002 Pairs Trading

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Introduction

A pairs trade is a trading strategy that involves matching a long position with a short position in two stocks with a high correlation. It was first introduced and popularized in the mid 1980´s by a group of technical analysts of Morgan Stanley. This kind of strategy is famous for using statistical and technical analysis. A long these years, this technique has been sophisticated and taught in different kind of careers and degrees. But like everything, this strategy has its advantages and disadvantages:

Advantages:

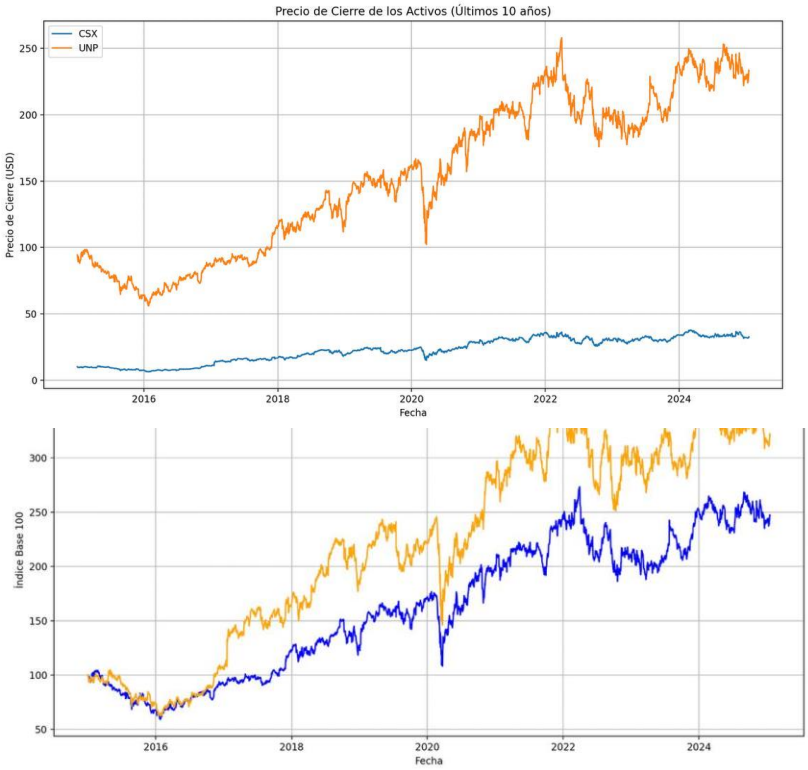
- Market neutrality: the investor can mitigate potential losses that have occurred in the process.
- Diversification: Minimizes risk while having a diversified portfolio.
- Profit potential: Profits are generated when the underperforming security regains value, and the outperforming security's price deflates. The net profit is the total gained from the two positions.

Disadvantages:

- Model Risk: It is sensitive to market disruptions.
- Execution Risk: It is exposed to several factors, such as: market frictions, erode profitability, transaction costs and slippage.
- Liquidity risk: Could be unsuccessful if the stocks selected have low liquidity.

Stocks we choose

In this project we decided to make a pair trading strategy with two stocks that will fit in with the criteria needed, “UNP” (UNION PACIFIC CORPORATION) and “CSX” (CSX CORPORATION). In our pair trading strategy project, we selected Union Pacific Corporation (UNP) and CSX Corporation (CSX), two leading freight rail companies in North America. The stocks were chosen because they were in the same industries and had all the criteria requested.



Both companies are major players in the rail industry, so they are exposed to similar economic factors. However, their differences, such as regional focus and market strategies, offer an opportunity for pair trading. By analyzing the price movements of these stocks, we can exploit any divergence in their performance, betting that the prices will eventually converge.

Time series non-stationary

First, we must know if both of our series are non-stationary. This means that their statistical properties, such as mean and variance change over time, exhibiting trends, seasonality and unpredictable fluctuations. This data, as a rule, cannot be modeled or forecasted. For proving this with our chosen stocks, we used the formula below.

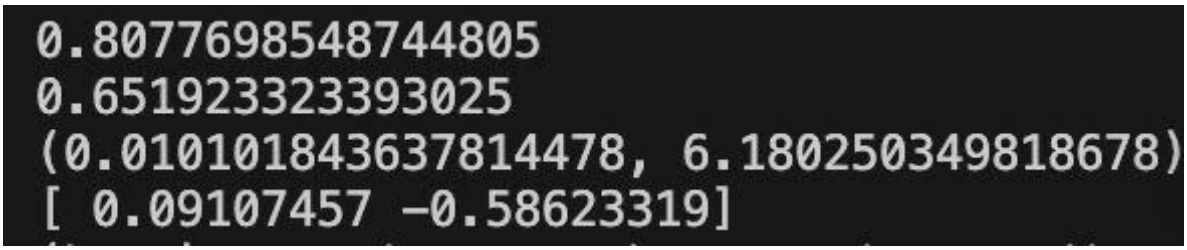
$$H_0 : \text{has unit root (non-stationarity)}$$

$$H_a : \text{stationary}$$

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \delta_1 \Delta y_{t-1} + \ldots + \delta_{p-1} \Delta y_{t-p+1} + \epsilon_t$$

The formula above is the ADF unit root test (ADF- Augmented Dickey-Fuller). The hypothesis here is that if it is H_0= means that the series has a unit root (it is non-stationary), on the other hand if it is H_a= meaning that the serie is stationary. By coding this equation, we will have as a result the ADF-statistics, P-value and critical values (1%, 5%, 10%).

After applying these equations to our series, we got the results below:



As we can see, UNP had an ADF of .8077 which show us that this stock is nonstationary, and CSX had an ADF of 0.6519 which means that is also nonstationary, up next we create the OLS test on which we are going to evaluate the p-value of both the stocks after going thru the process of normalizing, this value is presented as 0.0101 which mean that together this two stocks have an stationary behavior.

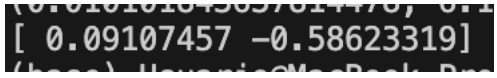
Engle-Grangers

Once we found out that our two series are non-stationary, we must continue with Engle-Grangers: P1 linear relation. This will help us to test and check if the linear combination (spread) is stationary. If both of our series have an order integration of d=1, we can define de linear combination as:

$$y_t - \beta x_t = u_t$$

In this case Beta will be known as our hedge ratio, and U_t should be stationary, so we can apply for an ADF test on the residuals of our series. After applying for this test, we should now have different metrics that will help us determine different aspects and data about our strategy:

- R-squared: Indicates what percent of the variability in dependent variable is explained by the independent variable.
- Adjusted R-squared: Since there is only one independent variable, this is the same as the normal R-squared.
- AMD: Indicates that for each unit an increase in the independent variable, the dependent variable increases by this number.
- Omnibus: A statistical test that evaluates whether the residuals of the model follow a normal distribution (Value close to 0 means it follows a normal distribution)
- Jarque-Bera: Test for normality based on the skewness and kurtosis of the residuals.
- Z: A statistic that measures how many standard deviations a coefficient is from 0 in a standard normal distribution.



This is the value of our Eigenvectors which means that this would be our spread model

Johansen Cointegration Test (VECM)

The Johansen test is an approach to cointegration which allows us to test more than two series at the same time. This test will help us prove whether multiple time series are cointegrated, meaning they share a long-term relationship despite being individually non-stationary.

➔ Where, we have a long run VECM:

$$\Delta X_t = \mu + \Phi D_t + \Pi X_{t-p} + \Gamma_{p-1}\Delta X_{t-p+1} + \ldots + \Gamma_1 \Delta X_{t-1} + \epsilon_t$$

➔ And a transitory VECM:

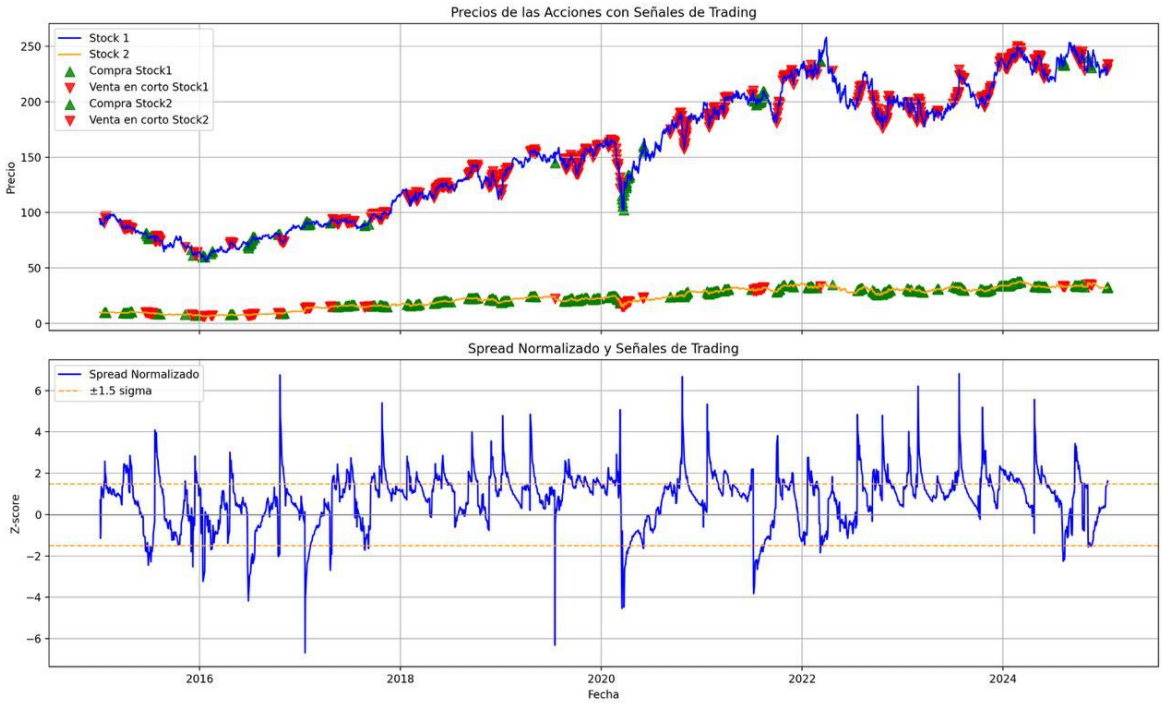
$$\Delta X_t = \mu + \Phi D_t + \Pi X_{t-1} - \sum_{j-1}^{p-1} \Gamma_j \Delta X_{t-j} + \epsilon_t$$

After doing this test, we should know have two principal statistics, were H_0: No cointegration, while H_a: Cointegration. These two principles are:

- **Trace Statistics:** Tests on whether the number of cointegrating relationships is at most the number of possible cointegration relationships
- **Eigenvalue Statistics:** checks for exactly the number of cointegration relationships and determines whether adding one more relationship significantly improves the model.

Spread signal

After doing the Johansen Cointegration test, we will have the values that help us to build our spread signal. In the first graph we can see all the buy and sell signals we would have to make throughout all the years. The stock in blue is the UNP stock, while the one in orange is CSX stock. These signals are made by the second graph, that when normalized spread touches de 1.5 sigma limit give us the alert to make the movements. As we can see, we have several movements along the 10 years, making us open and close several positions, but I the end, these positions will make us a profit.



Backtesting Process Summary

The backtesting process is designed to systematically evaluate the performance and robustness of the pairs trading strategy. It begins with data preparation, where we collect 10 years of historical price data from Yahoo Finance. The data is cleaned to remove missing values and ensure consistency before proceeding to the next stage.

To confirm the viability of the trading pair, we conduct cointegration testing and hedge ratio estimation. The Johansen Cointegration Test is applied to determine if the two stocks share a stable long-term relationship. The eigenvectors from the Johansen test

are used to compute an initial hedge ratio, which is further refined using an OLS regression to improve accuracy.

A key feature of the strategy is the dynamic hedge ratio calculation using a Kalman Filter. Unlike a fixed hedge ratio, the Kalman Filter allows for real-time adjustments, improving the adaptability of the model to changing market conditions while reducing estimation risk. This dynamic approach ensures that the hedge ratio remains robust over time.

With the hedge ratio in place, we calculate the spread between the two stocks and normalize it using a Z-score transformation. Trading signals are then generated based on statistical thresholds. A long position in Stock1 and a short position in Stock2 is initiated when the Z-score drops below -1.5, while a short position in Stock1 and a long position in Stock2 is triggered when the Z-score exceeds 1.5. Positions are closed when the spread reverts to the mean, indicated by a Z-score within ±0.5.

The strategy operates with an initial capital of $1,000,000 USD, executing trades in a market-neutral manner. Each transaction considers commissions of 0.125% and margin requirements for short-selling, ensuring a realistic simulation of market conditions.

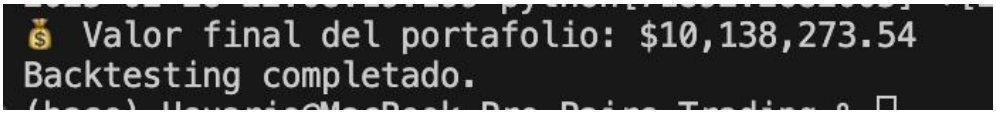
To assess the performance and risk of the strategy, we implement key financial metrics such as the Sharpe Ratio, which measures risk-adjusted returns, and Maximum Drawdown, which evaluates potential capital losses. Additionally, we analyze the Win/Loss Ratio to determine trade success rates, as well as annualized return and volatility to benchmark performance against the broader market.

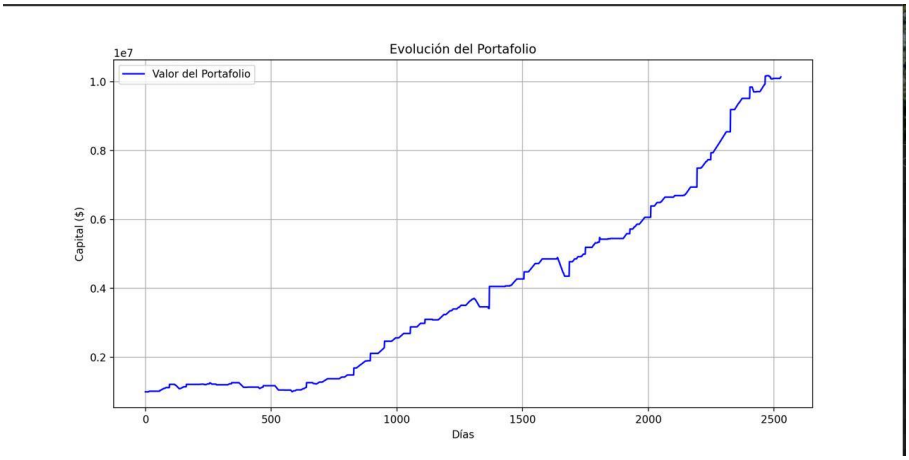
This structured backtesting approach ensures a rigorous evaluation of the pairs trading strategy, validating its profitability and risk profile under realistic market conditions. The integration of cointegration testing, Kalman Filtering, and statistical arbitrage techniques enhances the strategy's adaptability and robustness, making it a valuable tool for market-neutral trading.

Trading strategy

The result below represents the total value of our final portfolio. As shown in the first image, with an investment of millions of US dollars, our portfolio would have grown to $10,138,273.54 over the span of 10 years. The second graph illustrates the performance of our portfolio throughout this period. It is particularly interesting to

observe how, even with lesser-known stocks, we can capitalize on them using this effective trading strategy.





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