# Replicate "(Re-)Imag(in)ing Price Trends"
## by Jingwen Jiang, Bryan Kelly, and Dacheng Xiu (2021)

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https://youtu.be/xy2grOVvr2k

# Introduction

- Main findings of Jiang et al. (2021):
  - Use image as inputs for price trend prediction
  - Apply CNN to detect price pattern
  - Give more accurate return predictions and translate into profitable investment strategies

- Our tasks:
  - Construct a CNN model to learn stock price patterns
  - Evaluate the performance of the trained CNN model

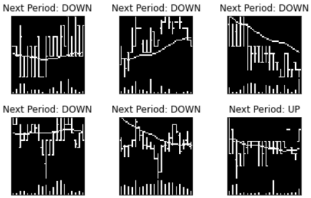
- Our findings:
  - CNN predictions beat random guess and form profitable portfolios
  - Profitable returns cannot be explained by current asset pricing model and driven by **small** firms
  - The portfolio requires high turnover rate, which may dry out the profits

# Agenda

- Data preparation
- Model design
- Model training
- Performance evaluation

# Data preparation

- Input: 20-day OHLC images from 1993 to 2019 in 64*60 gray scale
- Label: 1 if next 20-day return is positive, and 0 otherwise
- Drop data and labels if no future return available



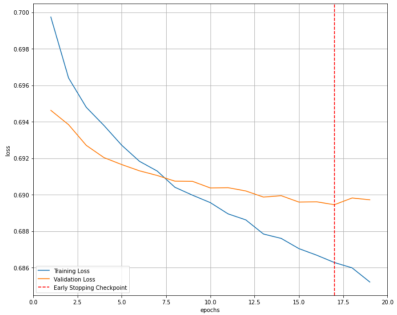
# Model design

- Follow Jiang et al. (2021)'s architecture
- Make some modifications:
  - Convolution layers: vertical dilation of 4
  - Pool layers: vertical stride of 2
- Characterize with the same number of parameters as Jiang et al. (2021)

```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1           [-1, 64, 48, 60]           1,024
       BatchNorm2d-2           [-1, 64, 48, 60]             128
         LeakyReLU-3           [-1, 64, 48, 60]               0
         MaxPool2d-4           [-1, 64, 24, 60]               0
            Conv2d-5          [-1, 128, 20, 60]         123,008
       BatchNorm2d-6          [-1, 128, 20, 60]             256
         LeakyReLU-7          [-1, 128, 20, 60]               0
         MaxPool2d-8          [-1, 128, 10, 60]               0
            Conv2d-9          [-1, 256, 6, 60]          491,776
      BatchNorm2d-10          [-1, 256, 6, 60]             512
        LeakyReLU-11          [-1, 256, 6, 60]               0
        MaxPool2d-12          [-1, 256, 3, 60]               0
           Linear-13                [-1, 2]              92,162
          Dropout-14                [-1, 2]               0
          Softmax-15                [-1, 2]               0
================================================================
Total params: 708,866
Trainable params: 708,866
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.01
Forward/backward pass size (MB): 11.48
Params size (MB): 2.70
Estimated Total Size (MB): 14.20
----------------------------------------------------------------
```

# Model training

- Data split: 1993-2000 data, among which we randomly select 70% as training set and use the rest as validation set. We test model with 2001-2019 data.
- Loss function: Cross-entropy loss function
- Optimizer: Adam algorithm with 1e5 learning rate
- Regularization: Xavier parameter initializer, batch normalization within each block, 50% dropout in FC layer, early stopping of patience 2



- The CNN's out-of-sample classification accuracy at the stock level is 51.8% for image sizes 20 days and forecast horizons 20 days. The significant level is over 99.9%.

Out-of-Sample Classification Accuracy (Null: mean = 0.5)

| accuracy | estimate | statistic | p.value |
|---|---|---|---|
| Total | 0.52 | 6.38 | 0.00 |
| Sensitivity | 0.53 | 2.17 | 0.03 |
| Specificity | 0.50 | 0.29 | 0.77 |
| Balanced | 0.51 | 13.75 | 0.00 |

[1] The Table reports out-of-sample forcast performance for imaged-based CNN models and benchmark signals.

[2] We calculate classification accuracy each period then report time series averages over each period in the test sample.

[3] Total Accuracy = (TP+TN)/(TP+FP+TN+FN)

[4] sensitiviy = TP/(TP+FP)

[5] specification = TN/(TN+FN)

[6] Balanced accuracy = 0.5*(sensitivity + specification)

# Performance evaluation

## Average return

- Decile 1, which corresponds to stocks having the lowest probability of a positive future return indeed realize lowest return.
- Average return increase monotonically across predicted "up" probability deciles.

Performance of Portfolios: Average Returns in 10 Single-Sorted Portfolios

| type | estimate | stat | Lowest | X_2 | X_3 | X_4 | X_5 | X_6 | X_7 | X_8 | X_9 | Highest | H_L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EW | Average ret | param | 0.21 | 0.60 | 0.74 | 0.87 | 0.89 | 0.95 | 0.97 | 1.08 | 1.17 | 1.26 | 1.05*** |
| EW | Average ret | T | (0.45) | (1.39) | (1.69) | (2.04) | (2.19) | (2.32) | (2.42) | (2.72) | (2.95) | (3.40) | (6.83) |
| VW | Average ret | param | 0.57 | 0.60 | 0.49 | 0.69 | 0.72 | 0.71 | 0.58 | 0.65 | 0.76 | 0.75 | 0.18 |
| VW | Average ret | T | (1.44) | (1.57) | (1.41) | (2.08) | (2.13) | (2.16) | (1.96) | (2.01) | (2.61) | (2.51) | (0.97) |
| EW_TC | Average ret | param | -0.69 | -0.30 | -0.17 | -0.04 | -0.02 | 0.04 | 0.06 | 0.17 | 0.26 | 0.35 | 0.03 |
| EW_TC | Average ret | T | (-1.52) | (-0.70) | (-0.39) | (-0.10) | (-0.06) | (0.09) | (0.15) | (0.44) | (0.66) | (0.95) | (0.21) |
| VW_TC | Average ret | param | -0.37 | -0.34 | -0.44 | -0.24 | -0.2 | -0.2 | -0.33 | -0.24 | -0.15 | -0.14 | -0.84*** |
| VW_TC | Average ret | T | (-0.95) | (-0.91) | (-1.30) | (-0.74) | (-0.61) | (-0.63) | (-1.14) | (-0.75) | (-0.52) | (-0.47) | (-4.37) |

[1] Performance of decile portfolios sorted on out-of-sample predicted up probability for next month (20-days).

[2] Monthly average returns (in percentage) acompanied by , , are significant at the 1%, 5%, and 10% significance level, respectively.

[3] EW and VW represents equal-weighted and value-weigthed respectively; TC indicates whether we consider the tranding cost.

[4] We assume transaction fees of 0.5% for the total dollar amount traded.

# Performance evaluation

## Average return

- For the VW portfolio, the slope is relative flatter and the H-L portfolios has no significant average returns.
- Considering the transaction cost, the 0.5% trading cost and monthly re-balancing will shift the average return downward both for EW and VW portfolio.

Performance of Portfolios: Average Returns in 10 Single-Sorted Portfolios

| type | estimate | stat | Lowest | X_2 | X_3 | X_4 | X_5 | X_6 | X_7 | X_8 | X_9 | Highest | H_L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EW | Average ret | param | 0.21 | 0.60 | 0.74 | 0.87 | 0.89 | 0.95 | 0.97 | 1.08 | 1.17 | 1.26 | 1.05*** |
| EW | Average ret | T | (0.45) | (1.39) | (1.69) | (2.04) | (2.19) | (2.32) | (2.42) | (2.72) | (2.95) | (3.40) | (6.83) |
| VW | Average ret | param | 0.57 | 0.60 | 0.49 | 0.69 | 0.72 | 0.71 | 0.58 | 0.65 | 0.76 | 0.75 | 0.18 |
| VW | Average ret | T | (1.44) | (1.57) | (1.41) | (2.08) | (2.13) | (2.16) | (1.96) | (2.01) | (2.61) | (2.51) | (0.97) |
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| VW_TC | Average ret | param | -0.37 | -0.34 | -0.44 | -0.24 | -0.2 | -0.2 | -0.33 | -0.24 | -0.15 | -0.14 | -0.84*** |
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[1] Performance of decile portfolios sorted on out-of-sample predicted up probability for next month (20-days).

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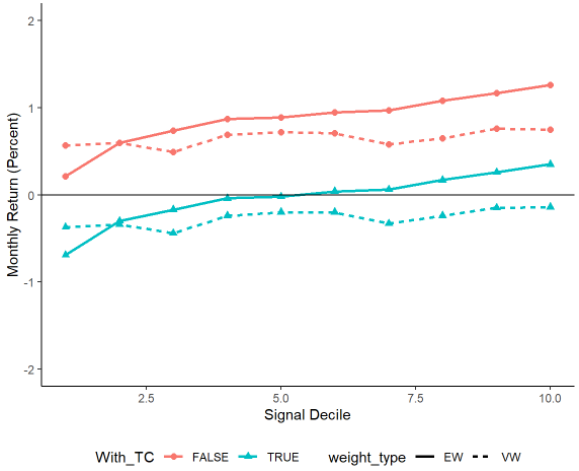
# Performance evaluation

## Average return



# Performance evaluation

## Sharpe Ratio and Turnover

- Sharpe Ratio has similar pattern as the average returns.
- The turnover rate is quite similar across deciles, on average 180%.
- Under 0.05% trading cost per dollar, **All profits are eaten**.

Out-of-Sample Sharpe Ratio and Turnover

| weight_type | statistic | Lowest | X_2 | X_3 | X_4 | X_5 | X_6 | X_7 | X_8 | X_9 | Highest | H-L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EW | SharpeRatio | 0.06 | 0.30 | 0.38 | 0.47 | 0.48 | 0.53 | 0.55 | 0.62 | 0.67 | 0.76 | 1.57 |
| EW | Turnvoer | 1.79 | 1.81 | 1.82 | 1.82 | 1.82 | 1.83 | 1.83 | 1.82 | 1.82 | 1.82 | 2.04 |
| EW | SharpeRatio_tc | -0.49 | -0.26 | -0.18 | -0.10 | -0.09 | -0.05 | -0.04 | 0.04 | 0.09 | 0.15 | -0.14 |
| VW | SharpeRatio | 0.31 | 0.35 | 0.28 | 0.44 | 0.47 | 0.47 | 0.37 | 0.42 | 0.51 | 0.50 | 0.08 |
| VW | Turnvoer | 1.89 | 1.88 | 1.86 | 1.85 | 1.84 | 1.83 | 1.83 | 1.80 | 1.81 | 1.79 | 2.05 |
| VW | SharpeRatio_tc | -0.33 | -0.33 | -0.41 | -0.28 | -0.25 | -0.25 | -0.36 | -0.28 | -0.21 | -0.20 | -1.11 |

[1] Performance of decile portfolios sorted on out-of-sample predicted up probability for next month (20-days).

[2] Each panel reports the annualized sharpe ratio and average turnover rate

[3] EW and VW represents equal-weighted and value-wegithed respectively; TC indicates whether we consider the tranding cost.

[4] We assume transaction fees of 0.5% for the total dollar amount traded.

# Performance evaluation

## What can Asset Pricing Theory say?

- Leading asset pricing model can not explain the abnormal return/mis-pricing sorted by the predictors offered by CNN model in equally weighed portfolios. **Something new here**

Alphas in 10 Single-Sorted Portfolios

| type | estimate | stat | Lowest | X_2 | X_3 | X_4 | X_5 | X_6 | X_7 | X_8 | X_9 | Highest | H_L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **EW** | | | | | | | | | | | | | |
| EW | FF6 Alpha | param | -0.51 | -0.14 | -0.02 | 0.11 | 0.09 | 0.17 | 0.20 | 0.27 | 0.36 | 0.47 | 0.98*** |
| EW | FF6 Alpha | T | (-3.71) | (-1.32) | (-0.18) | (1.04) | (1.06) | (1.84) | (2.32) | (3.21) | (3.84) | (5.25) | (6.15) |
| EW | Q5_ Alpha | param | -0.36 | -0.05 | 0.06 | 0.20 | 0.21 | 0.25 | 0.30 | 0.36 | 0.44 | 0.52 | 0.88*** |
| EW | Q5_ Alpha | T | (-3.04) | (-0.45) | (0.56) | (2.08) | (2.29) | (2.99) | (3.43) | (4.36) | (5.17) | (5.58) | (5.68) |
| EW | SY4 Alpha | param | -0.41 | -0.07 | 0.06 | 0.17 | 0.15 | 0.21 | 0.25 | 0.32 | 0.42 | 0.50 | 0.92*** |
| EW | SY4 Alpha | T | (-2.97) | (-0.68) | (0.51) | (1.49) | (1.61) | (1.92) | (2.76) | (2.95) | (3.62) | (5.06) | (6.04) |
| EW | BF3 Alpha | param | -0.39 | -0.03 | 0.12 | 0.22 | 0.25 | 0.32 | 0.31 | 0.42 | 0.51 | 0.58 | 0.96*** |
| EW | BF3 Alpha | T | (-2.00) | (-0.15) | (0.68) | (1.31) | (1.71) | (1.83) | (1.98) | (2.56) | (2.84) | (3.30) | (5.41) |
| **VW** | | | | | | | | | | | | | |
| VW | FF6 Alpha | param | -0.13 | -0.07 | -0.20 | -0.03 | 0.03 | 0.01 | -0.08 | -0.00 | 0.14 | 0.11 | 0.24 |
| VW | FF6 Alpha | T | (-1.11) | (-0.55) | (-2.37) | (-0.30) | (0.33) | (0.09) | (-0.80) | (-0.03) | (1.49) | (1.28) | (1.42) |
| VW | Q5_ Alpha | param | -0.09 | -0.03 | -0.22 | 0.03 | 0.10 | 0.04 | -0.05 | -0.00 | 0.11 | 0.08 | 0.17 |
| VW | Q5_ Alpha | T | (-0.91) | (-0.25) | (-2.41) | (0.29) | (1.04) | (0.44) | (-0.51) | (-0.01) | (1.38) | (0.90) | (1.19) |
| VW | SY4 Alpha | param | -0.08 | -0.06 | -0.22 | -0.00 | 0.06 | 0.03 | -0.08 | -0.02 | 0.12 | 0.10 | 0.19 |
| VW | SY4 Alpha | T | (-0.76) | (-0.45) | (-2.52) | (-0.01) | (0.58) | (0.30) | (-0.77) | (-0.20) | (1.40) | (1.21) | (1.18) |
| VW | BF3 Alpha | param | -0.14 | -0.02 | -0.23 | -0.01 | 0.06 | 0.04 | -0.09 | 0.01 | 0.12 | 0.09 | 0.23 |
| VW | BF3 Alpha | T | (-1.15) | (-0.19) | (-2.36) | (-0.16) | (0.64) | (0.44) | (-0.87) | (0.18) | (1.25) | (0.94) | (1.29) |

# Performance evaluation

## What can Asset Pricing Theory say?

- Alpha disappears once we use value weighted approach. **Size matters**
- Considering the trading cost, both EW/VW approach will not generate practical profits.

Alphas in 10 Single-Sorted Portfolios

| type | estimate | stat | Lowest | X_2 | X_3 | X_4 | X_5 | X_6 | X_7 | X_8 | X_9 | Highest | H_L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **EW_TC** | | | | | | | | | | | | | |
| EW_TC | FF6 Alpha | param | -1.41 | -1.04 | -0.92 | -0.79 | -0.81 | -0.74 | -0.71 | -0.63 | -0.55 | -0.44 | -0.15 |
| EW_TC | FF6 Alpha | T | (-10.23) | (-9.66) | (-8.12) | (-7.43) | (-9.17) | (-7.96) | (-8.44) | (-7.55) | (-6.00) | (-5.01) | (-0.96) |
| EW_TC | Q5_ Alpha | param | -1.25 | -0.95 | -0.85 | -0.71 | -0.70 | -0.66 | -0.60 | -0.55 | -0.46 | -0.39 | -0.25 |
| EW_TC | Q5_ Alpha | T | (-10.63) | (-8.83) | (-8.40) | (-7.57) | (-7.67) | (-8.10) | (-6.89) | (-6.82) | (-5.46) | (-4.22) | (-1.67) |
| EW_TC | SY4 Alpha | param | -1.30 | -0.97 | -0.85 | -0.74 | -0.75 | -0.70 | -0.65 | -0.59 | -0.48 | -0.40 | -0.21 |
| EW_TC | SY4 Alpha | T | (-9.49) | (-9.51) | (-7.32) | (-6.68) | (-8.06) | (-6.40) | (-7.24) | (-5.53) | (-4.21) | (-4.10) | (-1.44) |
| EW_TC | BF3 Alpha | param | -1.28 | -0.93 | -0.78 | -0.68 | -0.65 | -0.59 | -0.60 | -0.49 | -0.40 | -0.33 | -0.17 |
| EW_TC | BF3 Alpha | T | (-6.69) | (-5.48) | (-4.32) | (-4.03) | (-4.44) | (-3.47) | (-3.82) | (-2.99) | (-2.23) | (-1.88) | (-0.96) |
| **VW_TC** | | | | | | | | | | | | | |
| VW_TC | FF6 Alpha | param | -1.07 | -1 | -1.13 | -0.95 | -0.88 | -0.9 | -0.98 | -0.9 | -0.77 | -0.78 | -0.89*** |
| VW_TC | FF6 Alpha | T | (-9.17) | (-8.15) | (-13.28) | (-10.79) | (-8.62) | (-10.58) | (-10.43) | (-11.41) | (-8.50) | (-8.68) | (-5.14) |
| VW_TC | Q5_ Alpha | param | -1.03 | -0.96 | -1.14 | -0.9 | -0.82 | -0.87 | -0.95 | -0.89 | -0.79 | -0.81 | -0.96*** |
| VW_TC | Q5_ Alpha | T | (-10.09) | (-7.58) | (-12.76) | (-10.53) | (-8.85) | (-10.05) | (-10.09) | (-10.49) | (-10.29) | (-9.67) | (-6.82) |
| VW_TC | SY4 Alpha | param | -1.02 | -0.99 | -1.15 | -0.92 | -0.85 | -0.89 | -0.99 | -0.91 | -0.78 | -0.79 | -0.94*** |
| VW_TC | SY4 Alpha | T | (-9.23) | (-8.19) | (-13.03) | (-10.13) | (-8.49) | (-10.51) | (-9.57) | (-11.20) | (-9.48) | (-9.29) | (-5.87) |
| VW_TC | BF3 Alpha | param | -1.08 | -0.96 | -1.15 | -0.93 | -0.85 | -0.87 | -1 | -0.88 | -0.78 | -0.8 | -0.9*** |
| VW_TC | BF3 Alpha | T | (-8.88) | (-8.09) | (-12.20) | (-10.67) | (-8.56) | (-10.38) | (-9.69) | (-10.79) | (-8.01) | (-8.38) | (-5.04) |