Algorithmic and High Frequency Trading - Pairs Trading

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Abstract

This paper investigates or rather constructs a neutral trading strategy among the mean-reverting aspect of pairs trading. Six pairs of futures on agricultural commodities, grains and softs, are tested pairwise for co-integration with the Engle-Granger two step method for a five-year period, 2013 to 2018. The only co-integrating pair is corn-soybeans. Based on the mean-reversion of this pair, a trading strategy, as a combination of the Bollinger Bands and the Ad-Hoc-Bands is developed.
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1 Introduction

On January 1st, 2019 Algorithmic Trading, short Algo-Trading, dominated 80% of the daily moves in the US stock market.\footnote{Algo Trading Dominates 80% Of Stock Market} Merely 20% of the daily trading decisions on stocks at the US markets are taken by humans itself. Even in India, an emerging country, the percentage grew up to almost 50%. Remarkable is the speed of growing. Only eight years ago the volume of the algorithmic traded stocks at the Indian market noted 9% \footnote{Sharma: Algorithmic trading share in total turnover grows to 50% in 8 years}, not surprisingly in the era of artificial intelligence.

To investigate Algorithmic Trading in detail in this paper, the term is defined as follows to assure a common understanding for all readers. "Algorithmic trading is a type of trading done with the use of mathematical formulas run by powerful computers. An algorithm, in mathematics, is a set of directions for solving a problem."\footnote{Chen: Algorithmic Trading} Of course, computers do not develop the algorithms itself, it is human action.

This paper gives a short insight into algorithmic trading in general, developing strategies and specializes on the Pairs trading strategy. Chapter two defines Pairs Trading and explains the main idea behind the strategy, shown in an application for the agricultural commodities market. A pair is found by the Engle-Granger two step method, a test for co-integration. Chapter three is about optimal stopping problems, beginning with the simple example of the Bollinger Bands and a comparison with the known exercising problem of an American option. On this basis, the reader will be introduced to performance criterions and the Stopping Region, the set of times, optimal for stopping. This leads to the Dynamic Programming Principle, an often-used concept for practical applications. In chapter four algorithmic trading is finally directly addressed. Beginning with the fundamental knowledge about the exchange, the come-together of the orders by the rules of the Limit Order Book, and the classes of traders acting. Secondly, data reading, the basic for developing a trading strategy and thus, generating an algorithm, is thematised. The last chapter combines all the knowledge gained in the previous chapters, introduces trading with Ad-Hoc Bands, and finally creates a personal trading strategy.

As literary basis, I mainly used two books: "Algorithmic and High-Frequency Trading" by Cartea, Jaimungal and Penvala, working together for the University of Cambridge and "The Handbook of Pairs Trading" by Ehrman. Most of the content of this paper refers to one of these literary works, whether quoted directly or taken over indirectly.
2 Pairs Trading

2.1 Definition and conception

Pairs Trading defines a market-neutral investment strategy characterized by the mean-reversion of a co-integrated pair of assets. Co-integration implies two assets moving together very closely. A standard role model is Coke and Pepsi, as they are two companies from the same industry and thus share macroeconomic shocks. Another example is the pair JP Morgan Chase, the stock of one of the biggest banks worldwide, to be precise, the world’s sixth biggest bank by total assets in the year 2018, and the biggest in the US - Dow Jones US Bank Index (DJUSBK), an index representing the bank sector in the US. They clearly move together out of economic reasons, as the DJUSBK represents the sector, JP Morgan is operating in and out of mechanical reasoning. Around 10% of DJUSBK’s holdings are JP Morgan shares. Of course, it is an option to expand this strategy to a basket of co-integrated assets. But in this paper, the focus will be on the main idea of pairs trading, a portfolio existing only of two assets.

Thus, the idea is to build a portfolio consisting of two co-integrated assets, go long in the under-valued asset and short in the other one, the over-valued asset. The next step is to set a threshold, which should be mean-reverting to profit from the pairs trading strategy. It is obvious, that we choose the mean-reverting co-integration factor of the two assets. Figure 1 shows the idea. The strategy tells us to go long the portfolio when it is cheap, under the threshold, and close the position, sell it, when the value increases and reaches the threshold. On the opposite, go short the portfolio when it is dear, above the threshold, and close the position, buy it, when the value decreases and hits the threshold.

In comparison to a traditional portfolio, a market-neutral trading strategy makes returns with the relative performance, not the absolute performance. The relative performance is the return differential between the asset hold long and the asset hold short.

Market neutrality can be interpreted in many ways. The most important ones, on which we will use later, are Share neutrality, Dollar neutrality, and Sector neutrality.

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4Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, pp. 57-60
5Ehrman: The Handbook of Pairs Trading: strategies using equities, options and futures, pp. 4-6
6Ungever: PAIRS TRADING TO THE COMMODITIES FUTURES MARKET USING COINTEGRATION METHOD, p. 1
7Fua, Melgaard, Li: Pairs Trading: A Statistical Arbitrage Strategy, p. 3
8Sanders: Biggest Banks In The World 2018
Worth stressing is the difference between a spread trade, based on a share neutral strategy, and a pairs trade, based on a dollar neutral strategy. When spread trading the agent goes long and short the same number of shares (nearly always a different amount of money), when pairs trading the same amount of money, not shares.  

2.2 Co-integration of agricultural commodities

2.2.1 Agricultural future prices

In comparison to a standard option, ether American or European, a future contract on commodities, like oil or wheat, is executed for cash or physical delivery of the underlying. Futures, and also currency pairs, are more difficult than options, equities, etc. because the are very easily affected by extrinsic events, climatic, geopolitical and government forces, e.g. a drought is difficult to predict and its impact on the harvest yield can be fatal. In addition to that, the commodities’ big impact on other assets should be mentioned. The most common example is

\textsuperscript{9}\textsuperscript{\textsuperscript{9}}Ehrman: The Handbook of Pairs Trading: strategies using equities, options and futures, pp. 29-32
the soy crush. Soybeans and their market performance shapes soy meal and its prices, while soy meal shapes soy oil.10

As pairs trading works best with groups of assets that share common shocks, pairs are in most cases from the same industry.11 Hence, we will specify on one sector, agricultural commodities. In the following three grains, wheat, corn and soybeans, and the soft cocoa will be analysed for co-integration in pairs. Therefore, the most fundamental Engle-Granger method will be used, which will be discussed later.

The underlying prices for grains, in detail for futures on grains, are listed at the Chicago Board of Trade (CBOT). As one of the oldest futures and options exchanges worldwide, it demonstrates an important price guideline especially for farmers and investors.12 The deterministic prices for softs are listed at the ICE Futures U.S. (NYBOT), former New York Board of Trade. Figure 2 shows the performance of each asset for five years, 2013 to 2018. On the first sight, they seem to move together, and thus be co-integrated.

2.2.2 Engle-Granger two step method

To proof or debunk this statement, we test the sample pairwise for integration with the Engle-Granger two step method. In short, the first step is estimating the co-integration regression, the second is testing the residual process of the co-integrating regression for a unit root.13 MATLAB provides a predetermined function ”egcitest” for testing historical data.14

<table>
<thead>
<tr>
<th></th>
<th>corn</th>
<th>wheat</th>
<th>cocoa</th>
<th>soybeans</th>
</tr>
</thead>
<tbody>
<tr>
<td>corn</td>
<td></td>
<td></td>
<td></td>
<td>YES</td>
</tr>
<tr>
<td>wheat</td>
<td>NO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cocoa</td>
<td>NO</td>
<td></td>
<td></td>
<td>NO</td>
</tr>
<tr>
<td>soybeans</td>
<td>NO</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The result, which we can find in the tabular, shows that there is only co-integration between soybeans and corn (3.2%). Especially cocoa paired with a grain shows a high level of non-co-integration, 25 to 30 percent. The reasons are obvious: the soft and grain growing areas differ largely. Therefore, the weather, the most important impact factor on the agricultural industry and the prices for the according goods, differs. The non-co-integration degree

10Ehrman: The Handbook of Pairs Trading, pp. 13-14
11Cartea: ALGORIRHTMIC AND HIGH FREQUENCY TRADING, p. 57
12Chicago Board of Trade
13Sjö: Testing for Unit Roots and Cointegration, p. 10
14Test for Cointegration Using the Engle-Granger Test
for the pairs wheat-corn and wheat-soybeans is 16 and 12 percent.

Hence, the pair we will work with in the following sections is corn - soybeans, as they are highly correlated and thus serve a good match. The core question is now, how to use the information about the co-integration for trading.

3 Optimal Stopping Problems

To get a short insight in trading strategies and how they are constructed and work beforehand, for instance the optimal stopping problems will be discussed.
3.1 Bollinger Bands

As a brief introduction to trading strategies in general, especially technical analysis tools, the concept of the Bollinger Bands is going to be demonstrated. Bollinger Bands are upper and lower bands twice the standard-deviation around the mean from the last 20 days. Of course, the variables can be chosen different, but 20 and two are the standard values. Figure 3 shows the Bollinger Bands for the DAX for the 12th of December, 2018. The idea is to buy the stock, portfolio, etc. underneath the lower band, and sell it above the upper band. The minimum profit is fourth the standard deviation of the 20-day mean. Relating to our example, the DAX, the right time to go long was the beginning of December, as it can be seen in figure 3, the price of the index is underneath the lower band. The only risk is decreasing prices, never reverting whether to the upper band, nor the buy price, and instead decreasing constantly and hence making a loss.

3.2 American put option

In the example given above, the optimal stopping time, the ideal time to exit or rather close the position, is the point of time, the price of the asset

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15Bollinger Bands
16DAX 30 Index Werte
17Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, p. 122
reaches the upper band. Bollinger Bands represent a very simple technical analysis tool, often used as a component of a whole strategy. Indeed, for most strategies it is complicated to determine the optimal closing time. The following section addresses exactly this problem, optimal stopping problems. The problem we face, can be easily demonstrated or compared with an American put option. The owner of a put/ call option has the right, not the obligation, to sell/ buy the underlying to a predetermined price, the strike. The difference between an American and European option is, that the owner of an American option can sell/ buy until and including the expiration date, while the owner of a European option can only sell/ buy at the expiration date itself. Hence, the question that rises for an owner of an American option is, when to exercise. Of course, he wants to maximise his profit, which is given by

\[ \sup_{\tau \in T} E[e^{-r\tau}(K - S_\tau)_+]. \] (1)

\( K \) represents the strike, \( S_\tau \) the price of the underlying asset at the exercise date \( \tau \). Obviously, the cash value of this transaction, the difference between the strike and the current price, is positive, because otherwise the owner would not exercise the option, as he possesses the right, not the obligation to exercise the option and would not make profit out of this transaction.

### 3.3 Performance and Stopping Region\(^\text{18}\)

For a trading strategy, the agent has a performance criterion given by

\[ H^r(t, x) = E_{t,x}[G(X_\tau)]. \] (2)

\( G(X_\tau) \) is the reward upon exercise at the exercise date \( \tau \).

It goes without saying that the agent wants to maximise his reward and thus, he seeks to find the value function

\[ H(t, x) = \sup_{\tau \in T[t, T]} H^r(t, x). \] (3)

The rising question is, when exactly to stop to maximise the reward. At one point of time, assumed now, obviously, the agent has two options: exercise the strategy now or not, keep holding, to receive a larger amount at a future
date. The agent should wait if the value function has not attained a value of $G(x)$. Therefore, we define the stopping region.

\[ S = \{(t, x) \in [0, T] \times \mathbb{R}^m : H(t, x) = G(x)\} \]  

(4)

Whenever $(t, x) \in S$, the agent should stop immediately and exercise. Otherwise, as the name already says, at a state in the continuation region, he should continue with hopes of a larger reward in the future. Figure 4\textsuperscript{19} demonstrates both regions. The red point shows the right time for stopping, as it seems clear that the price of the asset/ portfolio is very likely to decrease again and hence reached his peak.

\textbf{Figure 4: Stopping region}

\underline{3.4 Dynamic Programming Equation/\textsuperscript{20}}

Embedding the optimal stopping problem for one point of time into a larger class of problems indexed by time $t \in (0, T)$ generates the Dynamic Programming Principle. For $t$ equal zero, the problem is equal to the original problem.

\textsuperscript{19}Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, p.124

\textsuperscript{20}Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, pp. 124-128
THEOREM 1  Dynamic Programming Principle for Stopping Problems. The value function (3) satisfies the DPP

\[ H(t,x) = \sup_{\tau \in T(t,T)} \mathbb{E}_{t,x}[G(X_{\tau})1_{\tau<\theta} + H(\theta, X_{\theta})1_{\tau\geq\theta}] \]  

for all \((t,x) \in [0,T] \times \mathbb{R}^m\) and all stopping times \(\theta \leq T\).

The final version, the infinitesimal version is the Dynamic Programming Equation, also called by its inventors, the Hamilton-Jacobi-Bellman Equation.

THEOREM 2  Dynamic Programming Equation for Stopping Problems. Assume that the value function \(H(t,x)\) is once differentiable in \(t\) and all second order derivatives in \(x\) exist, i.e. \(H \in C^{1,2}([0,T],\mathbb{R}^m)\) and that \(G: \mathbb{R}^m \rightarrow \mathbb{R}\) is continuous. Then \(H\) solves the variation inequality, also known as an obstacle problem, or free-boundary, problem:

\[ \max\{\partial_t H + \mathcal{L}_t H, G - H\} = 0, \text{ on } \mathcal{D} \]  

where \(\mathcal{D} = [0,T] \times \mathbb{R}^m\).

Hence, we have two options:

(i) \(H < G\) and \(\partial_t H + \mathcal{L}_t H = 0\)

(ii) \(H = G\) and \(\partial_t H + \mathcal{L}_t H < 0\)

For the first option the value function \(H\) is lower than the reward \(G\). This implies a state in the continuation region and thus, not optimal to stop. The second option, the value function equal to the reward, is the optimal time to stop, as it implies a state in the stopping region: the ideal point of time for closing the position is found.

4 Algorithmic Trading

4.1 Fundamental knowledge

This section provides the basic background knowledge about algorithmic trading, including knowledge about all order types and their characteristics, of course especially the ones trading oneself. Secondly, about investors likely to meet and their trading objectives. Third, the electronic exchanges, to be distinguished: the lit markets and the dark pools.
4.1.1 Limit Order Book

Lit markets have an open limit order book (LOB), in most cases published online, while dark pools do not. The Limit order book regulates the get-together of the incoming orders. The most common case, on which the focus will be on, is price-time-priority. The alternate exchange structure is prorating. Sometimes the LOB is a mix of both. Figure 5 demonstrates the

![Figure 5: Limit Order Book](image)

standard procedure of a LOB. Each block represents one limit order (LO). The length of the block is the quantity of the order. The length of all orders in one row is the available depth at the specific price level. On the upper side is the ask side, the blue-colored buy orders, on the lower side is the bid side, the red-colored sell orders. The distance between the lowest buy order and the highest sell order is the so called **Bid-Ask-Spread**, to be precise, the quoted Bid-Ask-Spread. When a new order comes in, it is placed on the left, next to the ordinate axis. Each row of blocks is for one price, rising by

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21Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, pp. 9-11
ticks, the minimum difference available between two prices. The procedure is as follows:

1. Addition of a LO to the Limit Order Book.

2. A market order (MO) "walks the book" and matches with a LO at the best price/ is rerouted.

LO are posted in the book - metaphorically speaking, they are waiting for an aggressive MO to want them, fulfil them. MO are executed immediately at the best price available. Especially the US has order protection rules, the so-called trade-trough rules, which ensure the trader to get the best possible price by re-routing the order to another exchange if necessary, also known as smart-routing. MOs walk the book beginning at the best price, fulfilling the oldest first. Once one tick level is empty, the MO fulfils the orders with the second-best price, beginning with the oldest again, and so on.

4.1.2 Market participants\textsuperscript{22}

Knowing how the orders match, the electronic exchanges work, is only helpful, when knowing or rather estimating the incoming order flow. Therefore, it is relevant to know the different classes of traders, to evaluate their intension. Essentially there are three classes of traders.

1. Informed traders

2. Liquidity traders (noise/ fundamental traders)

3. Market makers

The informed traders, as the name already says, have information about the assets, not reflected in the market prices. They profit from trading in anticipation of the depreciation or appreciation of the mispriced assets. But making profits out of this information is limited: In this context, the theory of price efficiency should be mentioned. It says, that the markets are efficient because of the diffusion of information. Hence, it is nearly impossible for investors to constantly earn returns.\textsuperscript{23}

The liquidity/ fundamental traders are driven by economic fundamentals outside the exchange and take the liquidity. In various models, it is assumed that they are risk-neutral because they only want to reach their external goals.

\textsuperscript{22}Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, pp. 6-9
\textsuperscript{23}Kenton: Price Efficiency
Market makers, in most cases working for banks, pension fund assets or insurance companies, provide liquidity. Their profit is the bid-ask-spread, as they buy for the bid-price and sell for the ask-price. So to say, they are paid with the liquidity premium for taking the holding risk that the ask-price decreases and at worst falls under the bid-price, so the agent makes a loss. Fewer market makers generate a bigger spread, and thus bigger profit. When the number of market makers increases, the spread decreases and for a big number of market makers it is close to zero.\textsuperscript{24} All in all, every experienced market participant considers the intentions of the other market participants while optimising his decision.

4.2 Data reading\textsuperscript{25}

Important, especially for technical analysis, e.g. technical chart tools, is data reading and thereby computing key indicators and on top of them building an investment strategy. Beforehand should be mentioned that it is possible to reconstruct the complete order book, as all Limit Orders are recorded. The following list obtains relevant measures and aspects.

4.2.1 Prices and Returns\textsuperscript{26}

- Asset prices and returns
- Trading activity
- Price predictability: valuation by means of the ordinary least squares regression
- Volume: driven by peaks (morning, noon) generated by information, liquidation targets and lower trading costs
- Volatility
- Latency: Delay between sending a message to the market and it being received and processed by the exchange. In this context, colocation should be explicitly mentioned. Colocation means physical nearness of the agent’s trading system, the server, to the electronic exchange’s data centre.\textsuperscript{27}

\textsuperscript{24}Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, p. 20
\textsuperscript{25}Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, pp. 39-41
\textsuperscript{26}Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, pp. 41-57
\textsuperscript{27}Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, pp. 11-12
- Minimum tick size

- Price chances: Naturally there is no relation between a current price change and a future one (Non-Markovian). But patterns do exist.

- Market fragmentation: Extent to which the market for one asset is distributed across different venues.

4.2.2 Market quality

- Depth: Visible liquidity (cf. quantity LOB)

- Probability of informed trading (PIN): Degree of information asymmetry

- Spreads

- Price impact: Impact of larger orders on the prices (seen as costs of execution)

- Resilience: The market’s ability to return to equilibrium after a trade.

Volume and volatility are highly correlated. Volume and market quality have a positive relation. High volume leads to high liquidity, high liquidity leads to high market quality, and of course, the same relation is valid for the opposite direction with small volume. Market quality also has an impact on volume, as market quality facilitates/complicates trading.

5 Trading Strategies

5.1 Ad-Hoc Bands

A band represents a range of prices, like the Bollinger Bands in section 3.1. Figure 6 shows a trading strategy with two ad-hoc bands: an inner band and an outer band. Both bands are around a mean-reverting level, e.g. the co-integration factor. The bands can be chosen randomly, standard case is once the standard deviation for the outer band, 0.1 times the standard deviation for the inner band. A possible scenario are wider bands, which will be discussed later. Assumed the agent trades a portfolio of two assets, a co-integrating pair. He goes long the portfolio underneath the lower outer band

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\(^{28}\text{Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, pp. 61-96}\)

\(^{29}\text{Cartea: ALGORITHMIC AND HIGH FREQUENCY TRADING, pp. 274-277}\)
and closes, liquidates, the position when reaching the inner band. Alternative
the agent goes short the portfolio above the upper outer band and as well
closes the position when reaching the inner band. Hence, the minimum profit
is the outer-inner-band spread. The strategy bears the risk of never reverting
to the inner band, thus never closing the position, once the agent either is long
or short, in other words outside the outer bands. This risk is even bigger
for wider bands. Wider bands imply larger profits because of the bigger
outer-inner-band-spread, but only when closing the position. However, for
the case-scenario of wider bands the strategy provides fewer transactions.

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{bands.png}
\caption{Ad-Hoc Bands}
\end{figure}

5.2 Example: Pairs Trading combined with Bands

Finally, a personal trading strategy will be constructed. It is a combination of
pairs trading and a mix of the technical chart analysis tools Bollinger Bands
and Ad-Hoc Bands. The pair we choose is corn - soybean, which we already
tested for co-integration in section 1. Our portfolio consists of two positions,
a long position in the under-priced commodity, and a short position in the
overpriced commodity. Now we have to compute the co-integration factor,
which we do by using MATLAB and its predefined Engle-Granger tools.
Figure 7 demonstrates the co-integration between corn and soybeans for the
last 5 years, 2013 to 2018. As the co-integration factor represents a mean-
reverting component we compute the mean of the co-integration, as it is a
strong trading signal compared to one asset. The trading strategy is shown in
Figure 8. Two bands are placed around the mean, the co-integration factor, an
outer and an inner band, like the ad-hoc bands in the previous chapter. The outer bands are chosen as the Bollinger Bands, twice the standard deviation. The inner band is 0.2 times the standard deviation. The agent goes short the portfolio above the upper outer band, long the portfolio underneath the lower outer band. Once the price hits an inner band, the agent liquidates, closes his position. The profit is the outer-inner-band spread, cf. figure 6. The only existing risk, which we already mentioned in section 5.1, is not closing the position, because the price does not revert to the inner band. Quite the contrary, the price removes from the outer band up/ down. This means our strategy does not give a closing signal and the agent has to decide according to instinct. To protect the agent from the risk of losing a huge amount of money, it is useful, to set stop-loss orders. A stop-loss-order in general is placed to sell/ buy an asset, when it reaches a limit, a certain price. Obviously, the stop-loss orders are placed above and underneath the upper and lower outer band, four times the standard deviation away from the mean. When the price hits one of these bands, the position gets liquidised.

Figure 7: Co-integration Corn-Soybeans
6 Conclusion

After creating an algorithm, it is very important to backtest it, that means testing the effectiveness of the algorithm for historical data. Of course, it is not a clear signal of success, but for sure an indication worth a try. Algorithmic trading is a very complex thematic but does exist in simple forms as our strategy constructed in chapter 5.2 shows. There is a plethora of opportunities, as multiple, even countless exchange traded products and predefined analyzing tools exist and the human creativity is endless. But first and foremost, what drives the rapid growth of Algorithmic trading at the moment is artificial intelligence, especially machine learning. But one should critically scrutinize this topic, as a primary machine leaded market, existing of many similar “participants”, entails major consequences.
References

1 Algo Trading Dominates 80% Of Stock Market, Seeking Alpha, 01.01.2019, URL: https://seekingalpha.com/article/4230982-algo-trading-dominates-80-percent-stock-market

2 Amaro S.: Sell-offs could be down to machines that control 80% of the US stock market, fund manager says, CNBC MARKETS, 05.12.18, URL: https://www.cnbc.com/2018/12/05/sell-offs-could-be-down-to-machines-that-control-80percent-of-us-stocks-fund-manager-says.html


4 Brooks C.: Introductory Econometrics for Finance, 2002


10 Commodities, Investopedia, URL: https://www.investing.com/commodities/


18 Sharma B.: *Algorithmic trading share in total turnover grows to 50% in 8 years*, Financial Express, 08.05.2018, URL: https://www.financialexpress.com/market/algorithmic-trading-share-in-total-turnover-grows-to-50-in-8-years/1159020/


21 Ungever C.: *PAIRS TRADING TO THE COMMODITIES FUTURES MARKET USING COINTEGRATION METHOD*, Istanbul Commerce University, Turkey, 2015

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