Factor forecasting with machine learning

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See Appendix A-1 for analyst certification, important disclosures, and the status of non-U.S. analysts.
Machine learning
almost everywhere

Source: R. Golub et al, Molecular Classification of Cancer: Class Discovery and Class Prediction by Gene Expression Monitoring, SCIENCE, Vol 286, 15 October 1999
Examples of Classification Problems

- Spam Filtering
- Cancer characterization
- Credit Card Fraud Detection
- Facial recognition
- Etc.

Machine Learning Techniques for Classification Problems

Supervised vs. Unsupervised Learning

Parametric or Algorithmic

- Logistic Regression with regularization
- Support Vector Machines
- Classification and Regression Trees (CART)
- Random Forest
- Neural Networks
- Etc.
Pattern recognition means classification

The relevant problem is digital (classification) rather than analogue (linear regression, CAPM)

Focus here on forecasting factor returns using two techniques

Two machines can be better than one – ensemble approach/wisdom of crowds
• What is the **future** beta of a stock?
  
  Adjusted beta = blend of estimated beta and beta of 1  
  Shrink the beta towards 1 for out-of-sample accuracy

• Bias – variance tradeoff
  
  relax the tightness of the training fit to improve test data performance
Training involves shrinkage/regularization

- Ridge regression shrinks regression coefficients through penalty on squared magnitude

$$\hat{\beta}_{\text{ridge}} = \min_{\beta} \left\{ \sum_{i=1}^{N} (y_i - \beta_0 - \sum_{j=1}^{p} x_{ij} \beta_j)^2 + \lambda \sum_{j=1}^{p} \beta_j^2 \right\}$$

- The Lasso shrinks regression coefficients through penalty on absolute magnitude

$$\hat{\beta}_{\text{Lasso}} = \min_{\beta} \left\{ \sum_{i=1}^{N} (y_i - \beta_0 - \sum_{j=1}^{p} x_{ij} \beta_j)^2 + \lambda \sum_{j=1}^{p} |\beta_j| \right\}$$

- The general form is

$$\hat{\beta} = \min_{\beta} \{ \text{Loss} + \text{Penalty} \}$$
• Prediction Error for *training* data may be very different than for *test* data

• Relax *training* fit (increase bias) to improve *test* performance (*decrease variance*)

![Graph showing model fit vs. model performance](image)
Logistic Regression with shrinkage for classification

- Classification is based on probability of category (y=0 or y=1); linear regression not appropriate

- \( p(X) = \text{Probability}(y=1|X) \)

\[
p(X) = \frac{e^{\beta_0 + \beta_1 X}}{1 + e^{\beta_0 + \beta_1 X}}
\]

- Classic logistic regression inadequate for predictions

- Shrinkage or regularization of betas makes prediction practical

\[
\log\left(\frac{p(X)}{1 - p(X)}\right) = \beta_0 + \beta_1 X
\]
Logistic Regression with shrinkage for Factor Return Prediction – Book/Price

Note: The chart shows cumulative monthly returns of Book/Price without modeling (Passive, blue line) and with modeling (Tactical, red line). Independent variables used for modeling are VIX, the one-month change of VIX, dispersion of Book/Price, the change of dispersion of Book/Price and the lagged one-month B/P returns. Analysis is from April 1990 to Dec. 2013.

Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.
Logistic Regression with shrinkage for Book/Price
The Power of Prediction

Note: The chart shows prediction probability for B/P returns (blue line) and the next month B/P returns (red line). Analysis is from April 1990 to Dec. 2013.
Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.
Logistic Regression with shrinkage for Factor Return Prediction – Book/Price

Note: The chart shows cumulative monthly returns of Book/Price without modeling (passive, blue line), with modeling using shrinkage method (tactical, red line) and with modeling but not using shrinkage method (Tactical w/o Shrinkage, green line). Independent variables used for modeling are VIX, the one-month change of VIX, dispersion of Book/Price, the change of dispersion of Book/Price and the lagged one-month B/P returns. Analysis is from April 1990 through April 2014.

Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.
• **February 2000** Tech bubble endgame, passive Book/Price lost 31%.
• LR w/shrinkage made correct prediction, but non-regularized LR failed
• Correct prediction reinforced by CART model

Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.

Note: The left chart shows beta coefficients multiply their respective independent variables at Feb. 2000. SUM is the sum of all products. If SUM is positive, it indicates positive returns for B/P of the next month and vice versa. The right table shows the next month return statistics under different VIX scenarios. Analysis is from April 1990 through Dec. 2013.

Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.
• **December 2008**: Book/Price gained 18% following 10% loss in Nov, 23% loss Jan - Nov

• Regularized LR forecast gain, non-regularized forecast loss.

• Correct prediction reinforced by CART model

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**Dec. 2008**

- **Not-Regularized**
- **Regularized**

**Predicting Negative Return**

**Predicting Positive Return**

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**Forward looking Book/Price Returns w.r.t. VIX**

<table>
<thead>
<tr>
<th>VIX &gt; 15</th>
<th>Next Mon. Ret</th>
<th># months</th>
<th>Ann ret</th>
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<tbody>
<tr>
<td>1990 to 2005</td>
<td>0.48</td>
<td>131</td>
<td>5.76</td>
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<tr>
<td>VIX &lt; 15</td>
<td>0.26</td>
<td>58</td>
<td>3.12</td>
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<tr>
<th>VIX &gt; 15</th>
<th>Next Mon. Ret</th>
<th># months</th>
<th>Ann ret</th>
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<tr>
<td>2006 to 2013</td>
<td>0.25</td>
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<tr>
<td>VIX &lt; 15</td>
<td>-0.23</td>
<td>23</td>
<td>-2.75</td>
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<table>
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<tr>
<th>VIX &gt; 30</th>
<th>Next Mon. Ret</th>
<th># months</th>
<th>Ann ret</th>
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<tbody>
<tr>
<td>2006 to 2013</td>
<td>3.95</td>
<td>13</td>
<td>47.34</td>
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<tr>
<td>VIX &lt; 30</td>
<td>-0.46</td>
<td>83</td>
<td>-5.54</td>
</tr>
</tbody>
</table>

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*Note: The chart shows beta coefficients multiply their respective independent variables at Dec. 2008. SUM is the sum of all products. If SUM is positive, it indicates positive returns for B/P of the next month and vice versa. The right table shows the next month return statistics under different VIX scenarios. Analysis is from April 1990 through Dec. 2013.*

*Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.*
Logistic Regression with shrinkage for Factor Return Prediction – Book/Price

- **April 2009**: passive Book/Price gained 47% following 11% loss from Jan. to March 2009.
- Regularized and non-regularized LR both correctly forecast the B/P recovery

**Note**: The chart shows beta coefficients multiply their respective independent variables at Apr. 2009. SUM is the sum of all products. If SUM is positive, it indicates positive returns for B/P of the next month and vice versa.

Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.
**Logistic Regression with shrinkage for Factor Return Prediction – Book/Price**

- **Sep. 2013**: passive Book/Price lost 4%.
  - Regularized LR made correct prediction, non-regularized LR failed.
  - 2013 bad for BP and non-regularized LR, good for regularized LR
- Correct prediction reinforced by CART model

Note: The chart shows beta coefficients multiply their respective independent variables at Sep 2013. SUM is the sum of all products. If SUM is positive, it indicates positive returns for B/P of the next month and vice versa.

Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.
Note: The chart shows cumulative monthly returns of 1-year price momentum without modeling (Passive, blue line) and with modeling (Tactical, red line). Independent variables used for modeling are VIX, the one-month change of VIX, dispersion of Book/Price, the change of dispersion of Book/Price. Analysis is from April 1990 through Dec. 2013.

Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.
Tactical Allocation B/P + Price Momentum

Note: The chart shows cumulative monthly returns of Book/Price plus 1-year price momentum without modeling (Passive, blue line) and with modeling (Tactical, red line). Analysis is from April 1990 through Dec. 2013.

Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.
Olive data: 572 olive oils were analyzed for their content of eight fatty acids (palmitic, palmitoleic, stearic, oleic, linoleic, arachidic, linolenic, and eicosenoic). There were 9 collection areas, 4 from Southern Italy (North and South Apulia, Calabria, Sicily), two from Sardinia (Inland and Coastal) and 3 from Northern Italy (Umbria, East and West Liguria).


Example based on Rafael Irizarry’s course notes on statistical learning at Harvard School of Public Health
Partition the data for classification
Note: The chart shows the categorical decision tree for Book/Price returns using the CART methodology. Positive returns are categorized as “YES” and negative returns are categorized as “NO”. The input features include VIX, the one-month change of VIX, dispersion of Book/Price, the change of dispersion of Book/Price and the lagged one-month B/P returns. Analysis is from April 1990 through Dec. 2005. This model was used for predictions after 2005.

Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.
Comparison between Logistic Regression w/shrinkage & CART – Book/Price

Note: The chart shows cumulative monthly returns of Book/Price without modeling (passive, blue line) , with modeling using logistic regression plus shrinkage method (Tactical LR, red line) and with CART modeling (Tactical CART green line). Independent variables used for modeling are VIX, the one-month change of VIX, dispersion of Book/Price, the change of dispersion of Book/Price and the lagged one-month B/P returns. Analysis is from April 1990 through April 2014.

Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.
The two models agree 62% of the time.

When the models agree forecast accuracy is enhanced.

Note: The left chart shows average annual returns of Book/Price without modeling (passive), with modeling using logistic regression plus shrinkage method (Tactical LR), with CART modeling (Tactical CART green) and when the two models (LR and CART) agree with each other (When Models Agree) since 1990 (red bars) or since 2006 (blue bars). The right table summarizes their return statistics in different periods. Analysis is from April 1990 through April 2014.

Source: Nomura Securities International Inc. Compustat, I/B/E/S, Russell and IDC.
Conclusion

• Machine learning *almost* everywhere

• Time for finance to catch up
Any Authors named on this report are Research Analysts unless otherwise indicated

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