

Too Much Work for Some Beer: Beer Project 1, Dr. Munson-McGee, Fall 2011

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Thirteen different commercial beers were purchased, consumed, and scored for eleven different beer attributes defined by Beer Judge Certification Program (BJCP) criteria. An overall preference rating was also assigned. Multivariate linear regression was used to create a model predicting overall preference based on the attribute scores. The model demonstrated high predictive strength. The model was examined to determine which attributes were correlated with the author's beer preference. Of the beer attributes examined, the author prefers beers with high body and low bitterness, but the largest factors correlated with his beer preference remain unknown.

Nomenclature

A	= coefficient matrix of BJCP scores
b	= vector of overall preference scores
\hat{b}	= vector of predicted overall preference scores
<i>BJCP</i>	= Beer Judge Certification Program
\backslash	= (backslash) Gaussian elimination operator
Q	= orthonormal matrix (part of QR decomposition)
R	= upper right triangular matrix (part of QR decomposition)
R^2	= coefficient of determination (measure of goodness of fit)
x	= vector of unknown score weights

I. Introduction

BEER is a beverage with amazing variety. It can be made in many ways, with many ingredients, resulting in a very large number of flavors, aromas, colors, and consistencies. Judging the relative merits of different beers, therefore, becomes a difficult task. To make it possible to hold beer competitions on a level playing field, the Beer Judge Certification Program (BJCP) has created a classification system for placing (Western) beer into style categories, and a description of the attributes that can be evaluated in order to assign scores to beer.

The BJCP classification and scoring system is a useful framework that can be used to deepen one's appreciation of beer. Learning to evaluate a beer teaches one to recognize some of the attributes of a beer, and noticing correlations between a beer's attributes and how much one enjoys that beer can enable one to predict what other beers one might also enjoy.

II. Selection of beers

The project required the selection of at least ten commercial beers. Each beer had to belong to a unique top-level BJCP style as listed in the 2008 BJCP Style Guidelines[1].

Beers were chosen by the author based on local availability and curiosity, with a few old favorites added. Preference was given to locally produced beers. Many beers were purchased at Toucan’s Market, which was having a sale on individual bottles of New Mexico beers. See Table 1.

Beer	Brewery	Location	Style Category	Reason
Monk’s Wit	Abbey Beverage Co	Santa Fe, NM	16A Belgian and French Ale	Local, made by monks
Red Ale	Marble Brewery	Santa Fe, NM	10B American Ale	Local, unfamiliar with style
Nut Brown	Sierra Blanca	Moriarty, NM	11 English Brown Ale	Local, US version of favored English style
Alien Wheat	Sierra Blanca	Moriarty, NM	6D Light Hybrid Beer	Local, curious about spices
Desert Pilsner	Rio Grande	Moriarty, NM	2A Pilsner	Local, unfamiliar with style
Pancho Verde	Rio Grande	Moriarty, NM	21A Spice/Herb/Vegetable beer	Local, love green chiles
IPA	Rio Grande	Moriarty, NM	14B India Pale Ale	Local, limited experience with style
Oatmeal Stout	Samuel Smith	Tadcaster, England	13C Stout	Curious about oatmeal
Octoberfest	Samuel Adams	Boston, MA	3B European Amber Lager	Curious about spices
Bohemian Black Lager	Spoetzl Brewery	Shiner, TX	4C Dark Lager	Unfamiliar with style
Summer Shandy	Leinenkugel	Chippewa Falls, WI	20A Fruit Beer	US version of English beverage
Boddington’s Pub Ale	Strangeways	Manchester, England	8A English Pale Ale	Old favorite
Framboise Lambic	Lindemans	Vlezenbeek, Belgium	17F Sour Ale	Old favorite

Table 1. Beer selections.

III. Experimental Protocol

A. Style Categories

Beer style categories were determined by consulting the online BeerAdvocate beer database[2].

B. Tasting Procedure

The beers were stored in the refrigerator until tasted. Tastings took place in the evenings, and at lunchtime on weekends. One or two beers were tasted in each session. A modified version of the BJCP Beer Scoresheet was used to score each beer. Before a taste test, the author drank water to clear the palate.

A taste test was begun by removing the beer from the refrigerator and allowing it to warm to a more appropriate temperature, as specified in [3]. Temperatures were measured by a non-contact thermometer.

The beer was opened and poured into a pint glass. Pouring speed was varied to manage the amount of head produced (usually to maximize it, occasionally to reduce it to prevent spills).

The beer was examined and scored for appearance, then sniffed and scored for aromas, and finally tasted and scored for flavors. This sequence was repeated one or more times as more attributes become apparent with familiarity, and scores modified as appropriate.

When enough of the beer had been consumed to generate an overall subjective impression, an overall score was assigned.

The author’s wife also participated in the taste tests, and differences in scores were discussed and integrated into the author’s final scores if appropriate.

C. Scoring

Attributes to be scored were chosen by the author by inspection of the Beer Flavor Wheel [4].

All scores were numeric and range from 1 to 5. Low numbers indicate low intensities; high numbers indicate high intensities. The overall preference score ranged from 1 (hate it) to 5 (love it). The scores are presented in Table 2, below.

Beer	Aroma					Appearance			Flavor			
	Spicy	Fruity	Floral	Roasted	Hoppy	Color	Head	Sour	Sweet	Bitter	Body	Pref
Monk’s Wit	3	3	2	1	1	2	2	2	2	2	3	4
Red Ale	1	1	2	1	4	4	5	1	3	4	2	2
Nut Brown	2	1	1	3	2	5	2	1	3	2	3	4
Alien Wheat	2	2	3	1	2	2	2	1	3	2	2	3
Desert Pilsner	1	1	1	1	2	2	5	1	1	3	3	3
Pancho Verde	3	2	1	1	1	2	2	1	3	2	2	3
IPA	1	1	3	1	5	3	5	1	3	5	2	1
Oatmeal Stout	3	1	1	4	1	5	5	1	3	2	5	4
Octoberfest	3	1	2	2	2	4	4	2	3	2	4	4
Bohemian Black Lager	1	1	1	3	1	5	2	1	3	2	2	2
Summer Shandy	1	4	2	1	1	2	3	3	2	1	2	3
Boddington’s Pub Ale	1	2	2	1	1	3	5	1	2	3	4	4
Framboise Lambic	1	5	1	1	1	4	2	4	5	1	3	4

Table 2. Summary of beer scores.

IV. Analysis

A linear model was chosen to predict the author’s beer preferences. An overall predicted preference score \hat{b} is computed by a linear combination of the scores A_i :

$$\hat{b} = A_1x_1 + A_2x_2 + \cdots + A_nx_n + x_{n+1} \quad (1)$$

where x_i are weight factors for the scores. The weight factors were chosen to best fit (in a least squares sense) the preference scores. Note that x_{n+1} is a factor that represents all of the variables *not* measured in these tests that had an influence on the preference score.

Each taste test results in one equation in the form of (1). The tests can conveniently be represented in matrix form:

$$Ax = \hat{b} \quad (2)$$

where \mathbf{A} is a matrix representing the attribute scores, one row per test. Each column contains the scores for a particular attribute. One column is filled with ones to allow the calculation of x_{n+1} . \mathbf{A} is constructed by taking the numbers from Table 2 and replacing the last column (the final preference scores) with ones.

To get a least squares solution for x , we substitute the preference score vector b (the last column of Table 2) for \hat{b} :

$$Ax = b \quad (3)$$

As written, (3) will probably not be consistent and will have no explicit solution. However, we can decompose \mathbf{A} into the product of an orthornormal matrix \mathbf{Q} and an upper-right-triangular matrix \mathbf{R} and substitute into (3):

$$QRx = b \quad (4)$$

Multiplying each side by the transpose of \mathbf{Q} produces:

$$Rx = Q^T b \quad (5)$$

Solving for x now produces a least squares answer[4]. This can be done using Gaussian elimination:

$$x = R \setminus (Q^T b) \quad (6)$$

A MATLAB program was written to analyze the data, presented in Appendix 1. MATLAB contains operators for Gaussian elimination and \mathbf{QR} decomposition, enabling a solution to (6) in two lines of code.

To calculate \hat{b} , we substitute x into (2).

To evaluate the goodness of the fit, an R^2 value was computed for the true values b and the predicted values \hat{b} .

Once the weight vector x was determined, it was examined to determine the attributes that were most highly correlated with the author's preferences. Percentage scores for the weight of each attribute were calculated, and positive or negative correlations were assigned to each attribute based on the sign of the weight for that attribute.

Results

Tables 3 and 4 summarize the model and the output from the model. Note the high predictive power of this model as shown by the small residuals and resulting R^2 value of 0.99836.

Unknown	3.41	34.16
Body	1.19	11.92
Bitter	-0.98	9.79
Roasted	-0.88	8.82
Sour	-0.82	8.23
Hoppy	0.62	6.21
Color	0.52	5.19
Fruity	0.49	4.88
Sweet	-0.45	4.49
Head	-0.31	3.08
Floral	-0.21	2.07
Spicy	0.12	1.18

Table 3. Beer preference prediction model.

4	4.049	0.049
2	2.045	0.045
4	3.95	-0.05
3	3.042	0.042
3	3.037	0.037
3	2.952	-0.048
1	0.965	-0.035
4	4.025	0.025
4	3.978	-0.022
2	2.023	0.023
3	2.958	-0.042
4	3.957	-0.043
4	4.019	0.019

Coef. Of Determination: 0.99836

Table 4. Accuracy of model.

Figure 1 presents a pie chart showing the correlations between the attributes and the preference score, as well as the percentage contribution of each attribute to the score. Exploded pie slices represent attributes with a positive correlation; the others represent attributes with a negative correlation.

By far the largest contribution to the author’s preference scores (34%) is caused by unknown variables. The largest known positive contribution (12%) is the flavor attribute called “body”, which can be considered a “thickness” or viscosity. The largest known negative correlation (10%) is bitterness, a flavor normally caused by hops. We can observe that the author prefers beers with high body and low bitterness, but we have not identified the primary causes for his beer preferences. Perhaps they lie elsewhere on the Beer

Beer Attributes Correlated With Doug’s Beer Preference

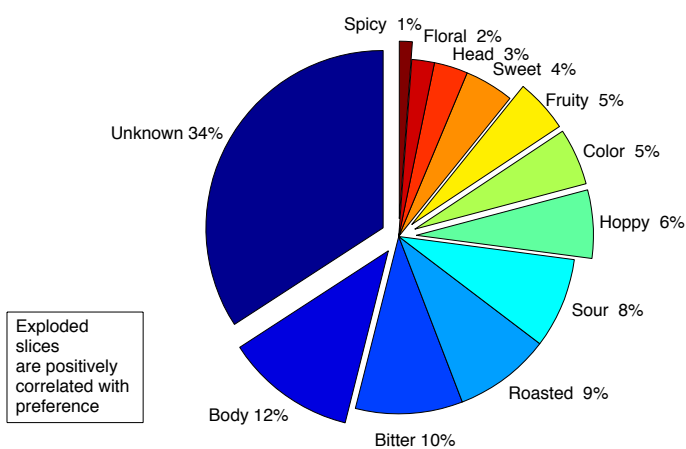


Figure 1. Attributes correlated with beer preference.

Flavor Wheel, or perhaps they have nothing to do with physical attributes of the beer and his preferences primarily depend upon present environment or memories of past experiences. Further research into the author’s beer preferences is highly recommended.

Appendix 1 – Program Listing

```
%% Beer Project 1

% For CH E 395V, Dr. Munson-McGee, Fall 2011
% Doug Weathers, 26 Sept 2011

clc
clear
close all

%% Set up the problem

% Name the attributes we're measuring
attrs = { 'Spicy'
          'Fruity'
          'Floral'
          'Roasted'
          'Hoppy'
          'Color'
          'Head'
          'Sour'
          'Sweet'
          'Bitter'
          'Body'
          'Unknown' };

% Encode the data from the taste tests. Each row is a test, each column
% is a score for one of the attributes named in attrs. The last column is
% the overall preference score, not 'Unknown', but we'll need that name
% later.
scores = [ 3 3 2 1 1 2 2 2 2 2 3 4
           1 1 2 1 4 4 5 1 3 4 2 2
           2 1 1 3 2 5 2 1 3 2 3 4
           2 2 3 1 2 2 2 1 3 2 2 3
           1 1 1 1 1 2 2 5 1 1 3 3 3
           3 2 1 1 1 2 2 1 3 2 2 3
           1 1 3 1 5 3 5 1 3 5 2 1
           3 1 1 4 1 5 5 1 3 2 5 4
           3 1 2 2 2 4 4 2 3 2 4 4
           1 1 1 3 1 5 2 1 3 2 2 2
           1 4 2 1 1 2 3 3 2 1 2 3
           1 2 2 1 1 3 5 1 2 3 4 4
           1 5 1 1 1 4 2 4 5 1 3 4 ];

% Extract the coefficient and result matrices
[rows, cols] = size(scores);

A = [ scores(:, 1:cols-1), ones(rows,1) ];

b = scores(:,end);

%% Define the coefficient of determination function
R2 = @(y,f) 1-sum((y-f).^2)./sum((y-mean(y)).^2);

%% Solve multivariate linear regression using QR factorization
[Q,R] = qr(A);
x = R \ (Q' * b);

%... that was easy!

% Calculate coefficient of determination (goodness of fit)
bhat = A*x;
goodness = R2(b, bhat);

%% Output results
```

```

% Calculate percentages of magnitude of weights
xpct = abs(x) / sum(abs(x)) * 100;

% Sort xpct in descending order, return a permutation index we can use on other
% things
[~, idx] = sort(xpct, 'descend');

sxpct = xpct(idx);
sx = x(idx);
sattrs = attrs(idx);

% Find positive and negative correlations
poscor = sx >= 0;
negcor = sx < 0;

% Print a report!

fprintf('Beer Preference Model of Doug Weathers\n\n')
fprintf('Attribute      Weight      %% of Pref\n')
fprintf('=====')
for ii = 1:length(sx)
    fprintf('%9s      %6.2f      %6.2f \n', sattrs{ii}, sx(ii), sxpct(ii))
end
fprintf('=====')

fprintf('Accuracy of Model\n\n')
fprintf('Preference      Prediction      Difference\n')
fprintf('=====')
fprintf('%6.3f      %6.3f      %6.3f\n', [b, bhat, bhat-b])
fprintf('=====')
fprintf('Coefficient of Determination (R-squared): %8.5f\n', goodness)

%% Make a pie chart

% Label the slices with attribute and percentage
pielabel = sattrs;
for ii = 1:length(xpct)
    pielabel{ii} = [ pielabel{ii} sprintf('%3.0f%%', sxpct(ii)) ];
end

% Plot the pie chart
pie(sxpct, poscor, pielabel)

% Give it a nice big title
title(sprintf('Beer Attributes Correlated With Doug's Beer Preference\n'), ...
    'FontUnits','Points', 'FontSize',18)

```

References

- 1 Beer Judge Certification Program, Inc. BJCP 2008 Style Guidelines. [Internet]. [cited 2011 Sept 25]. Available from: <http://www.bjcp.org/2008styles/catdex.php>.
- 2 BeerAdvocate community. Site Search. [Internet]. [cited 2011 Sept 25]. Available from: <http://beeradvocate.com/search>.
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- 4 Meilgaard M. Meilgaard's Beer Flavor Wheel. [Internet]. [cited 2011 Sept 28]. Available from: <http://www.brew-monkey.com/brewschool/beerwheel.php>.
- 5 Meyer CD. Matrix analysis and applied linear algebra. Philadelphia (PA): SIAM; 2000.