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# Stock Chart Pattern Recognition

Can future stock movements be predicted by locating patterns in historical data?


**Barnabás Paksi** and **Karina Pekarek-Kostka**

# ° Project Introduction

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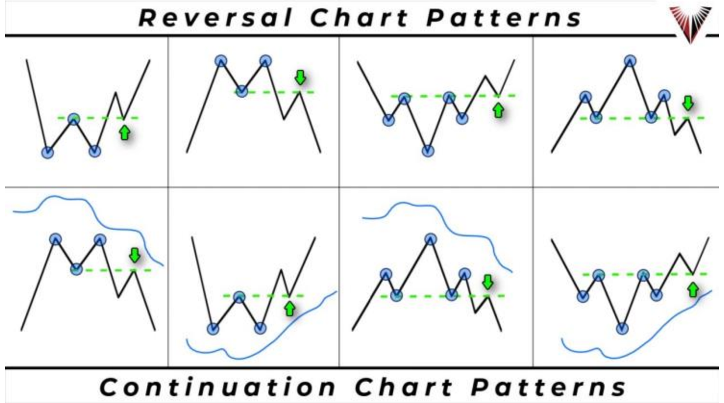


FOUNDATIONS OF TECHNICAL ANALYSIS: COMPUTATIONAL ALGORITHMS, STATISTICAL INFERENCE, AND EMPIRICAL IMPLEMENTATION

Andrew W. Lo
Harry Mamaysky
Jiang Wang

# ° Introduction: Pattern Types

[Head and Shoulders]

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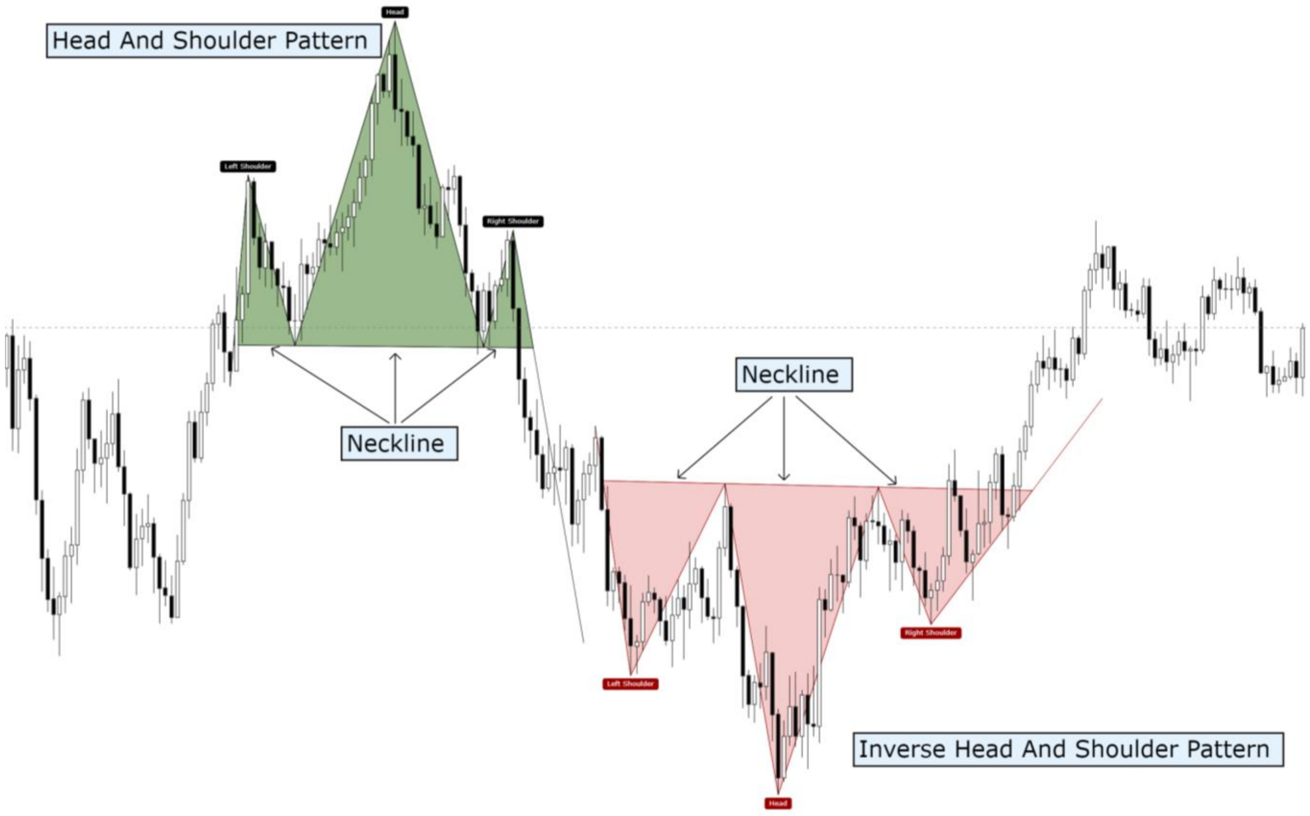
**H**ead and **S**houlders (**HS**) and **I**nverse **H**ead and **S**houlders (**IHS**)



# ° Introduction: Pattern Types

[Broadening]

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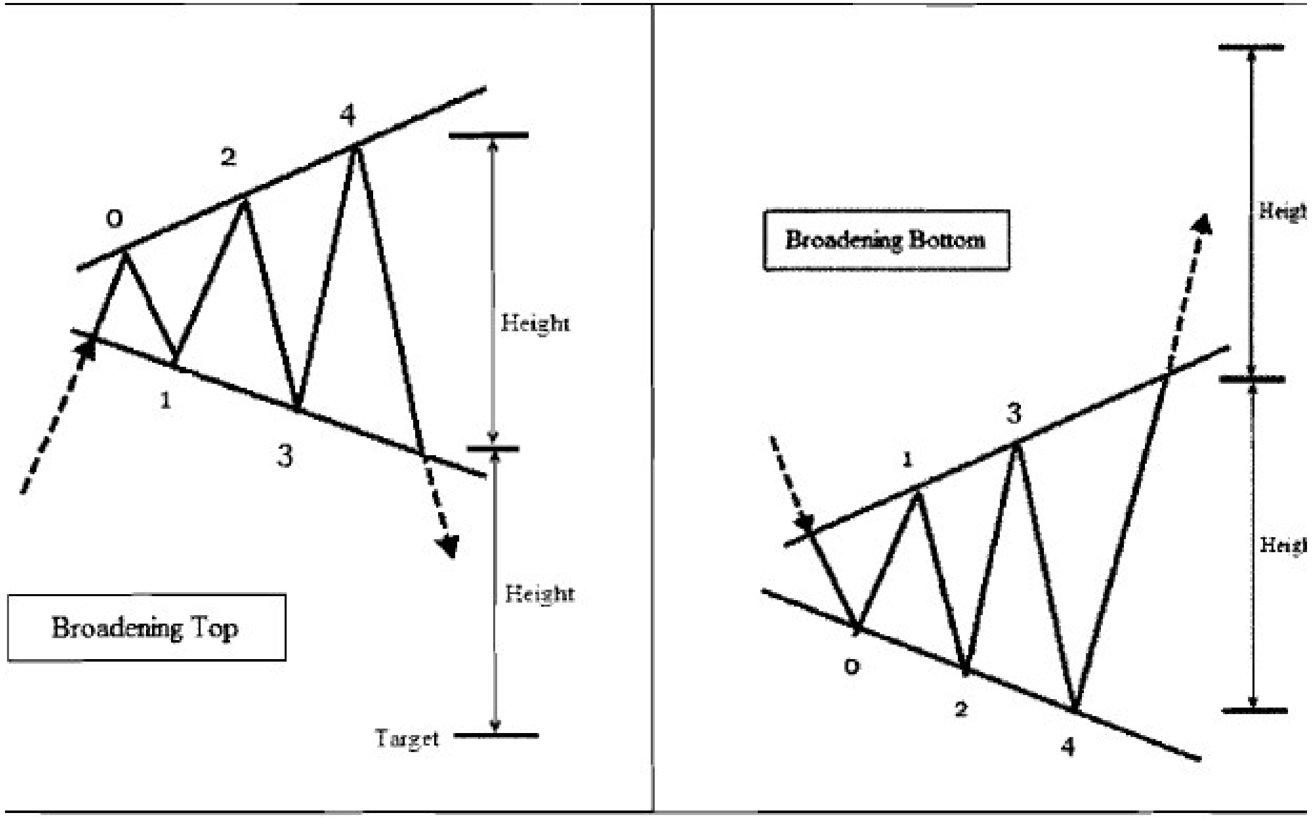
**B**roadening **T**ops (**BTOP**) and **B**roadening **B**ottoms (**BBOT**)



# ° Introduction: Pattern Types

[Other Patterns]

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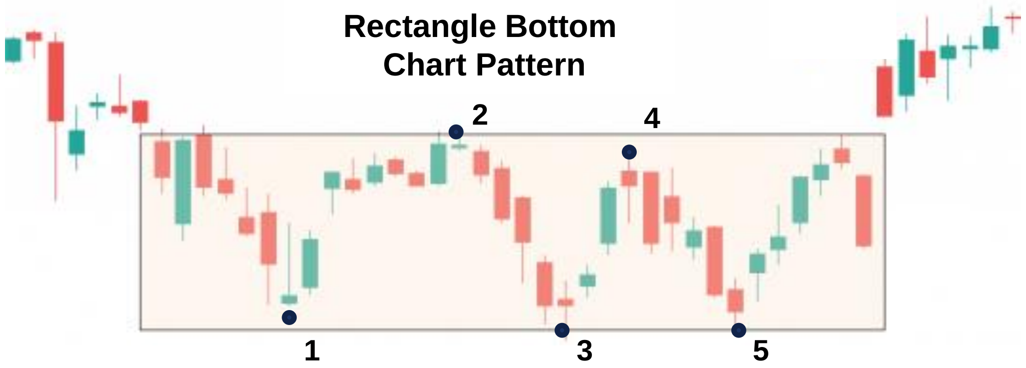
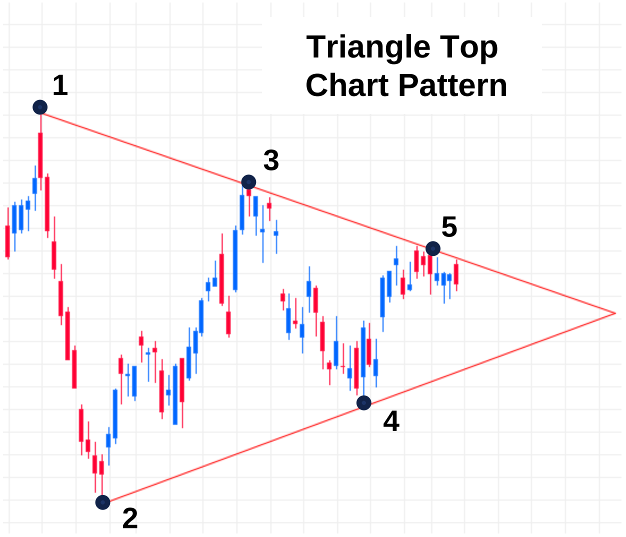
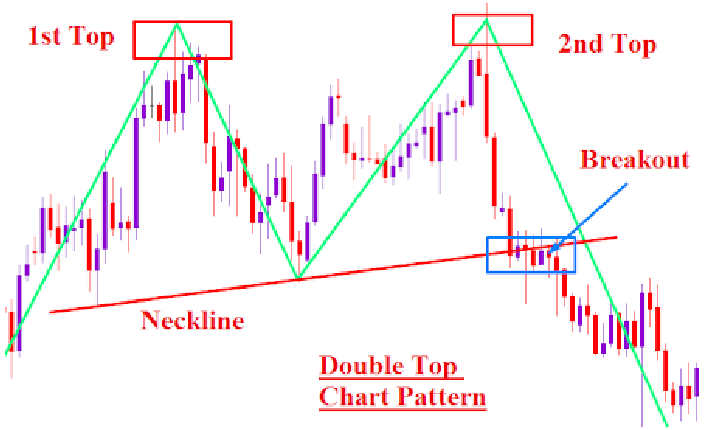



- **R**ectangle **T**ops (**RTOP**) and **Bot**toms (**RBOT**)
- **T**riangle **T**ops (**TTOP**) and **B**ottoms (**TBOT**)
- **D**ouble **T**ops (**DTOP**) and **B**ottoms (**DBOT**)



# ° Algorithm and Implementation

[Structure]

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## Algorithm Structure

**Step 1.** Use smoothing estimators to draw non-linear relationship in the data: Kernel Regression (incl. bandwidth gamma)

**Step 2.** Locate local optima based on kernel regression estimates and categorize them (maxima or minima)

**Step 3.** Define technical pattern-types and indicate matches of consecutive optima in the data

**Step 4.** Calculate post-pattern returns (3-day, 5-day, and 15-day) for each located pattern-type

**Step 5.** Check if any pattern-type has a significant effect on the returns of the stock or index

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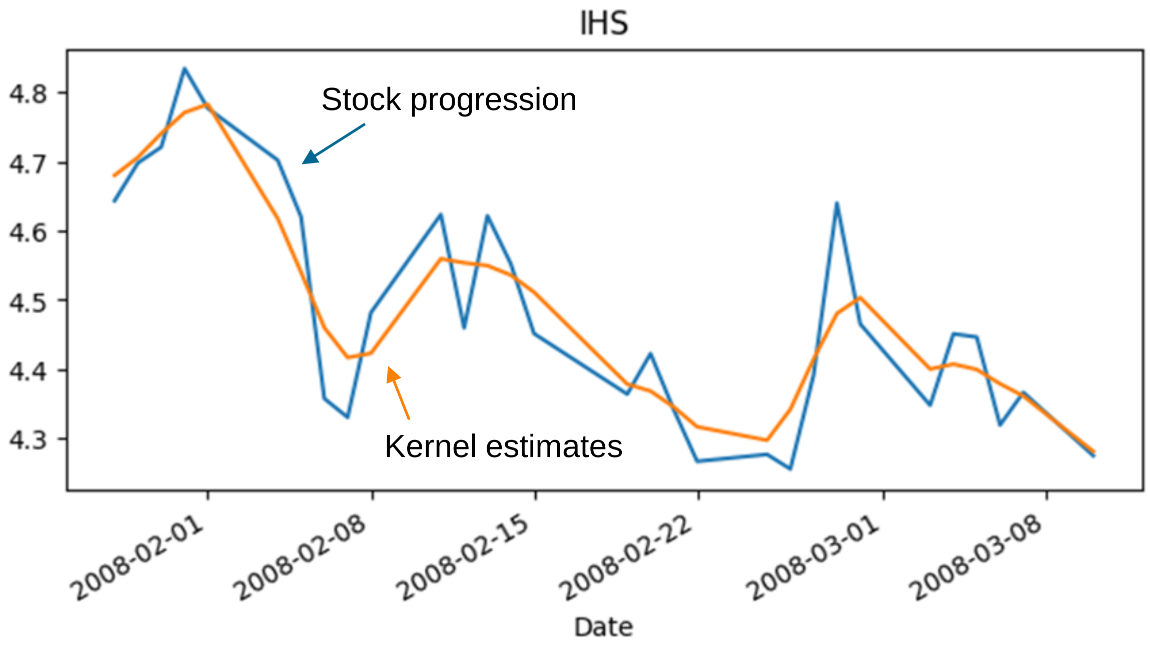
**Step 1.** Use smoothing estimators to draw non-linear relationship in the data: Kernel Regression (incl. bandwidth gamma)



# Algorithm and Implementation

[Execution]

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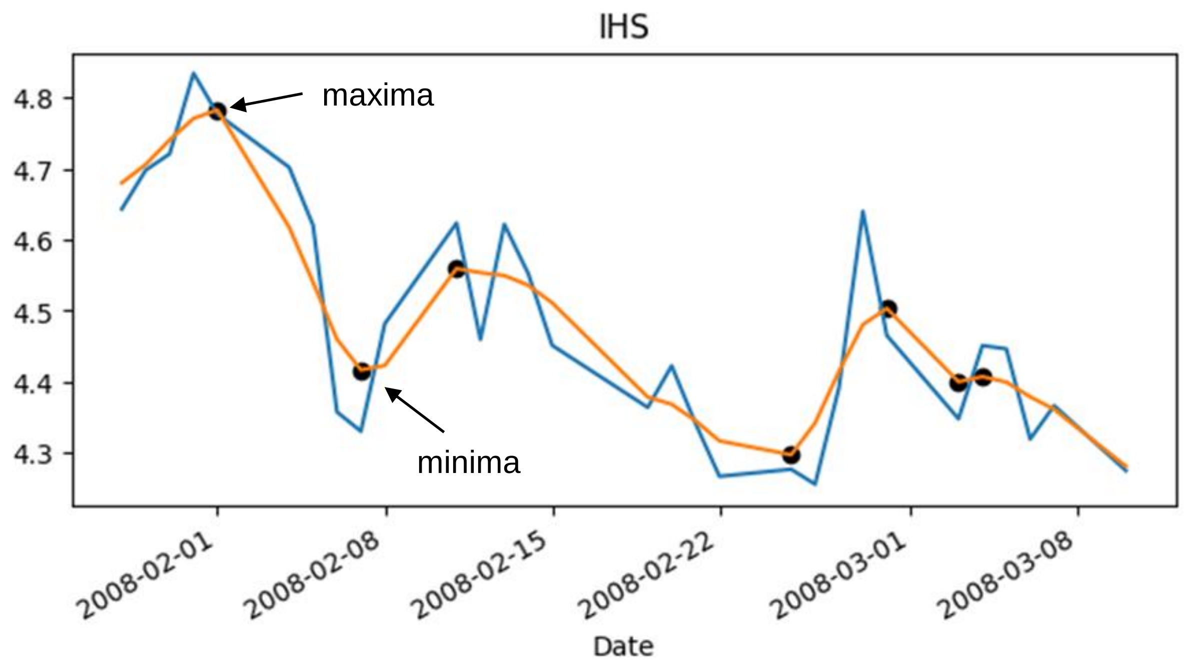
**Step 2.** Locate local optima based on kernel regression estimates and categorize them (maxima or minima)



# ° Algorithm and Implementation

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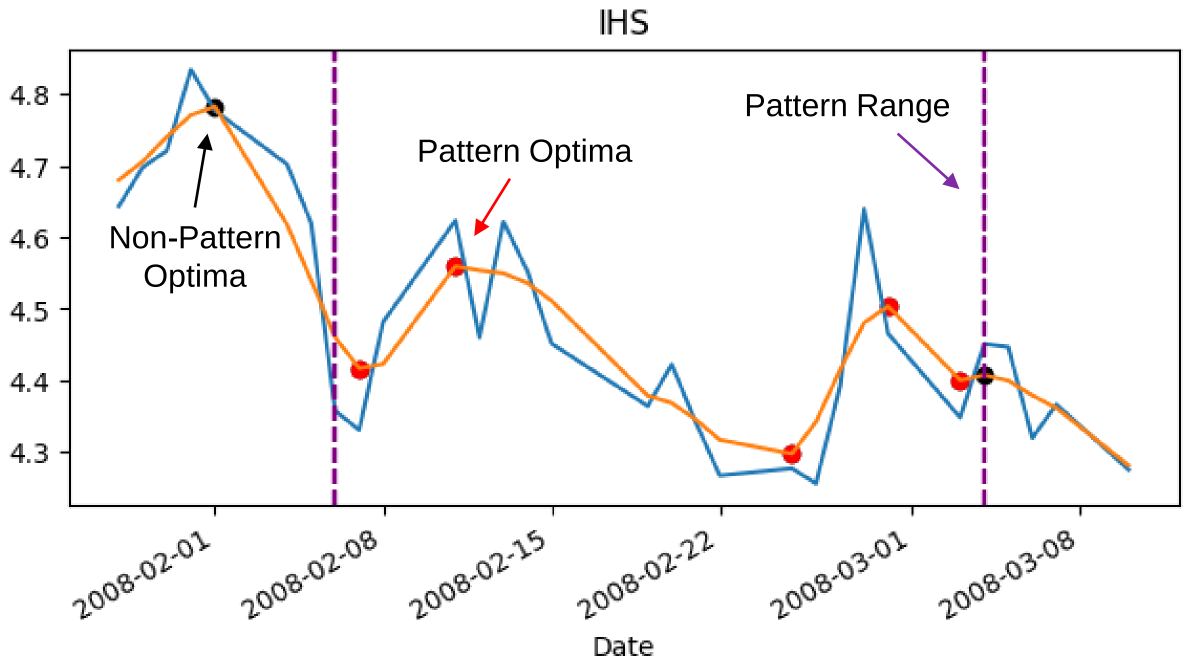
**Step 3.** Define technical pattern-types and indicate matches of consecutive optima in the data



# ° Dataset

[Variable Introduction]

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**Stocks/Indices:**

- **Apple** (AAPL): 15 years (2008-2023)
- **Bitcoin USD** (BTC-USD): 6 years (2017-2023)
- **Nasdaq** (^IXIC): 40 years (1983-2023)
- **Gold** (GC=F): 22 years (2001-2023)
- **Walmart** (WMT): 35 years (1988-2023)
- **Crude Oil** (CL=F): 22 years (2001-2023)
- **Exxon Mobil** (XOM): 50 years (1973-2023)
- **Solar Edge** (SEDG): 8 years (2015-2023)

# ° Parameters

[Tuning the Algorithm: Data Frequency I]

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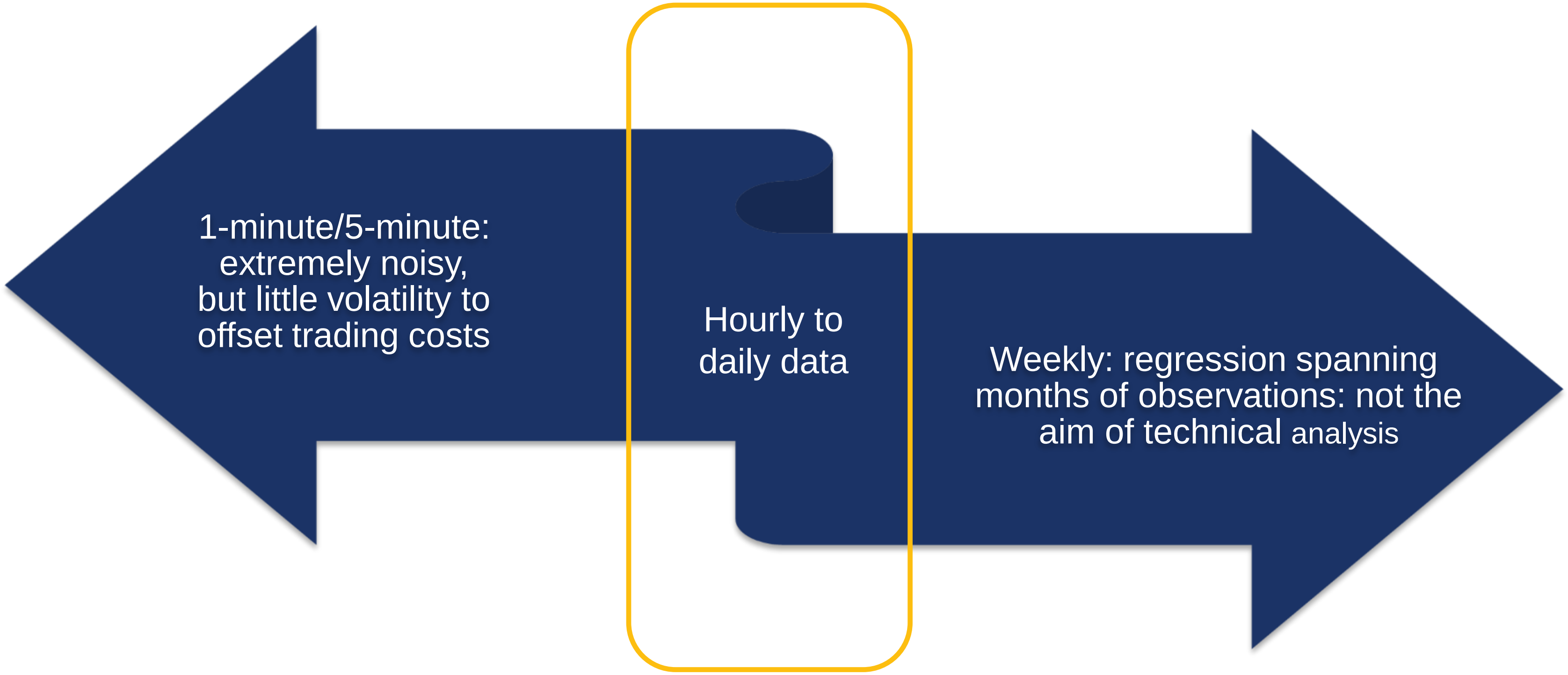

# ° Parameters

[Tuning the Algorithm: Data Frequency II]

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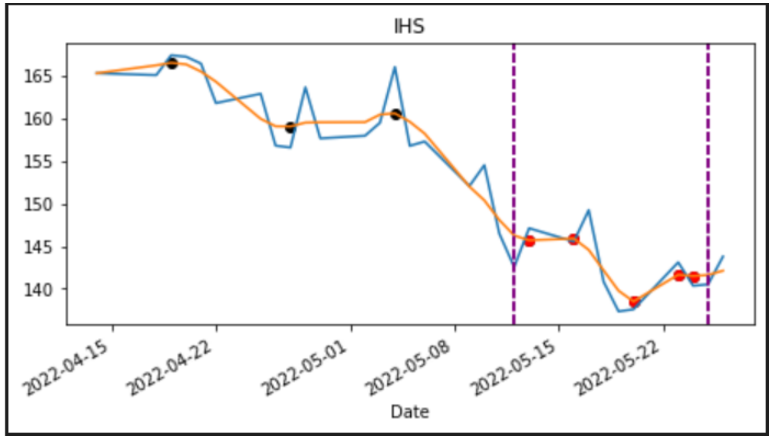
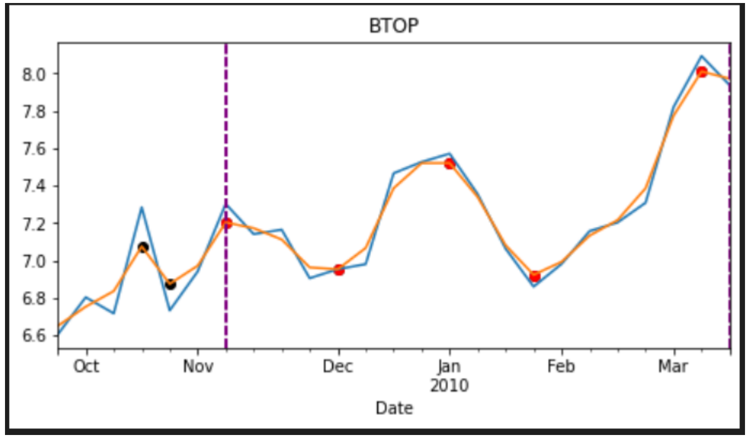



Hourly/daily: reasonable fit with appropriate gamma value and window size

Frequency = daily
Gamma = 0.3
Window size = 30 days




5min/weekly: too noisy/too general, not in the focus of technical analysis

Frequency = weekly
Gamma = 0.025
Window size = 25

**Frequency used: daily**

# ° Parameters

[Tuning the Algorithm: Gamma]

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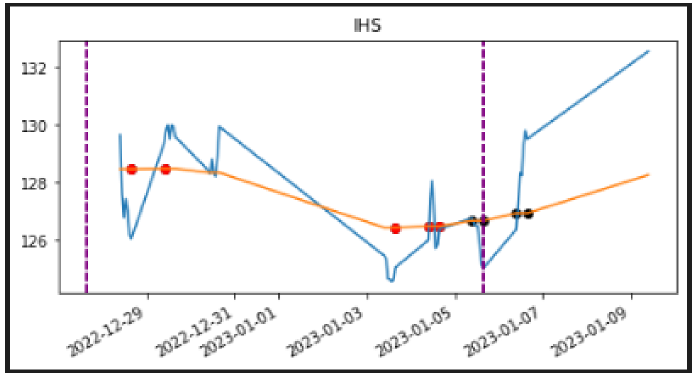
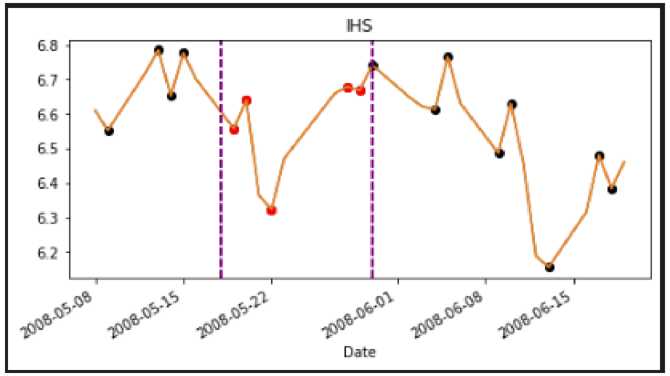
Changing the hyperparameter regulating the flexibility of the kernel regression, we can decide on the right fit for our purposes: trying to capture more than the long-term trend while finding a point where noise is not too much either.




Underfitting: lack of local information




Overfitting: capturing the noise, resulting in too many extrema

Frequency = hourly
Gamma = 0.1
Window size = 50 days

**Gammas used: 0.1, 0.3, 1.0**

Frequency = daily
Gamma = 15
Window size = 30 days

# ° Parameters

[Tuning the algorithm: window size]

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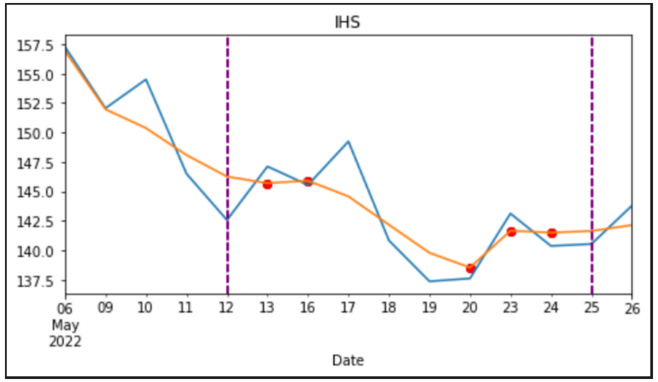
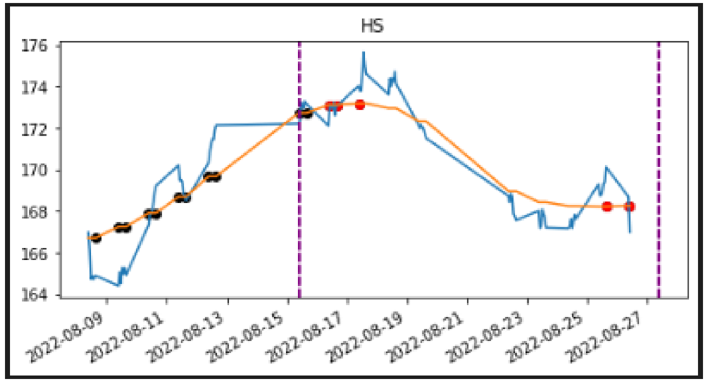
Window size controls the number of optima included and the sample on which we estimate the kernel regression. Since 5 extrema are required for patterns, we should choose windows which contain at least 5 but not many more (effect of older movements is less and less defined, only 5 points are used in these patterns, skipping intermediates is not implemented)




Small windows yield fewer patterns as each set of 5 points is assessed only once

Frequency = daily
Gamma = 0.3
Window size = 15d




Large windows allow for many optima even if the curve is underfitted

Frequency = hourly
Gamma = 0.1
Window size = 100h

**Windows used: 20d, 30d, 45d**

# Interpreting Results

[Results I – Tally of significant patterns by type]

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**# of significant post-pattern avg. returns by stock and pattern**

| Pattern | Apple | Bitcoin | Nasdaq | Gold | Walmart | Crude Oil | Exxon | Solar Edge |
|---|---|---|---|---|---|---|---|---|
| **IHS** | **24** | **9** | **26** | **27** | **27** | **22** | **27** | **0** |
| HS | 9 | 5 | 20 | 20 | 21 | 16 | 27 | 5 |
| BTOP | 2 | 3 | 11 | 12 | 18 | 13 | 23 | 1 |
| BBOT | 4 | 0 | 12 | 17 | 21 | 4 | 25 | 3 |

**# of significant post-pattern avg. returns by stock and return-type**

| Return-Type | Apple | Bitcoin | Nasdaq | Gold | Walmart | Crude Oil | Exxon | Solar Edge |
|---|---|---|---|---|---|---|---|---|
| 3day | 17 | 12 | 29 | 32 | 33 | 26 | 35 | 6 |
| 5day | 11 | 3 | 23 | 29 | 31 | 23 | 34 | 1 |
| 15day | 11 | 2 | 17 | 15 | 23 | 6 | 33 | 2 |

# ° Interpreting Results

[Results III]

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**Avg. returns of patterns across all tickers**

| Pattern | 3day | 5day | 15day |
|---|---|---|---|
| IHS | 0.0148 | 0.0162 | 0.0227 |
| HS | -0.0121 | -0.0109 | -0.0054 |
| BTOP | -0.0128 | -0.0105 | -0.0064 |
| BBOT | 0.0116 | 0.0116 | 0.0179 |

**Avg. positive post-pattern return**

**Avg. negative post-pattern return**

# °Further Points

[Outlook]

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As a continuation of this project, further analysis could focus on:

- Comparing the outlined method with alternatives built upon mean-reversion
- Building signals generated by the framework into a larger ML model
- Backtesting long-term performance accounting for trading costs
- Optimizing parameters based on returns and the underlying asset
- Assessing the performance of other alternatives for smoothing

# Appendix

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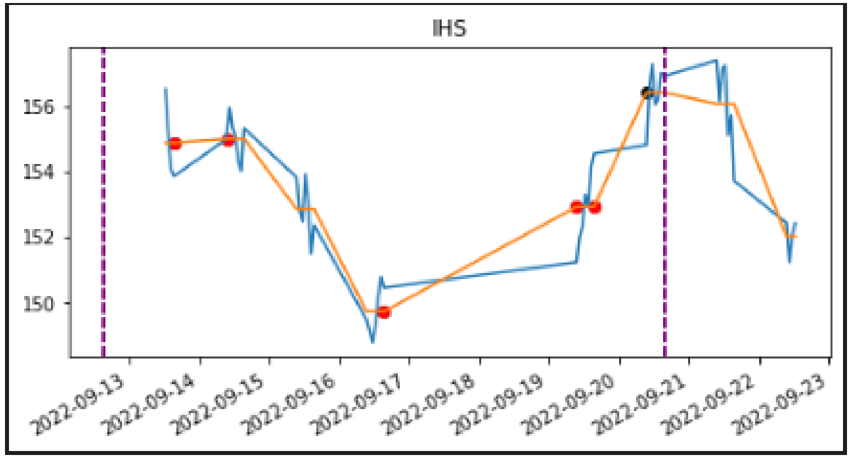
**Avg. returns of significant patterns across all tickers**

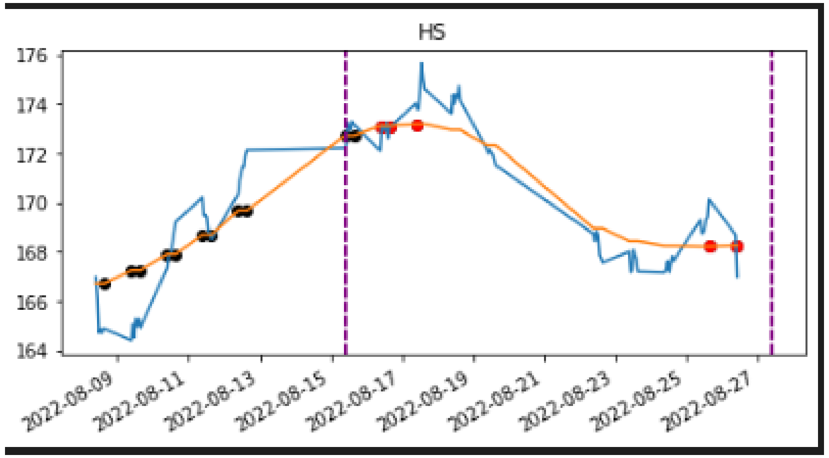
| Pattern | 3day | 5day | 15day |
| --- | --- | --- | --- |
| IHS | 0.0148 | 0.0162 | 0.0225 |
| HS | -0.0121 | -0.0109 | -0.0085 |
| BTOP | -0.0128 | -0.0135 | -0.0148 |
| BBOT | 0.0158 | 0.0164 | 0.0238 |

**Avg. positive post-pattern return**

**Avg. negative post-pattern return**

# Example: hourly data fit




Low gamma = 0.1 to avoid overfitting
May not be enough as the curve will have a lot of optima for large windows.
Window = 100
Frequency = 1h

# Appendix: AAPL

## [Significance of post-pattern returns] Code Output [Frequency: Daily]

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Gamma Input: ↑

| Gamma: 0.1; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 4 | 0.2767797 | 0.5055845 | 0.09168277 |
| 1 | HS | 3 | 0.1688136 | 0.9593731 | 0.42807581 |
| 2 | BTOP | 3 | 0.7129389 | 0.4607928 | 0.93562472 |
| 3 | BBOT | 2 | 0.3048544 | 0.1134831 | 0.91129793 |

| Gamma: 0.3; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 44 | 8.533E-05 | 0.048529 | 0.00067909 |
| 1 | HS | 27 | 0.101048 | 0.8390097 | 0.90748642 |
| 2 | BTOP | 16 | 0.2994309 | 0.619576 | 0.73858882 |
| 3 | BBOT | 14 | 0.1807897 | 0.356069 | 0.15024456 |

Gamma Input: ↑

| Gamma: 1.0; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 83 | 9.825E-07 | 1.623E-06 | 2.8632E-05 |
| 1 | HS | 88 | 2.52E-05 | 0.021807 | 0.71537913 |
| 2 | BTOP | 24 | 0.4153405 | 0.7100944 | 0.81498338 |
| 3 | BBOT | 15 | 0.1742634 | 0.4529007 | 0.33407722 |

Window Size: ↑

| Gamma: 0.1; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 27 | 1.336E-06 | 0.0001145 | 0.00022161 |
| 1 | HS | 16 | 0.0302318 | 0.120009 | 0.152203 |
| 2 | BTOP | 9 | 0.8803331 | 0.8443969 | 0.44071266 |
| 3 | BBOT | 8 | 0.0570611 | 0.8778699 | 0.90060688 |

| Gamma: 0.3; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 55 | 1.586E-08 | 0.0001874 | 6.8433E-06 |
| 1 | HS | 39 | 0.0031571 | 0.233051 | 0.29391596 |
| 2 | BTOP | 29 | 0.1868557 | 0.8275097 | 0.05946954 |
| 3 | BBOT | 24 | 0.0522505 | 0.3113712 | 0.03915444 |

| Gamma: 1.0; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 87 | 9.847E-08 | 4.677E-07 | 1.4183E-05 |
| 1 | HS | 97 | 3.244E-05 | 0.0445852 | 0.54169892 |
| 2 | BTOP | 30 | 0.3371644 | 0.5270511 | 0.35804742 |
| 3 | BBOT | 18 | 0.1114314 | 0.3275282 | 0.16739379 |

Window Size: ↑

| Gamma: 0.1; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 36 | 1.052E-08 | 2.277E-06 | 4.6562E-06 |
| 1 | HS | 23 | 0.0854756 | 0.0923114 | 0.25611653 |
| 2 | BTOP | 13 | 0.338364 | 0.4610382 | 0.32878613 |
| 3 | BBOT | 14 | 0.0376705 | 0.4914992 | 0.79277367 |

| Gamma: 0.3; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 57 | 1.799E-09 | 8.388E-06 | 2.9078E-06 |
| 1 | HS | 38 | 0.000768 | 0.0856474 | 0.41497754 |
| 2 | BTOP | 36 | 0.04054 | 0.6511486 | 0.03448059 |
| 3 | BBOT | 27 | 0.0609054 | 0.1312845 | 0.00504009 |

| Gamma: 1.0; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 87 | 9.709E-09 | 1.944E-07 | 5.8033E-06 |
| 1 | HS | 99 | 3.552E-06 | 0.0376284 | 0.7747698 |
| 2 | BTOP | 33 | 0.1559079 | 0.2234287 | 0.43532693 |
| 3 | BBOT | 21 | 0.0315337 | 0.2393283 | 0.39792602 |

Total sign. post-pattern return averages (by pattern)

| Total | 17 | 11 | 11 |
|---|---|---|---|
| IHS | 8 | 8 | 8 |
| HS | 6 | 3 | 0 |
| BTOP | 1 | 0 | 1 |
| BBOT | 2 | 0 | 2 |

*Freq.*: number of times that pattern was detected by the algorithm

*Note:* p-values were calculated under the assumption that expected returns are equal to zero (for the 3days to 15days calculated)

# Appendix: AAPL

**[Average post-pattern returns]** Code Output [Frequency: Daily]

W U T I S

| Gamma: 0.1; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 4 | 0.007255 | 0.011711 | 0.0595657 |
| 1 | HS | 3 | -0.015784 | 0.000741 | -0.0053409 |
| 2 | BTOP | 3 | -0.0101 | -0.012869 | -0.0037462 |
| 3 | BBOT | 2 | 0.035295 | 0.050939 | 0.0108759 |

| Gamma: 0.3; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 44 | 0.012961 | 0.010098 | 0.0394542 |
| 1 | HS | 27 | -0.010612 | -0.001239 | 0.0016456 |
| 2 | BTOP | 16 | -0.007638 | -0.002894 | 0.0052237 |
| 3 | BBOT | 14 | 0.012321 | 0.010783 | 0.0286569 |

| Gamma: 1.0; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 83 | 0.015577 | 0.02045 | 0.0306639 |
| 1 | HS | 88 | -0.013441 | -0.008691 | 0.0025315 |
| 2 | BTOP | 24 | -0.004802 | -0.00291 | 0.0037436 |
| 3 | BBOT | 15 | 0.015398 | 0.009734 | 0.0244076 |

| Gamma: 0.1; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 27 | 0.016526 | 0.02661 | 0.0586358 |
| 1 | HS | 16 | -0.010732 | -0.011348 | -0.012982 |
| 2 | BTOP | 9 | -0.001649 | -0.002992 | 0.0285402 |
| 3 | BBOT | 8 | 0.031077 | 0.004395 | 0.0051412 |

| Gamma: 0.3; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 55 | 0.015184 | 0.016644 | 0.0450534 |
| 1 | HS | 39 | -0.013026 | -0.004959 | -0.0109301 |
| 2 | BTOP | 29 | -0.005758 | -0.00083 | 0.0237028 |
| 3 | BBOT | 24 | 0.013438 | 0.008558 | 0.0273724 |

| Gamma: 1.0; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 87 | 0.016101 | 0.020658 | 0.0309927 |
| 1 | HS | 97 | -0.012388 | -0.007316 | 0.0039688 |
| 2 | BTOP | 30 | -0.004823 | -0.004003 | 0.0125674 |
| 3 | BBOT | 18 | 0.015477 | 0.011647 | 0.0295987 |

| Gamma: 0.1; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 36 | 0.019012 | 0.028528 | 0.0589354 |
| 1 | HS | 23 | -0.008774 | -0.012628 | -0.0105741 |
| 2 | BTOP | 13 | -0.008758 | -0.007949 | 0.0252986 |
| 3 | BBOT | 14 | 0.022977 | 0.011725 | 0.0061085 |

| Gamma: 0.3; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 57 | 0.015909 | 0.019761 | 0.0459241 |
| 1 | HS | 38 | -0.015201 | -0.007561 | -0.008762 |
| 2 | BTOP | 36 | -0.008575 | -0.001505 | 0.0234339 |
| 3 | BBOT | 27 | 0.012142 | 0.011847 | 0.0343527 |

| Gamma: 1.0; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 87 | 0.016749 | 0.021297 | 0.0324516 |
| 1 | HS | 99 | -0.013363 | -0.007444 | 0.0018195 |
| 2 | BTOP | 33 | -0.006579 | -0.007281 | 0.0103077 |
| 3 | BBOT | 21 | 0.017543 | 0.012095 | 0.0169584 |

Total post-pattern return averages (by pattern)

| Total avg. | 3days | 5days | 15days |
|---|---|---|---|
| IHS | 0.0159 | 0.0201 | 0.0392 |
| HS | -0.0128 | -0.0074 | -0.0009 |
| BTOP | -0.0064 | -0.0037 | 0.0155 |
| BBOT | 0.0164 | 0.0111 | 0.0237 |

*Freq.*: number of times that pattern was detected by the algorithm

*Total avg.*: calculated by dividing absolute sum of returns by the sum of all pattern occurrences (of a given type)

# Appendix: Nasdaq

## [Significance of post-pattern returns] Code Output [Frequency: Daily]

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Gamma Input: ↑

Gamma Input: ↑

| Gamma: 0.1; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 13 | 0.0057106 | 0.0032423 | 0.0203817 |
| 1 | HS | 20 | 0.0917031 | 0.4019819 | 0.78398588 |
| 2 | BTOP | 4 | 0.2063604 | 0.1142148 | 0.9030216 |
| 3 | BBOT | 5 | 0.1367723 | 0.0786976 | 0.30583565 |

| Gamma: 0.3; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 110 | 7.587E-12 | 5.591E-08 | 5.1017E-07 |
| 1 | HS | 125 | 1.675E-09 | 8.152E-05 | 0.30844333 |
| 2 | BTOP | 25 | 0.0877852 | 0.5930577 | 0.14265705 |
| 3 | BBOT | 21 | 0.0887111 | 0.6759689 | 0.13698014 |

| Gamma: 1.0; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 276 | 1.089E-28 | 8.102E-20 | 3.6785E-16 |
| 1 | HS | 273 | 2.083E-13 | 1.233E-05 | 0.38249254 |
| 2 | BTOP | 59 | 0.0003301 | 0.3196694 | 0.51283139 |
| 3 | BBOT | 52 | 0.3536955 | 0.8333632 | 0.13694126 |

Window Size: ↑

| Gamma: 0.1; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 63 | 1.195E-07 | 1.736E-08 | 0.00089855 |
| 1 | HS | 95 | 7.115E-11 | 2.236E-07 | 0.0210689 |
| 2 | BTOP | 24 | 0.0009654 | 0.008399 | 0.6623081 |
| 3 | BBOT | 27 | 0.0005848 | 0.0075397 | 0.02521202 |

| Gamma: 0.3; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 189 | 6.043E-21 | 7.9E-16 | 1.2125E-10 |
| 1 | HS | 209 | 3.033E-20 | 1.013E-09 | 0.04975549 |
| 2 | BTOP | 57 | 0.0147047 | 0.1481504 | 0.63708282 |
| 3 | BBOT | 46 | 0.0024355 | 0.5681883 | 0.11989929 |

| Gamma: 1.0; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 296 | 1.034E-31 | 6.199E-22 | 7.4166E-17 |
| 1 | HS | 294 | 3.661E-18 | 6.223E-08 | 0.9804245 |
| 2 | BTOP | 75 | 5.848E-05 | 0.1496226 | 0.88433579 |
| 3 | BBOT | 61 | 0.092184 | 0.7177512 | 0.05627305 |

Window Size: ↑

| Gamma: 0.1; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 122 | 1.026E-17 | 3.985E-17 | na |
| 1 | HS | 144 | 4.532E-24 | 2.496E-16 | 0.00030933 |
| 2 | BTOP | 52 | 5.041E-11 | 3.782E-06 | 0.03130211 |
| 3 | BBOT | 34 | 1.25E-05 | 0.0003349 | 0.00773443 |

| Gamma: 0.3; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 220 | 4.915E-25 | 6.431E-18 | 3.4295E-10 |
| 1 | HS | 221 | 5.006E-26 | 6.04E-13 | 0.00045777 |
| 2 | BTOP | 76 | 4E-06 | 0.0026705 | 0.71068022 |
| 3 | BBOT | 59 | 2.134E-06 | 0.019335 | 0.00361985 |

| Gamma: 1.0; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 315 | 3.663E-35 | 8.301E-26 | 2.1087E-18 |
| 1 | HS | 299 | 1.762E-21 | 8.047E-10 | 0.96857972 |
| 2 | BTOP | 86 | 2.705E-06 | 0.1132102 | 0.89457434 |
| 3 | BBOT | 61 | 0.0118823 | 0.0523394 | 0.0038598 |

Total sign. post-pattern return averages (by pattern)

| Total | 29 | 23 | 17 |
|---|---|---|---|
| IHS | 9 | 9 | 8 |
| HS | 8 | 8 | 4 |
| BTOP | 7 | 3 | 1 |
| BBOT | 5 | 3 | 4 |

*Freq.*: number of times that pattern was detected by the algorithm

*Note:* p-values were calculated under the assumption that expected returns are equal to zero (for the 3days to 15days calculated)

# Appendix: Nasdaq

## [Average post-pattern returns] Code Output [Frequency: Daily]

W U T I S

| Gamma: 0.1; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 13 | 0.018829 | 0.027473 | 0.0339388 |
| 1 | HS | 20 | -0.006517 | -0.003632 | -0.0015512 |
| 2 | BTOP | 4 | -0.013648 | -0.025112 | -0.0031676 |
| 3 | BBOT | 5 | 0.010204 | 0.013385 | -0.0137414 |

| Gamma: 0.3; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 110 | 0.01117 | 0.013987 | 0.0207514 |
| 1 | HS | 125 | -0.009896 | -0.008924 | -0.0035118 |
| 2 | BTOP | 25 | -0.004935 | -0.002251 | 0.0120887 |
| 3 | BBOT | 21 | 0.011088 | 0.004747 | 0.0252703 |

| Gamma: 1.0; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 276 | 0.011919 | 0.013722 | 0.0195148 |
| 1 | HS | 273 | -0.008021 | -0.006301 | 0.0019892 |
| 2 | BTOP | 59 | -0.009002 | -0.00327 | 0.0037384 |
| 3 | BBOT | 52 | 0.003412 | -0.001263 | 0.0144351 |

| Gamma: 0.1; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 63 | 0.011815 | 0.016767 | 0.0181946 |
| 1 | HS | 95 | -0.011162 | -0.012681 | -0.0102928 |
| 2 | BTOP | 24 | -0.007462 | -0.012602 | -0.0032235 |
| 3 | BBOT | 27 | 0.021416 | 0.016653 | 0.0303035 |

| Gamma: 0.3; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 189 | 0.012918 | 0.014198 | 0.019581 |
| 1 | HS | 209 | -0.011544 | -0.010676 | -0.0051586 |
| 2 | BTOP | 57 | -0.004842 | -0.003924 | 0.0024388 |
| 3 | BBOT | 46 | 0.012661 | 0.004227 | 0.0178941 |

| Gamma: 1.0; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 296 | 0.011977 | 0.013768 | 0.0193625 |
| 1 | HS | 294 | -0.009176 | -0.007436 | 5.483E-05 |
| 2 | BTOP | 75 | -0.008492 | -0.003967 | 0.0007199 |
| 3 | BBOT | 61 | 0.005495 | 0.001895 | 0.0168472 |

| Gamma: 0.1; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 122 | 0.01272 | 0.017343 | 0.0185582 |
| 1 | HS | 144 | -0.013403 | -0.016608 | -0.0137348 |
| 2 | BTOP | 52 | -0.008458 | -0.012929 | -0.0104625 |
| 3 | BBOT | 34 | 0.024773 | 0.022461 | 0.0304071 |

| Gamma: 0.3; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 220 | 0.012552 | 0.013648 | 0.0178692 |
| 1 | HS | 221 | -0.012113 | -0.011556 | -0.0088382 |
| 2 | BTOP | 76 | -0.0074 | -0.006461 | -0.001596 |
| 3 | BBOT | 59 | 0.017311 | 0.012841 | 0.0248602 |

| Gamma: 1.0; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 315 | 0.012005 | 0.014319 | 0.0195252 |
| 1 | HS | 299 | -0.009989 | -0.008207 | -8.691E-05 |
| 2 | BTOP | 86 | -0.008686 | -0.003999 | 0.0005651 |
| 3 | BBOT | 61 | 0.00793 | 0.008069 | 0.0231221 |

Total post-pattern return averages (by pattern)

| Total avg. | 3days | 5days | 15days |
|---|---|---|---|
| IHS | 0.0122 | 0.0144 | 0.0193 |
| HS | -0.0103 | -0.0095 | -0.0035 |
| BTOP | -0.0078 | -0.0059 | 0.0000 |
| BBOT | 0.0118 | 0.0079 | 0.0213 |

*Freq.*: number of times that pattern was detected by the algorithm

*Total avg.*: calculated by dividing absolute sum of returns by the sum of all pattern occurrences (of a given type)

# Appendix: Crude Oil

## [Significance of post-pattern returns] Code Output [Frequency: Daily]

W U T I S

**Gamma Input: ↑**

**Gamma Input: ↑**

| Gamma: 0.1; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 15 | 5.558E-05 | 0.02381 | 0.74118988 |
| 1 | HS | 16 | 0.0661012 | 0.9116343 | 0.3958954 |
| 2 | BTOP | 1 | na | na | na |
| 3 | BBOT | 1 | na | na | na |

| Gamma: 0.3; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 39 | 0.0371431 | 0.0282082 | 0.92744285 |
| 1 | HS | 56 | 7.668E-07 | 0.0010828 | 0.16349774 |
| 2 | BTOP | 15 | 0.0044616 | 0.0122553 | 0.99778684 |
| 3 | BBOT | 14 | 0.0072143 | 0.0003105 | 0.00559855 |

| Gamma: 1.0; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 114 | 2.571E-14 | 1.203E-08 | 7.3225E-05 |
| 1 | HS | 118 | 4.769E-09 | 2.871E-05 | 0.60103019 |
| 2 | BTOP | 31 | 0.0049242 | 0.0028446 | 0.1352852 |
| 3 | BBOT | 35 | 0.0434886 | 0.6167591 | 0.84520262 |

**Window Size: ↑**

| Gamma: 0.1; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 33 | 1.304E-09 | 2.424E-06 | 0.10667819 |
| 1 | HS | 38 | 2.895E-05 | 0.0559929 | 0.84392812 |
| 2 | BTOP | 14 | 0.1490777 | 0.0603227 | 0.38838663 |
| 3 | BBOT | 11 | 0.5118571 | 0.4529004 | 0.311368 |

| Gamma: 0.3; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 64 | 0.0001415 | 0.0003499 | 0.09246206 |
| 1 | HS | 64 | 5.868E-07 | 0.0006673 | 0.34862791 |
| 2 | BTOP | 32 | 0.0001292 | 0.0062212 | 0.78397689 |
| 3 | BBOT | 29 | 0.5724057 | 0.6945926 | 0.73603999 |

| Gamma: 1.0; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 115 | 7.637E-17 | 1.439E-10 | 1.6678E-05 |
| 1 | HS | 119 | 1.421E-09 | 2.051E-05 | 0.56500056 |
| 2 | BTOP | 37 | 0.0019146 | 0.0024853 | 0.13631681 |
| 3 | BBOT | 45 | 0.6549082 | 0.660552 | 0.69061478 |

**Window Size: ↑**

| Gamma: 0.1; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 49 | 3.926E-14 | 2.615E-10 | 0.00774311 |
| 1 | HS | 57 | 2.036E-09 | 5.086E-05 | 0.02115707 |
| 2 | BTOP | 28 | 0.0041887 | 0.416582 | 0.20852443 |
| 3 | BBOT | 17 | 0.5979997 | 0.5417364 | 0.36571797 |

| Gamma: 0.3; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 69 | 1.213E-05 | 5.972E-05 | 0.06471952 |
| 1 | HS | 73 | 2.469E-09 | 4.781E-05 | 0.18511561 |
| 2 | BTOP | 41 | 0.0004986 | 0.0175608 | 0.5742156 |
| 3 | BBOT | 34 | 0.6527613 | 0.830224 | 0.94394683 |

| Gamma: 1.0; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days pval | 5days pval | 15days pval |
| 0 | IHS | 116 | 3.036E-17 | 1.016E-10 | 1.109E-05 |
| 1 | HS | 119 | 7.359E-11 | 7.166E-06 | 0.45659019 |
| 2 | BTOP | 41 | 0.0005178 | 0.0010782 | 0.10352233 |
| 3 | BBOT | 48 | 0.6458474 | 0.6964126 | 0.75751696 |

Total sign. post-pattern return averages (by pattern)

| Total | 26 | 23 | 6 |
|---|---|---|---|
| IHS | 9 | 9 | 4 |
| HS | 8 | 7 | 1 |
| BTOP | 7 | 6 | 0 |
| BBOT | 2 | 1 | 1 |

*Freq.*: number of times that pattern was detected by the algorithm

*Note:* p-values were calculated under the assumption that expected returns are equal to zero (for the 3days to 15days calculated)

# Appendix: Crude Oil

## [Average post-pattern returns] Code Output [Frequency: Daily]

W U T I S

| Gamma: 0.1; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 15 | 0.029041 | 0.024581 | 0.0089419 |
| 1 | HS | 16 | -0.013927 | 0.001797 | -0.0140813 |
| 2 | BTOP | 1 | -0.048957 | -0.032925 | 0.0505085 |
| 3 | BBOT | 1 | 0.044139 | 0.054682 | 0.0814868 |

| Gamma: 0.3; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 39 | 0.014156 | 0.016173 | 0.0013049 |
| 1 | HS | 56 | -0.025152 | -0.024059 | -0.0125351 |
| 2 | BTOP | 15 | -0.023634 | -0.028165 | 5.116E-05 |
| 3 | BBOT | 14 | 0.020697 | 0.032985 | 0.0784961 |

| Gamma: 1.0; Window Size: 20 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 114 | 0.021293 | 0.022476 | 0.0296586 |
| 1 | HS | 118 | -0.018472 | -0.019224 | -0.003645 |
| 2 | BTOP | 31 | -0.018341 | -0.031204 | -0.030495 |
| 3 | BBOT | 35 | 0.012715 | 0.003742 | 0.0041814 |

| Gamma: 0.1; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 33 | 0.034275 | 0.029271 | 0.0241225 |
| 1 | HS | 38 | -0.018285 | -0.016525 | 0.0020792 |
| 2 | BTOP | 14 | -0.009744 | 0.015636 | 0.0176478 |
| 3 | BBOT | 11 | -0.092363 | -0.102072 | -0.1660132 |

| Gamma: 0.3; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 64 | 0.018588 | 0.019814 | 0.0174883 |
| 1 | HS | 64 | -0.022335 | -0.022132 | -0.0080061 |
| 2 | BTOP | 32 | -0.021371 | -0.018211 | 0.0033906 |
| 3 | BBOT | 29 | -0.028936 | -0.018939 | -0.021368 |

| Gamma: 1.0; Window Size: 30 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 115 | 0.024176 | 0.024483 | 0.032321 |
| 1 | HS | 119 | -0.019296 | -0.019593 | -0.0040019 |
| 2 | BTOP | 37 | -0.017884 | -0.027171 | -0.0256278 |
| 3 | BBOT | 45 | -0.014742 | -0.01371 | -0.0166131 |

| Gamma: 0.1; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 49 | 0.030533 | 0.029635 | 0.0297638 |
| 1 | HS | 57 | -0.019218 | -0.026532 | -0.0236057 |
| 2 | BTOP | 28 | -0.015819 | 0.006648 | -0.0153537 |
| 3 | BBOT | 17 | -0.047187 | -0.052957 | -0.0951179 |

| Gamma: 0.3; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 69 | 0.01987 | 0.020796 | 0.0183545 |
| 1 | HS | 73 | -0.024507 | -0.024537 | -0.0112722 |
| 2 | BTOP | 41 | -0.015435 | -0.012345 | 0.0057891 |
| 3 | BBOT | 34 | -0.019675 | -0.008871 | 0.0038548 |

| Gamma: 1.0; Window Size: 45 | | | | | |
|---|---|---|---|---|---|
| | Pattern | Freq | 3days avg | 5days avg | 15days avg |
| 0 | IHS | 116 | 0.024179 | 0.024533 | 0.0328992 |
| 1 | HS | 119 | -0.020573 | -0.020814 | -0.0052295 |
| 2 | BTOP | 41 | -0.018482 | -0.027516 | -0.0251674 |
| 3 | BBOT | 48 | -0.014201 | -0.011515 | -0.0121982 |

Total post-pattern return averages (by pattern)

| Total avg. | 3days | 5days | 15days |
|---|---|---|---|
| IHS | 0.0231 | 0.0234 | 0.0256 |
| HS | -0.0206 | -0.0208 | -0.0077 |
| BTOP | -0.0179 | -0.0177 | -0.0113 |
| BBOT | -0.0166 | -0.0145 | -0.0168 |

*Freq.*: number of times that pattern was detected by the algorithm

*Total avg.*: calculated by dividing absolute sum of returns by the sum of all pattern occurrences (of a given type)