ADAM: An Autonomous Agent for High-Frequency Currency Trading in the Brazilian Market

Vicente Matheus M. Zuffo, Paulo André L. de Castro

Divisão de Ciência da Computação (IEC) – Instituto Tecnológico de Aeronáutica (ITA)
São José dos Campos – SP – Brazil

vicentematheus@gmail.com, pauloac@ita.br

Abstract. *This paper presents an autonomous system called ADAM (Autonomous Dollar futures Agent Model) that implements a strategy based in the "Follow The Leader" concept to trade liquid futures contracts in the Brazilian exchange BM&F, taking in consideration peculiarities of the respective market. The agent operates at high frequency, being one of the first of its kind in this market.*

1. Introduction

Nowadays, the so called high-frequency trading (trades made in short time intervals between each other) are responsible for about seventy percent of the American financial market. Although it is growing rapidly, in Brazil this figure is yet around five percent. They are characterized as being predominantly performed by computer algorithms. Basically, the set of factors that determine the investor decisions are compressed into strategies that allow the development of programs which, in theory, simulate the characteristics of the investor.

Many hedge funds, banks and brokers with a strong operation in the United States are opening offices in Brazil to explore the robustness of the local market (one of the largest and safest stock exchanges in the world). Within this scenario, it is happening a lot of investment in technology for the creation of infrastructure and software, aiming the market opportunities that can be leveraged trading at high frequency.

In this study, we implemented a high-frequency strategy based on the "Follow-The-Leader" concept, through an algorithm called ADAM (Autonomous Dollar futures Agent Model). It is an autonomous system for trading dollar futures contracts in the "Bolsa de Mercadorias e Futuros" (BM&F). This type of algorithm is free of human interference in its decisions, since it negotiates according to a pre-established model.

It was chosen the dollar futures market at BM&F as the tool of study due to its high liquidity (measured in volume of trades) and the price of the contract is approximately continuous (the minimum interval between orders is fifty "centavos" per thousand dollars and it has a satisfactory intraday volatility).

The motivation to implement the proposed strategy is to use the concept of high frequency as an advantage over traditional trading agents and to explore opportunities to gain in the dollar futures market in particular. Differently from the usual literature about quantitative investment strategies (mostly based on Technical Analysis), this paper introduces an idea of approaching the market players based on the concept of a leader agent. In addition, it explores a technology branch still very incipient in Brazil, which is the high-frequency trading algorithm.

For testing the algorithm, it was created a simple market simulation platform, which allows the use of real data (historical) from FIX protocol.

2. Dollar Futures Market in the BM&F

Currency futures are contracts in which is negotiated a standard amount of one currency against another. Basically, at the time of the deal, it is fixed a conversion rate of a certain amount of one currency for another at a future date. In the BM&F, the most negotiated currency futures contract is the dollar future. Commonly, each contract defines an amount of US$ 50.000 and maturity date as the first business day of each month.

The trade is always performed between two parts (a buyer and a seller) and, at the end of every day, according to the variation of the dollar futures rate, the difference of the contract value is paid or charged to the respective part. Thus at the maturity date, the total contract value is not transferred from one part to another, but only the difference between the initial and the final contract values (in Brazilian currency, real), according to the exchange rate.

For instance, a dollar future for June 2012 is a contract, which amount value is US$ 50.000, and it expires in the first working day of June. Assuming that the rate negotiated between the buyer A and the seller B for this contract is 1.6 reais per dollar, then in the first working day of august, assuming that the exchange rate is 1.7 reais per dollar, then the buyer A will receive a positive difference resulted from the rate variation, which in this case is US$ 50.000 x (1,7 – 1,6) R$/ US$ = R$ 5.000, while the seller B should pay only this difference and not the entire value of the contract (US$ 50.000).

In the BM&F, the quotes for these contracts are given as reais per thousand dollars with one decimal place and the minimum price fluctuation is fifty centavos per thousand dollars. That is to say the least negotiable price greater than R$ 1.600 per US$ 1.000 will be R$ 1.600,5 per US$1.000.

The most traded contract among the dollar futures contracts is the one that expires on the first day of the next month of the trade date, because it is the closest to a spot trade. In addition, the quantities negotiated are always multiple of five, i.e., an amount equivalent to US$ 250.000.

Naturally, the Supply and Demand Law applies to the pricing of any asset traded on a stock exchange. Basically, the agents willing to buy the asset publish buy orders for a specified price on a certain number of contracts. Similarly, the agents willing to sell it publish sell orders with higher prices. Thus are formed the so called bid and ask books, which line up all the buy and sell orders available in the market.

A trade occurs when an agent decides to buy contracts at a price greater than or equal to the first order of the ask book or when an agent decides to sell a contract at a price less than or equal to the first order of the bid book.

The only institutions authorized to buy and sell these futures contracts at BM&F are the securities brokers. Thus, every investor must have an account at a brokerage house in order to participate in the market. That is, brokers act as intermediary elements between the investors and the exchange, where the trades occur. Particularly in Brazil, the information published by BM&F to the market, regarding to the bid and ask books contain not only the prices and quantities of each order, but also the name (or code) of the brokerage house involved, information that is not present in the United States where the markets are called “blind”.

Tables 1 and 2 illustrate examples of bid and ask books of the Brazilian dollar futures market:

Table 1. Example of the Bid Book

Brokerage House	Quantity	Price (R$ / US$ 1.000)
BM000188	10	1.700,0
BM000072	50	1.700,0
BM000213	25	1.699,5
BM000012	5	1.699,5
BM000001	5	1.699,0

Table 2. Example of the Ask Book

Brokerage House	Quantity	Price (R$ / US$1.000)
BM000174	20	1.700,5
BM000030	30	1.701,0
BM000255	15	1.701,0
BM000008	10	1.701,0
BM000009	15	1.701,5
BM000008	5	1.701,5

Naturally, the first price of the bid book is always lower than the first price of the ask book. In addition, orders with the same price are classified chronologically according to their arrival instant in the BM&F servers. It is possible to change parameters of an order previously sent, since it is still available in the market. In the case of a change in the price or an increase in the number of contracts of the order, it goes to the end of the line between the orders of the desired price. In the case in which only the number of contracts is decreased, the order does not lose its position in the order queue.

3. Strategy Description

The financial market is composed of a multitude of agents. In particular, the dollar futures market on the BM&F is one of the most liquid which means it is extremely accessible, where there are a huge number of agents trading a high financial volume.

Within this context, it is assumed that there is at least one agent (or set of agents, as discussed below) on the market that somehow manages to obtain positive results consistently over various periods of time. This agent is then called leader. The strategy is based on a “follow the leader” tactics.

There are several possibilities for the consistent gain of the leader. Among those options, one can highlight the following:

- The leader has a considerable amount of resources so that his investment decisions (his price expectations) could alter significantly the prices of certain assets, even very liquid ones in a way that even others actors feel compelled to reassess their own decision because of considerable movements in the asset price;
- The leader is able to perform an analysis that is consistent with market movements, be it technical or fundamental. This capability can exist for skill or might have been developed with experience;
- The leader has some insider information that gives him extreme advantage over other market players.

Finally, the leader is an agent capable of obtaining considerable gains in certain movement in the price of an asset. Roughly, the strategy consists in, after a certain period of time, identify an agent as the leader and try to perform the same trades that he does.

The first problem identified in the development of ADAM was the time interval considered for the assessment of the leader, because this time interval must necessarily be less than the duration of the price movement. Otherwise, the result obtained by the movement does not happen.

For the agent proposed, the leader is defined as one that has the largest result function within the time interval evaluated. This definition does not guarantee that the agent chosen as leader in fact presents a consistent gain in the coming periods, but given the information publicly available by the market, this heuristic becomes the most coherent. To determine the result of an agent in the financial market (and the method is very similar for all types of assets) is necessary to monitor all trades made by this agent.

A trade in which the agent is one of the two parts involved can be represented by the pair $O = (Q, P)$, being Q the quantity negotiated and P the price (or quote).

Suppose that a particular agent A bought Q contracts of an asset at a price P. For the derivatives market, where the agent does not necessarily have the physical asset, as the settlement is given only by paying or receiving the financial adjustment of the price change, given such operation, it is Said that A is long and B is short in Q contracts, both at the price P.

Thus, if there is a movement in the price of the asset from P to P', then the respective result functions of the agents will be given by:

$$Res(A) = Q \times T \times (P' - P) \quad (1)$$

$$Res(B) = -Q \times T \times (P' - P) \quad (2)$$

Where T is the size (financially) of the contract.

If the agent made several trades, his generalized result function is given by:

$$Res(A) = T \times \left[P_{MARKET} \times Position(A) - \sum Q_{C,i}P_{C,i} + \sum Q_{V,i}P_{V,i}\right] \quad (3)$$

Where:

- Q_C and P_C correspond, respectively, to the Quantity and to the Price of an buy order traded by agent A;
- Q_V and P_V correspond, respectively, to the Quantity and to the Price of an sell order traded by agent A;
- P_{MARKET} is the last price negotiated in the market;
- $Position(A) = \sum Q_{C,i} - \sum Q_{V,i} \quad (4)$

As previously mentioned, in the Brazilian financial market, the buying and selling brokerage houses of each order are available information, published by the Exchange, both for orders available in the books and for the past trades.

Therefore, for every new trade, it is possible to evaluate the result function for all the brokers in the market. One cannot know which agents negotiate in each brokerage house and neither which agents trade through different brokers. Thus, it is not possible to determine exactly which agent, but only the set of agents (brokerage house) that represents the market leader at the moment.

In the dollar futures market, on average, there are new trades every second (even tens per second). Hence the need to create an algorithm that can do the analysis of market data at high frequency.

To determine the leader to be followed, there have been created two types of definition:

- Static Definition of Leader: agent (broker) with the biggest result function in a given period P (in hours) which, once evaluated, remains the leader throughout the day. That is, every day, only one assessment is made to determine the leader, during the first P hours of the trading time.
- Dynamic Definition of Leader: agent (broker) with the biggest result function after each period of P hours. Thus, it is possible, during the day, that there are many different leaders. The result function for each agent takes into account all the trades made in the day.

It was defined as the operating period of the strategy a whole Day, because it is the longest period in which the market operates in quasi-continuous mode. Therefore, it was decided that the strategy always ends the day with no position, i.e., the sumo f the contracts bought must equal the sumo f the contracts sold.

The algorithm then can be divided into two phases. During the first phase, it is made only the monitoring of the orders in the market. After a period P, the leader is determined, according to the result functions of all agents. Figure 1 shows a simple flowchart of this phase, in which the start is given by each new event that hits the market:

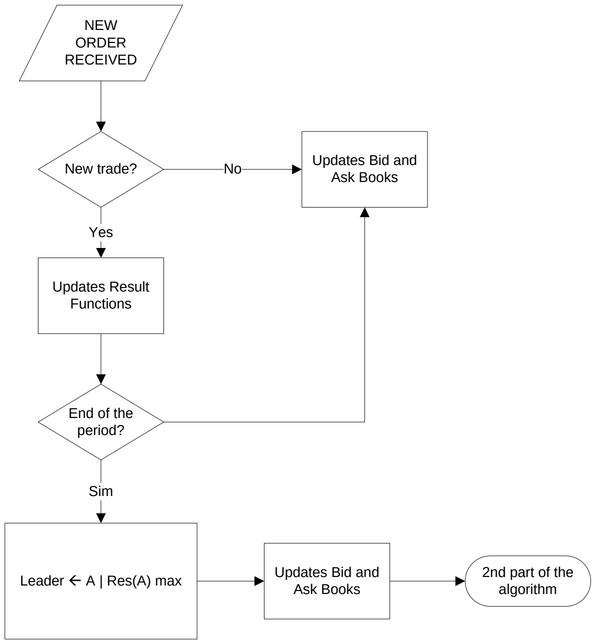

Figure 1. Flowchart of the first phase of the algorithm

Once the leader is determined, the algorithm buys or sells contracts in order to match its position to the leader's position. From this moment, for any new trade, it will check if the leader was one of the parts involved (and only one, so that there is a change in position). If the leader has bought X contracts, it will buy X contracts in the market. If the leader has sold X contracts, it will sell X contracts in the market, so that the positions of the agent and the leader will be the same.

Eventually, the agent will not be able to execute trades at the same price as the leader did, but slightly worse (higher when to buy and lower when to sell, according to market conditions). This difference is meaningful only if the period of analysis for the determination of the leader is not compatible with the average period of price movements for this asset, which generates the leader's advantage. For this reason, we used different periods in the experiments, as described in section V.

So the second part of the algorithm is represented by the flowchart in Figure 2:

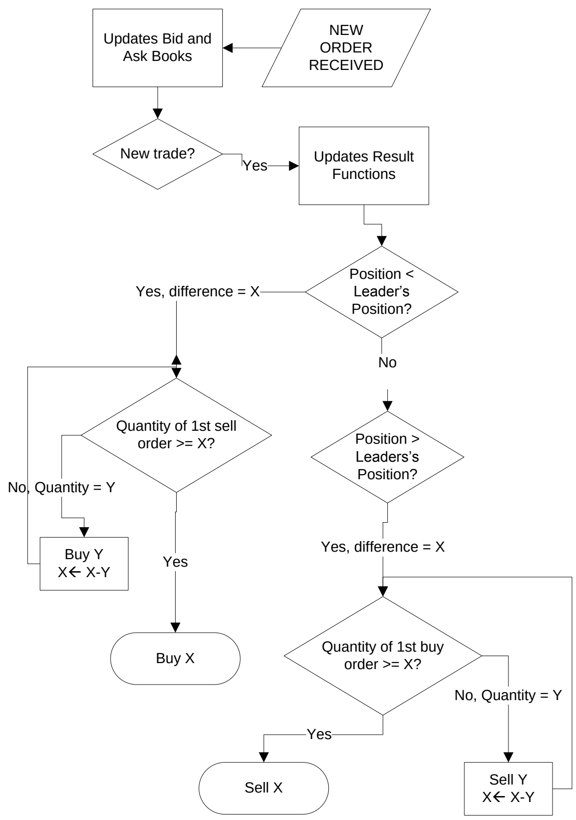

Figure 2. Flowchart of the second phase of the algorithm

For the model that uses dynamic definition of a leader, the re-evaluation of the leader after a new period P happens in a manner analogous to that of the first flowchart, but simultaneously to the second flowchart processing.

In the last minutes of trading, the algorithm stops following the leader and only performs the necessary trades to make its position null, as explained above.

4. Implementation

For testing the model it was developed a trading platform with three operating modes: manual, simulated and historical (with actual market data, from a database).

This platform runs on a server and can be remotely accessed by different processes, each one representing a market agent. It has a simple graphical interface for a better visualization of the bid and ask books. The client and the server send and receive messages via UDP protocol through a simplified model, created only for this purpose, based on FIX protocol (Financial Information Exchange), which is the standard among financial markets worldwide.

Both processes were developed in JAVA language. The platform has a main class called Market which processes the orders received by participants and matches them when a trade is supposed to happen. The different operating modes of the market run on separate threads, simulating the different participants that send orders (messages) to the market.

For the experiments, we used the historical operating mode because it allows the use of real market data, obtained from the BM&F for the period of January 2009. All messages (in FIX protocol) of the dollar futures market of that period have been translated and stored in a database, according to the entity in Figure 3:

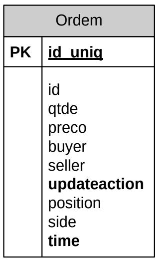

Figure 3. Order from the database that stores the historical data

On the Server, there is a separate thread to handle messages received by the new agent, to avoid concurrence with the messages received by the historical mode (database). In this mode, the system is designed in a way the presence of the new agent does not interfere with the order book, so that the simulation accurately represents the same events happened in the actual market, what is reasonable to assume for the dollar futures market due to its high liquidity. In practice, any new agent will interfere with market dynamics, the more the higher quantities are traded.

In Figure 4, there is a snapshot of the market platform with the algorithm in operation:

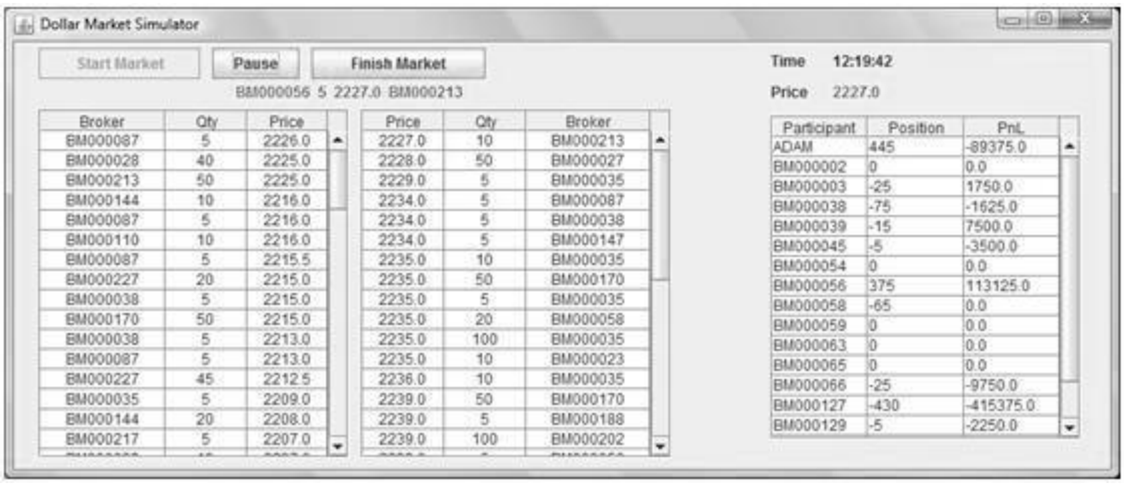

Figure 4. Simulator in execution

5. Experiments

The experiments were divided into two groups. The first group aimed to test the performance of the algorithm using the model with static definition of leader, while the second group used the model of dynamic definition of leader.

As mentioned in section III, when the definition of the strategy was proposed, a central question in the development of the strategy is the length of the period to be considered for the evaluation of the leader. There is no convincing theoretical model that justifies the choice of a certain period over another. In this context, three distinct periods were chosen for both experiments with static and dynamic definitions of leader.

For the first group of experiments (with static definition of leader), the periods chosen for the tests were one hour, two hours and four hours. One entire running market day takes about nine hours. Therefore, the periods were chosen so as to consider about 10%, 20% and 40% of the session duration. A period longer than four hours apparently is not consistent with the proposal because the lower the time that the algorithm works after setting the leader, in theory, the less will be exploited the advantage that the leader provides. In addition, it was considered that different periods would not have an effect significantly different from one of the three chosen periods, since the price movements over a period of one hour are relatively small. If the participant identified as the leader is actually advantageous, so in theory, he should continue to be the leader at least for a short period of time, as one hour.

For the second group of experiments, in which the leader is chosen dynamically, the periods considered were half an hour, one hour and two hours. In this case, it would make no sense to use the four-hour period, since the second definition of the leader would occur only by the end of the trading session. This group of tests aimed to verify whether the algorithm could profit from the advantage of the leader in the short term. By changing the leader, the algorithm theoretically believes that the advantage of the previous leader is over.

Tests were conducted for all weekdays from the 5th to the 23rd of January 2009, using the three different periods for each test group (with static and with dynamic definition of leader). These dates were chosen due to the available data provided by BM&F, being the most liquid and recent between the available data set.

The criterion for evaluating the performance of the ADAM was the relative result function compared to the result function of the other market participants in the same period of analysis. The result does not consider the transaction costs for any of the participants (although in practice, they are not equal). Because of the using of real data, the simulation considers all the market participants, what accounts for about 60 brokerages (we take each set of clients as one participant).

6. Results

In Figure 5, it is possible to observe the results (by the end of the session) of the ADAM in the first group of tests (with static leader), using periods of one hour (white), two hours (grey) and four hours (black).

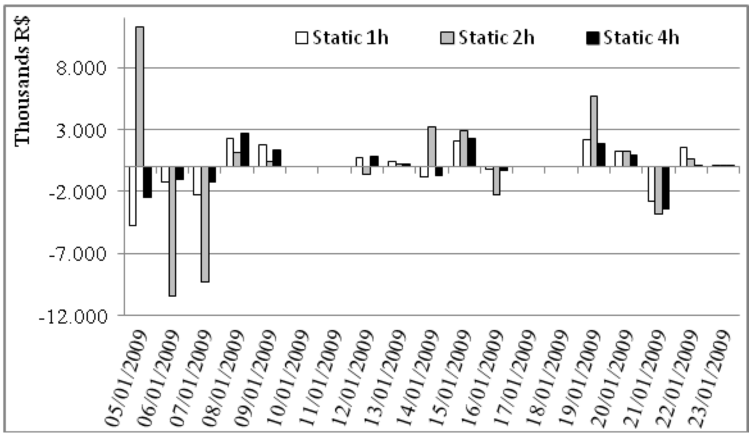

Figure 5. Results from the tests with static definition of leader

With the tests made, it was possible to observe that the results using the two-hour period were more volatile than the others. In other words, the standard deviation of the results in this period was higher than the standard deviations of the results with periods of one and four hours. This means that for the study period, the price movements were more concentrated near two hours intervals.

Moreover, it is possible to observe that, on most days, the results using different periods were all positive or all negative and they seldom happened to have opposite signs. That is, in general, the results of the leaders of each day kept the same trend throughout the day.

As a criterion for measuring the performance of the algorithm, we compared its results with the other market participants during the study period, as a ranking. Tables 3, 4 and 5 show the comparison between the first group of tests' results:

Table 3. Performance for One-Hour Period with Static Leader

Ranking	Agent	Result
1	BM000188	+33.401.100
26	ADAM	+624.375
65	BM000072	-34.093.725

Table 4. Performance for Two-Hour Period with Static Leader

Ranking	Agent	Result
1	BM000188	+33.401.100
29	ADAM	+454.400
65	BM000072	-34.093.725

Table 5. Performance for Four-Hour Period with Static Leader

Ranking	Agent	Result
1	BM000188	+33.401.100
26	ADAM	+1.128.850
65	BM000072	-34.093.725

Similarly, Figure 6 shows the chart with the results of the second group of tests (with dynamic leader) using half-hour (white), one-hour (grey) and two-hour (black) periods:

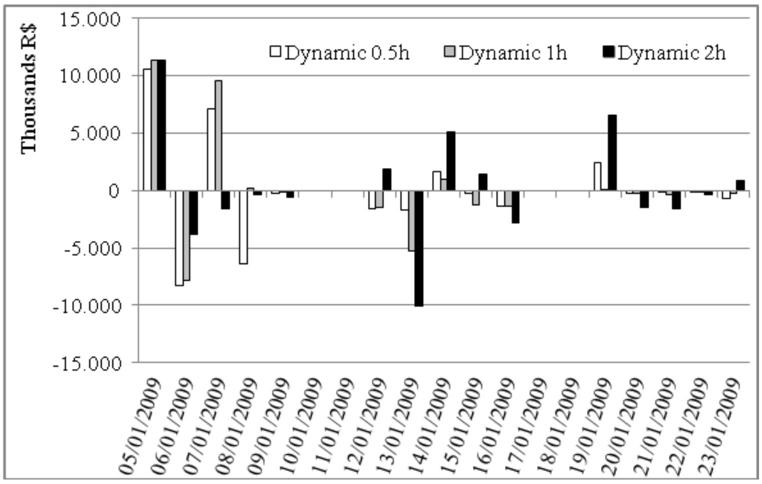

Figure 6. Results from the tests with dynamic definition of leader

The results obtained from the tests with different periods are not as dissimilar as those obtained with static definition of leader. That is, using the dynamic definition, we obtained more consistent results and relatively less volatile than the ones from the first group. In the same line, tables 6, 7 and 8 represent the performance of the algorithm for this group of tests:

Table 6. Performance for Half-Hour Period with Dynamic Leader

Ranking	Agent	Result
1	BM000188	+33.401.100
26	ADAM	+736.875
65	BM000072	-34.093.725

Table 7. Performance for One-Hour Period with Dynamic Leader

Ranking	Agent	Result
1	BM000188	+33.401.100
17	ADAM	+3.544.375
65	BM000072	-34.093.725

Table 8. Performance for Two-Hour Period with Dynamic Leader

Ranking	Agent	Result
1	BM000188	+33.401.100
15	ADAM	+4.499.550
65	BM000072	-34.093.725

7. Conclusion

Given the content exposed, we conclude that using the static definition of leader, the algorithm performance was reasonable compared to the other market participants, with positive results in all three sets of tests. However, we can see that those results do not even have a significant order of magnitude. Although it performed well, it would be convenient to make an analysis with more extensive samples of data in order to reach a more reliable conclusion, because such results may be biased by the historical data used. If we had obtained more consistent results, we could affirm categorically that the algorithm's performance is satisfactory.

In contrast, the use of dynamic definition of leader showed much higher performance. The evaluation periods with the best results were, respectively, of two and one hour.

Because it is very likely that, in each trading day, the leader is not the same as the previous day, ideally the strategy would take advantage of some of the gains of the leader of the day. Therefore, in the long term, ADAM's performance would probably be among the best between all the market participants, if not the best one.

The implementation happened to be a very useful tool because it allows the test of any algorithm with real market data, since the latter communicates with the system through well-defined messages. It also allows in a simple way to convert real FIX messages of the market in registers in a database to be used for testing.

In a more sophisticated analysis of the algorithm's details, we notice that it can be improved in several aspects. For instance, in general, the price paid by the algorithm to match its position to the leader's is always equal to or slightly worse than the price paid by the leader in a trade. This kind of detail observed in high frequency eventually becomes relevant when many operations are performed on the same day. In this case, it is appropriate to refine the model to minimize the influence of this issue.

Possible studies that may be performed include the introduction of rules for entering orders into the market. One example of rule could be to consider the sums of the quantities of orders on the bid and ask books to try to establish a greater probability of the next trades be done in the bid price or in the ask price

Moreover, as the leader in most cases is a brokerage house with a large trade volume, it would be interesting to create filters to define the leader. For example, excluding the brokers with the greatest volume traded, as well the brokers whose result is more volatile, so the algorithm will be more secure, given the limitations of the investment capacity.

In practice, ADAM appears to be relatively simple to be built with different technologies, given a platform (or framework) capable of handling events at high frequency. Today, there are several companies that offer this type of product, such as frameworks, in which the algorithms can be customized according to the operating agent that one wants to create. This strategy, in particular the way it was conceived, is very restrictive to use for trading in the Brazilian market due to the large financial volume involved. For small investors, it would be ideal to customize the strategy for lower volumes to make it viable, according to their investment power, as well considering transaction costs when carrying out back-tests.

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