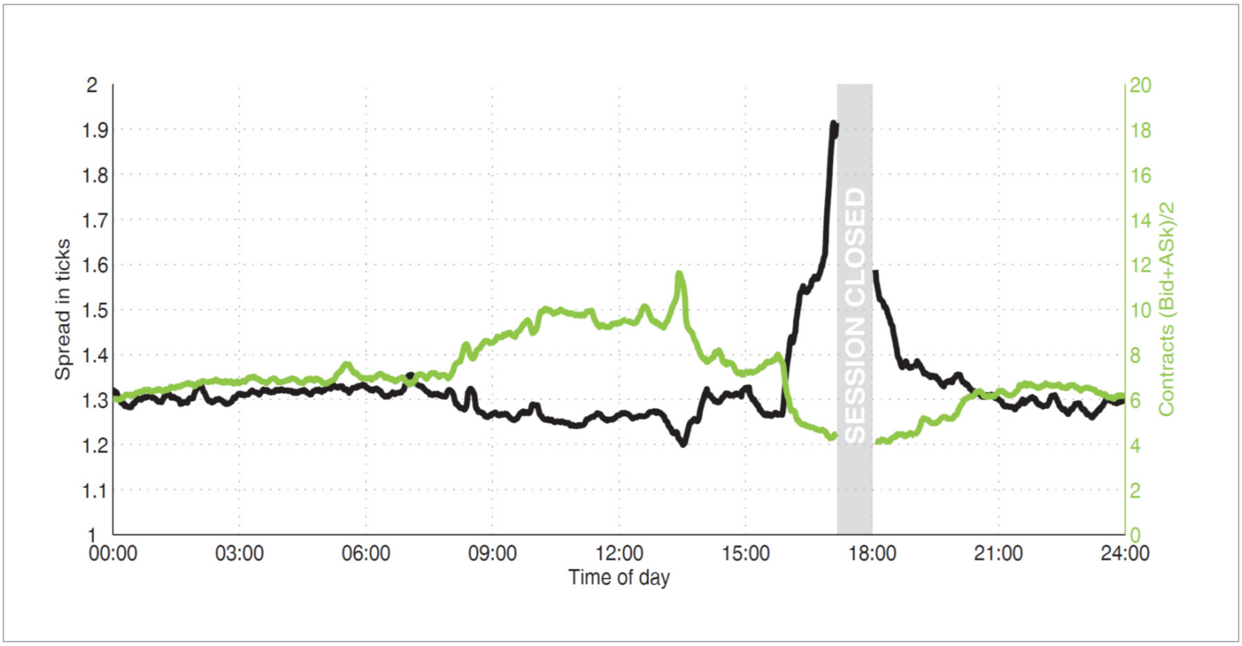
**Table 1**

Commodity and financial futures with exchanges and total count of ticks. The symbols in column one abbreviate the descriptions

| Symbol | Description | First date | Last date | Tick count | Symbol | Description | First date | Last date | Tick count |
|---|---|---|---|---|---|---|---|---|---|
| AD | Australian Dollar (CME) | 29/08/2013 | 23/07/2015 | 20,909,132 | KC | Coffee (ICEUS) | 30/08/2013 | 23/07/2015 | 3,528,402 |
| BO | Soybean Oil (CBOT) | 29/08/2013 | 23/07/2015 | 11,398,140 | MP1 | Mexican Peso (CME) | 29/08/2013 | 23/07/2015 | 5,827,635 |
| BP | British Pound (CME) | 29/08/2013 | 23/07/2015 | 21,836,717 | NG | Natural Gas (NYMEX) | 29/08/2013 | 23/07/2015 | 26,276,355 |
| C | Corn Continuous (CBOT) | 29/08/2013 | 23/07/2015 | 24,011,221 | NK | Nikkei 225 (CME) | 29/08/2013 | 23/07/2015 | 4,651,137 |
| CD | Canadian Dollar (CME) | 29/08/2013 | 23/07/2015 | 13,376,261 | NQ | E-Mini NASDAQ-100 (CME) | 29/08/2013 | 23/07/2015 | 72,783,598 |
| CL | Crude Oil (NYMEX) | 15/08/2013 | 23/07/2015 | 77,363,445 | PL | Platinum (NYMEX) | 29/08/2013 | 23/07/2015 | 3,545,469 |
| DX | U.S. Dollar Index (ICEUS) | 29/08/2013 | 23/07/2015 | 7,607,007 | S | Soybeans (CBOT) | 29/08/2013 | 23/07/2015 | 23,900,256 |
| EC | Euro FX (CME) | 29/08/2013 | 23/07/2015 | 48,834,910 | SB | Sugar No. 11 (ICEUS) | 30/08/2013 | 23/07/2015 | 6,547,180 |
| EMD | E-Mini S&P MidCap 400 (CME) | 29/08/2013 | 23/07/2015 | 6,819,037 | SF | Swiss Franc (CME) | 29/08/2013 | 23/07/2015 | 8,502,416 |
| ES | E-mini S&P 500 (CME) | 03/10/2013 | 22/07/2015 | 154,726,387 | SI | Silver (COMEX) | 29/08/2013 | 23/07/2015 | 14,091,077 |
| FC | Feeder Cattle (CME) | 29/08/2013 | 23/07/2015 | 1,053,648 | TF | mini Russell 2000 (ICEUS) | 29/08/2013 | 23/07/2015 | 38,769,032 |
| FDAX | DAX (EUREX) | 30/08/2013 | 23/07/2015 | 26,749,831 | TU | 2 Year U.S. Treas. Notes (CBOT) | 29/08/2013 | 23/07/2015 | 19,139,844 |
| FESX | EURO STOXX 50 (EUREX) | 30/08/2013 | 23/07/2015 | 22,497,730 | TY | 10 Yr U.S. Treas. Notes (CBOT) | 29/08/2013 | 23/07/2015 | 80,231,285 |
| FGBL | Euro Bund (EUREX) | 30/08/2013 | 23/07/2015 | 18,597,411 | US | 30 Yr U.S.Treas. Bonds (CBOT) | 29/08/2013 | 23/07/2015 | 41,040,148 |
| FV | 5 Yr U.S.Treas. Notes (CBOT) | 29/08/2013 | 23/07/2015 | 45,492,811 | VX | CBOE Volatility Index (CBOEF) | 29/08/2013 | 23/07/2015 | 5,943,833 |
| GC | Gold (COMEX) | 15/08/2013 | 23/07/2015 | 44,498,285 | W | Wheat (CBOT) | 29/08/2013 | 23/07/2015 | 13,451,632 |
| HG | Copper (COMEX) | 29/08/2013 | 23/07/2015 | 14,099,824 | YM | E-mini Dow (CBOT) | 29/08/2013 | 23/07/2015 | 45,530,486 |
| JY | Japanese Yen (CME) | 29/08/2013 | 19/06/2015 | 29,897,867 | | | | | |

**Figure 5**

Systematized bid/ask data of gold futures. The left axis shows the spread average between the best bid and the best ask by ticks. For market trades, $\Delta p$ is half of this spread. The right axis displays contract average placed on best bid and best ask prices




For calculating the average spread between bid and ask prices and a number of contracts placed as limit orders on best bid/ask, for each future we used bid/ask data. We obtained eight months of bid/ask data from December, 2014 to July, 2015 using the same data source, *TradeStation Securities*. Since they are not continuous, have some gaps and are not reliable enough for execution analysis we chose not to use them as our main source of data. Instead, we grouped the data by minute and used them for calculating additional costs $\Delta p$ (as half bid and ask spread) and average of contracts offered as limit orders on best bid and ask prices for every minute of the day. Figure 5 offers an example of these calculations for gold futures. Spread and liquidity negatively correlate. Bid/ask spread has a tendency to increase during the market closing and opening hours while the number of contracts offered drops during those timeframes.

For trade execution simulations, we use tick data as the finest reliable market data we could get. It is sufficient for the first step analysis of various execution tactics in futures markets. The range of our data is from August, 2013 to July, 2015, except for Japanese Yen. The history of this future was shortened because of a tick change on June 21, 2015 by the CME. In total, more than 1 billion ticks are used in trade execution simulations in this paper.

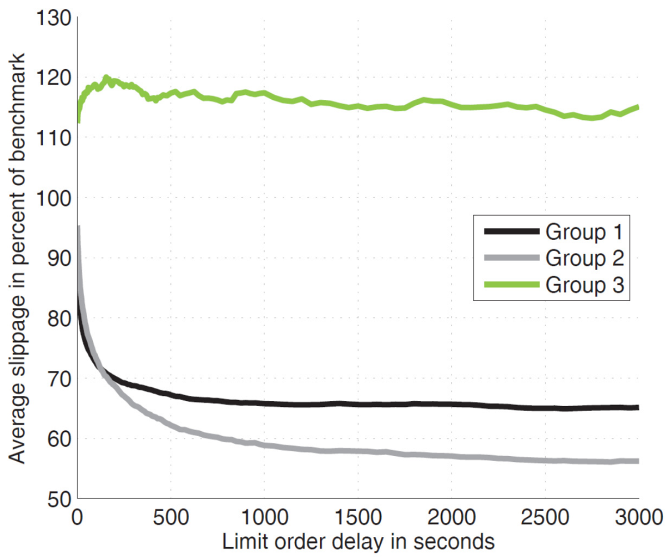
### Methodology

For each futures contract analysed in this paper, we perform two simulations: one for “buy” type orders and another for “sell” type orders. We simulate orders every $k$'th tick, where $k$ is such that there would be about 20 000 orders. All the orders are analysed with various validities $t$ and prices of limit orders $p^L$. We try different time frames and repeat the same execution of orders to see if any would have been filled when the waiting period is prolonged or shortened.

## Computational results

This section presents results of the experiments. We combine buy and sell results to avoid the market direction influence on results.

**Figure 6**
Group 1 shows a rapid decrease of slippage at first, but it slows down later. Group 2 is slower at first but slippage keeps decreasing even with long limit order delay times. Group 3 shows no signs of improvement and has bigger slippage than the benchmark




## Benchmark

The benchmark method is to execute by market order. Simulation shows for all the futures listed in Table 1, it costs 0.729 ticks to fill a market order. The benchmark trading cost of mostly liquid futures on average is close to 0.5–0.6 tick.

## *LM* method

The results of *LM* method show lower trading cost compared to the benchmark method. Based on results, futures can be split into three groups:

1. AD, BO, BP, C, CD, CL, EC, EMD.D, EMD, ES.D, ES, FC, FDAX, FESX, FGBL, GC, HG, JY, KC, MP1, NK, NQ.D, NQ, S, SF, SI, TF.D, TF, W, YM.D, YM;
2. FV, NG, PL, SB, TU, TY, US, VX;
3. DX.

The first group of futures shows a very rapid decrease in slippage during the first 50-200 seconds, but, after that, slippage does not significantly change (see Figure 6). There is no need to trade these futures with long limit trade durations, and it is better to stay within the 50-200 seconds interval. We aim for a 20-80% rule, where we try to get 80% improvement with 20% of effort (or waiting time). For the first 100 seconds, Group 1 shows better results than Group 2. However, after 500 seconds performance does not significantly improve. If, for Group 1, we use 3000 seconds as the limit order waiting time, the result would be only 5% better on average than waiting only 200 seconds. Table 2 lists the average groups results. If the limit order is held for a long time, then there is a considerable probability that price might drastically diverge from the limit price, and we might incur huge slippage when converting the limit order to market order. In a long time period, slippage would converge to the average, but in a shorter period of time, a longer waiting period might generate too large slippage for a trader. To reduce that probability, a trader should use no more than 200 seconds to hold the limit order. Waiting much longer gives only a 5% smaller slippage.

**Table 2**
Average results of groups with different waiting times

| Seconds | Group 1 | Group 2 | Group 3 |
|---|---|---|---|
| 25 | 79 % | 83 % | 116 % |
| 50 | 76 % | 78 % | 117 % |
| 100 | 73 % | 73 % | 119 % |
| 200 | 70 % | 69 % | 119 % |
| 500 | 67 % | 62 % | 117 % |
| 1000 | 66 % | 59 % | 117 % |
| 2000 | 66 % | 57 % | 115 % |
| 3000 | 65 % | 56 % | 115 % |

Group 2 acts like Group 1. The main difference is that the decrease in slippage during the first 200 seconds is slower but the tendency for slippage persist longer. This feature is especially noticeable for shorter term bonds (2 and 10 year U.S. treasury notes) and CBOE volatility index futures. The tendency is caused by low volatility and big tick sizes or a small range of movement. These three futures should be traded using limit orders up to 1000 seconds. Waiting an additional 800 seconds to 200 seconds decreases slippage by 10% from the benchmark, a significant decrease in slippage for a trader. Waiting even more seconds is not beneficial enough, especially since a longer waiting period means larger slippage extremes.

Group 3, consisting only of the U.S. dollar index future, showed no cost reduction compared to trading by market. An increasing limit trade duration caused higher trading costs. It would be best to trade this future with a limit trade duration up to 10 seconds or instant market orders.

### *LBM* method

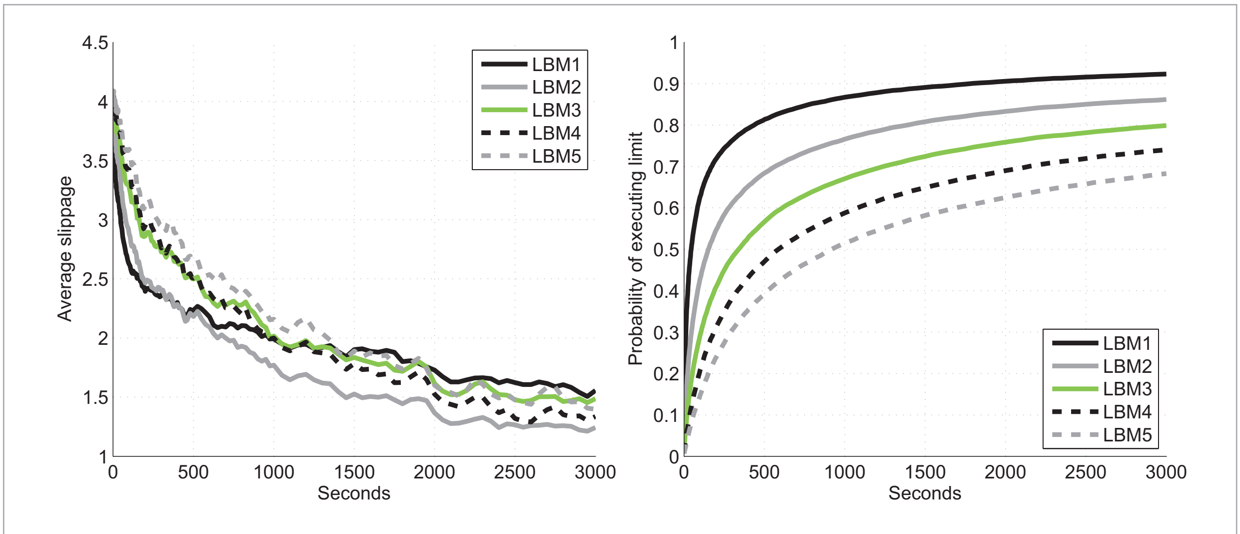
The *LBM* method shows similar results as the *LM* method and works on all futures except the U.S. dollar index and 2 year U.S. treasury note futures. For all futures, there is a clear tendency that the more we improve desired (limit) price, the more average price of execution lags behind during the first 500–1000 seconds. Figure 7 shows an example.

If we limit the holding time to 200 seconds, then, for almost all futures, the best *LBM* method would be *LMB1* – with one tick improved (added/subtracted to the desired price depending on the order direction). The bigger deviation from desired price for limit order works better only with long waiting periods such as 10 minutes and longer. This statement is not valid for all futures.

An interesting feature is observed for futures with a clear tendency in price movement for longer periods like the decreasing prices of oil during the second half of 2014. Such market conditions allow one to use *LBM* to its advantage and decrease trading costs significantly. However, this tactic works for only buy (if price decreases), sell (if price increases) and inflates execution costs for the opposite direction. In the example of falling oil prices, the *LBM* method decreases slippage of buying a future because limit order of buying at a price lower than the current market price (as *LBM* tries to do) is filled more frequently as the oil price has a tendency to fall and the market is willing to make a deal at lower prices. In contrast, the probability of filling a selling limit order at a higher price,

**Figure 7**

Selling British Pound futures by *LBM* method. The *X*–axis denotes limit trade duration in seconds, the left chart depicts the average cost of selling British pound futures with the *LBM* method, and the chart in the right pictures the limit trade filling probability



when oil price has a tendency to fall, is reduced and it significantly increases slippage. Because of this, a slightly more complicated order execution strategy can be implemented using *LBM* for one direction and *LM* with short limit order holding times, or a straightforward *M* method for the opposite direction.

## Comparison

We conclude it is possible to reduce trading costs by trading with the *LBM* method, but if one wants to trade in higher frequencies and therefore in shorter periods, it is best to improve the desired price only a tick or two or use the *LM* method instead. This follows from the basic logic that for a price to deviate more (more than 3 ticks), we need to wait longer, but it results in a greater risk of the limit order not being filled (see the right part of Figure 7).

Although both, *LM* and *LBM* methods work successfully, for individual markets one may pick the best performer. From a practitioner's point of view, simplicity is very important and sometimes only one method can be selected. Figure 8 shows that the *LM* method is better than others on average for a short limit holding time (0–500 seconds), but, for a longer waiting time period, *LBM1* and *LMB2* shows more promising results. It is beneficial to try to achieve negative slippage by using the *LBM* method if a practitioner is patient enough.

Table 3 reveals the method of using *LM* if a practitioner wants to hold a limit order for short period of time and using *LBM* otherwise holds for most futures, especially in Group 1, but this is not true for all futures. Twenty-six of 34 futures in Group 1 and Group 2 show best results when using *LM* method with 50 seconds waiting time. For the rest, the *LBM* method is more beneficial in average. For Group 2, there is no clear tendency of switching from *LM* to *LBM* at all. Even if waiting for 500 seconds or 1000 seconds, it is more beneficial to use *LM* method. Six out of eight futures yield better results for *LM* in Group 2 if waiting time is 500 or 1000 seconds.

Table 4 indicates it is almost always possible to improve execution costs for liquid futures by applying the methods under investigation. Table 4 shows that 488 of 510 results have better performance than the benchmark. For some futures, *LM* or *LBM* could save more than 50% for both, selling and buying orders (i.e. the simulation shows a 75% decrease for ES future

**Figure 8**
Comparison of different methods for all analysed futures

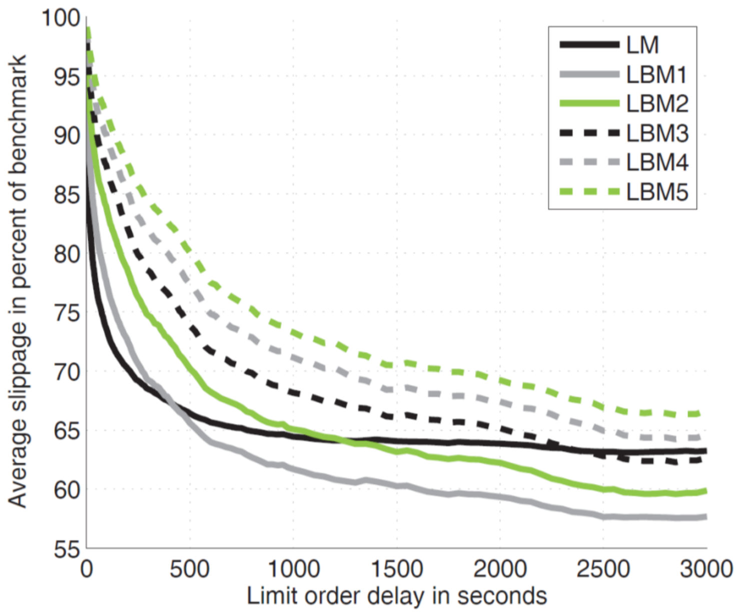


**Table 3**

Execution costs (in percent) for *LM* and *LBM* methods with different limit trade duration compared to the costs of the benchmark method *M*. For example, 80% means that the method yields 80% of the benchmark slippage. In other words, it reduces the cost by 20%

| | | 50 seconds | | | 100 seconds | | | 200 seconds | | | 500 seconds | | | 1000 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Symbol | LM | LBM1 | LBM2 | LM | LBM1 | LBM2 | LM | LBM1 | LBM2 | LM | LBM1 | LBM2 | LM | LBM1 | LBM2 |
| Group 1 | AD | 79 | 84 | 91 | 75 | 77 | 86 | 72 | 69 | 77 | 68 | 58 | 65 | 66 | 52 | 57 |
| | BO | 72 | 77 | 82 | 69 | 71 | 76 | 65 | 63 | 69 | 62 | 56 | 60 | 58 | 49 | 51 |
| | BP | 69 | 75 | 82 | 65 | 67 | 73 | 62 | 61 | 63 | 60 | 57 | 55 | 59 | 51 | 45 |
| | C | 77 | 85 | 92 | 72 | 80 | 88 | 68 | 73 | 83 | 64 | 64 | 77 | 61 | 57 | 69 |
| | CD | 78 | 85 | 92 | 73 | 79 | 88 | 69 | 72 | 82 | 65 | 64 | 71 | 61 | 59 | 63 |
| | CL | 65 | 57 | 62 | 62 | 54 | 58 | 61 | 50 | 51 | 57 | 45 | 43 | 53 | 40 | 33 |
| | EC | 66 | 76 | 85 | 61 | 68 | 78 | 58 | 60 | 65 | 54 | 48 | 51 | 54 | 43 | 45 |
| | EMD | 85 | 86 | 89 | 85 | 87 | 90 | 83 | 84 | 87 | 81 | 78 | 80 | 80 | 76 | 75 |
| | ES | 52 | 64 | 80 | 49 | 52 | 70 | 46 | 42 | 56 | 44 | 30 | 38 | 44 | 26 | 25 |
| | FC | 70 | 78 | 80 | 67 | 73 | 76 | 64 | 71 | 73 | 61 | 67 | 68 | 60 | 67 | 67 |
| | FDAX | 64 | 54 | 58 | 63 | 51 | 52 | 60 | 46 | 45 | 59 | 40 | 35 | 57 | 34 | 29 |
| | FESX | 71 | 79 | 91 | 65 | 69 | 84 | 60 | 59 | 74 | 56 | 44 | 57 | 54 | 38 | 46 |
| | FGBL | 67 | 72 | 86 | 64 | 64 | 80 | 60 | 54 | 69 | 57 | 44 | 56 | 55 | 38 | 49 |
| | GC | 71 | 69 | 75 | 68 | 63 | 68 | 66 | 60 | 63 | 63 | 54 | 55 | 62 | 52 | 47 |
| | HG | 72 | 78 | 87 | 68 | 71 | 80 | 66 | 68 | 76 | 62 | 61 | 68 | 61 | 62 | 67 |
| | JY | 80 | 85 | 94 | 75 | 79 | 90 | 70 | 72 | 83 | 67 | 65 | 75 | 64 | 57 | 64 |
| | KC | 84 | 84 | 86 | 82 | 81 | 82 | 80 | 80 | 79 | 78 | 77 | 73 | 78 | 78 | 75 |
| | MP1 | 76 | 97 | 90 | 72 | 94 | 85 | 67 | 91 | 79 | 63 | 86 | 69 | 61 | 85 | 65 |
| | NK | 100 | 98 | 98 | 98 | 98 | 98 | 95 | 96 | 96 | 94 | 94 | 94 | 92 | 92 | 92 |
| | NQ | 70 | 64 | 72 | 67 | 61 | 67 | 66 | 61 | 63 | 66 | 54 | 50 | 64 | 54 | 52 |
| | S | 73 | 74 | 81 | 72 | 70 | 78 | 70 | 65 | 73 | 67 | 58 | 65 | 65 | 51 | 56 |
| | SF | 68 | 83 | 92 | 64 | 79 | 89 | 62 | 73 | 83 | 59 | 66 | 76 | 59 | 68 | 77 |
| | SI | 80 | 83 | 91 | 75 | 77 | 87 | 72 | 72 | 80 | 70 | 67 | 73 | 69 | 65 | 69 |
| | TF | 74 | 65 | 69 | 73 | 62 | 64 | 70 | 58 | 58 | 70 | 57 | 54 | 68 | 48 | 48 |
| | W | 71 | 76 | 83 | 67 | 69 | 78 | 65 | 64 | 75 | 62 | 59 | 67 | 60 | 52 | 58 |
| | YM | 76 | 71 | 75 | 72 | 67 | 70 | 68 | 62 | 61 | 65 | 53 | 46 | 63 | 51 | 43 |
| Group 2 | FV | 76 | 92 | 99 | 70 | 87 | 97 | 65 | 78 | 92 | 59 | 66 | 79 | 57 | 59 | 70 |
| | NG | 77 | 76 | 82 | 76 | 72 | 80 | 73 | 68 | 74 | 67 | 59 | 61 | 65 | 56 | 57 |
| | PL | 69 | 82 | 82 | 67 | 79 | 79 | 65 | 76 | 74 | 63 | 74 | 72 | 61 | 71 | 69 |
| | SB | 82 | 87 | 94 | 77 | 83 | 92 | 72 | 76 | 86 | 65 | 64 | 73 | 63 | 59 | 66 |
| | TU | 99 | 100 | 101 | 94 | 100 | 101 | 87 | 99 | 101 | 75 | 96 | 100 | 68 | 91 | 99 |
| | TY | 64 | 89 | 98 | 57 | 81 | 95 | 53 | 74 | 92 | 46 | 57 | 75 | 43 | 47 | 63 |
| | US | 60 | 87 | 96 | 53 | 78 | 93 | 50 | 69 | 86 | 45 | 55 | 73 | 44 | 47 | 63 |
| | VX | 91 | 95 | 99 | 86 | 93 | 99 | 80 | 88 | 96 | 72 | 79 | 89 | 67 | 71 | 80 |
| G.3 | DX | 117 | 115 | 111 | 119 | 120 | 117 | 119 | 125 | 122 | 117 | 121 | 119 | 117 | 120 | 118 |

using *LBM2* method with 1000 seconds). However, there are many traders who trade using the market orders and think that they must execute trades as fast as possible in case the price drifts in the opposite direction. Our analysis demonstrates that in individual cases this may be true, but, on average, it is not. In most cases, the price comes back; 82% of the times the price will come back within 200 seconds. And the benefit of waiting (0 slippage for the *LM* method or negative slippage for the *LBM* method) outweighs slippage on average when limit orders are not filled and converted to market orders.

## Conclusions

Several atomic order execution tactics were evaluated for futures markets to find the optimal one. Research in this area is surprisingly theoretical and mostly concentrated on large (bigger than instantaneously available liquidity) order execution problems. No other thorough empirical research on the topic could be found.

The statement that an order must be filled quickly or the price will run away seems to be exaggerated. It is shown that the price comes back quite often. If calculated on average by many transactions, it is more profitable to be patient and wait. By applying an optimal atomic execution tactic for specific futures, one can noticeably reduce trading slippage. The simple strategy (*LM*) of placing a limit order at the last seen price and holding for fifty to hundred seconds and then converting the order to the market order if limit order was unfilled reduces trading costs up to 50% for some futures. This is a general concept and is not applicable to all markets. One has to take all the assumptions and possible market impact into account as our research is made using only historical data and simulated trades. There are some exceptions and some markets exhibit different forms of behaviour. There is a possibility of reducing trading costs even further by using the *LBM* method, but the waiting time should be substantially increased (up to 1000 seconds).

Market direction bias has some influence on our results. If the price of the future had a clear trend over the selected period, there is a tendency that sell (when price fell) or buy (when price rose) orders will be more costly than the other way round. Fortunately, this bias was minimized because of the lengthy historical data and combination of both order directions.

Systematic trading firm initiating this research applied the *LM* method in practice and reported that it seems to work or at least it is not worse than the previous execution method. More time is needed to demonstrate any advantages as individual cases can be misleading. We hope to get some more feedback in the future.

In future research we plan to investigate dependency between intraday volatility and intraday slippage. In other words, we will pay more attention to the time of the day, as market activity and volatility highly depends on time. We grouped simulated trades in 15 minute intervals by arrival time. It allowed us to check the impact of intraday volatility on the execution methods. Intuitively, one would expect that during more volatile times both, *LM* and *LBM* would work better, meaning that there is a negative correlation between the day's volatility and slippage. Our simulation results support this hypothesis, but not for all futures contracts, as correlation between average slippage and volatility can vary significantly. Further research should be done.

A preliminary research was done for large order execution using the *LM* method. Tests show that the order needs to be broken down into smaller bits and executed as several smaller separate orders to reduce market impact.

In addition, another execution strategy can be applied in further research – the limit can trail the price if the price runs away from it by a number such as 5 ticks, a scenario similar to the trailing stop.

### Acknowledgments

This work was supported by the Research Council of Lithuania under grant MIP-100/2015. Authors also want to express their appreciation to Vilnius University.

## References

1. R. Almgren, N. Chriss. Optimal execution of portfolio transactions. Journal of Risk, 2001, 3(2), 5-39. https://doi.org/10.21314/JOR.2001.041
2. R. Almgren. Optimal execution with nonlinear impact functions and trading-enhanced risk. Applied Mathematical Finance, 2003, 10(1), 1–18. https://doi.org/10.1080/135048602100056
3. R. Almgren. Execution costs. Encyclopedia of Quantitative Finance, 2008.
4. R. Almgren. Optimal trading with stochastic liquidity and volatility. SIAM Journal on Financial Mathematics, 2012, 3(1), 163–181. https://doi.org/10.1137/090763470
5. T. Hendershott, C. M. Jones, A. J. Menkveld. Does algorithmic trading improve liquidity? The Journal of Finance, 2011, 66(1), 1–33. https://doi.org/10.1111/j.1540-6261.2010.01624.x
6. B. Johnson. Algorithmic Trading & DMA: An introduction to direct access trading strategies. 4Myeloma Press, 2010.
7. W. Liu, E. Schultz, J. Swieringa. Price dynamics in global crude oil markets. Journal of Futures Markets, 2015, 35(2), 148–162. https://doi.org/10.1002/fut.21658
8. R. Cesari, M. Marzo, P. Zagaglia. Effective trade execution. Portfolio Theory and Management, 2013, 411-437.https://doi.org/10.1093/acprof:oso/9780199829699.003.0018

9. S. Masteika, A. V. Rutkauskas. Research on futures trend trading strategy based on short term chart pattern. Journal of Business Economics and Management, 2012, 13(5), 915–930. https://doi.org/10.3846/16111699.2012.705252

10. R. K. Narang. Inside the Black Box: A Simple Guide to Quantitative and High Frequency Trading (2nd ed.). John Wiley & Sons, 2013. https://doi.org/10.1002/9781118662717

11. K. Omura, Y. Tanigawa, J. Uno. Execution probability of limit orders on the Tokyo Stock Exchange. https://ssrn.com/abstract=252588 or http://dx.doi.org/10.2139/ssrn.252588. Accessed on March 10, 2016. https://doi.org/10.2139/ssrn.252588

12. A. Raudys, S. Matkėnaitė. Analysis of execution methods in US and European futures. The Journal of Trading, 2016, 11(1), 38–52. https://doi.org/10.3905/jot.2016.11.1.038

13. Š. Raudys, A. Raudys, Ž. Pabarškaitė. Sustainable economy inspired large-scale feed-forward portfolio construction. Technological and Economic Development of Economy, 2014, 20(1), 79–96. https://doi.org/10.3846/20294913.2014.889773

14. C. Yingsaeree. Algorithmic trading: Model of execution probability and order placement strategy. PhD thesis, UCL (University College London), 2012.

## Summary / Santrauka

This research investigates a better way to execute buy or sell orders in the futures markets than using instant market orders. Every trader faces an execution cost which comes from the di_erence in observed price and executed price. The goal of this paper is to optimize orders execution to make it cheaper. 35 most liquid futures, over 1 trillion ticks of real market data and 20000 simulated orders per futures are investigated. For most futures, our proposed methods have given significantly better order execution costs than executing with widely used execution method – market orders. The improvement is obtained over large number of trades and may not hold for individual order. This can be achieved by placing a limit order of the desired price and waiting for definite amount of time and converting this order to market order if it was not filled in time. For some futures, even better results can be obtained by improving limit order price by one or two ticks. The proposed order execution method can be attractive for any futures market practitioners whose orders are small or medium size.

Šiame tyrime analizuojamas geresnis būdas vykdyti ateities sandorių rinkos pirkimo ar pardavimo sandorius, nei naudojant paprasčiausią metodą – vykdymą geriausia tuometine rinkos kaina (angl. market order). Kiekvienas prekybininkas susiduria su sandorių įvykdymo išlaidomis, kurios atsiranda dėl sandorio įvykdymo blogesne kaina, nei buvo norima. Šio darbo tikslas yra minimizuoti sandorių vykdymo kaštus. Tyrime naudojama 35 likvidžiausi ateities sandoriai, iš viso pasitelkiama virš 1 milijardo istoriškai įvykdytų sandorių ir simuliuojama po 20000 sandorių kiekvienam iš 35 finansinių instrumentų. Šiame darbe pasiūlyti įvykdymo metodai daugumai ateities sandorių reikšmingai sumažina įvykdymo kaštus lyginant su sandorių vykdymu tuometine rinkos kaina. Tai pasiekiama teikiant pavedimą norima kaina (angl. limit order) bei laukiant fiksuotą laiką ir pakeičiant sandorį į geriausią tuometinės kainos sandorį po praėjusio fiksuoto laiko. Kai kuriems finansiniams instrumentams galima pasiekti dar geresnius rezultatus, kai pavedimas yra teikiamas vienu ar keliais mažiausiais rinkos kitimo žingsniais geresne kaina. Siūlomi sandorių vykdymo metodai yra priimtini bet kuriems rinkos dalyviams, kurių sandoriai yra mažo arba vidutinio dydžio.