



THE STATISTICAL SOMMELIER

An Introduction to Linear Regression

15.071 – The Analytics Edge

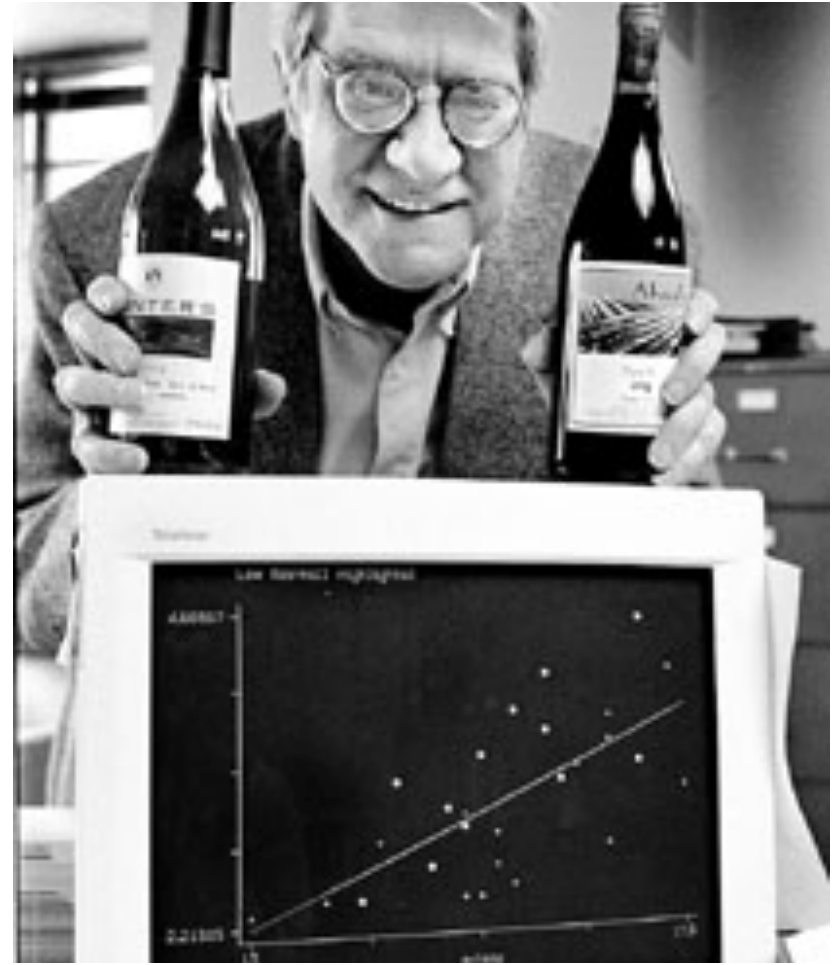
Bordeaux Wine



- Large differences in price and quality between years, although wine is produced in a similar way
- Meant to be aged, so hard to tell if wine will be good when it is on the market
- Expert tasters predict which ones will be good
- Can analytics be used to come up with a different system for judging wine?

Predicting the Quality of Wine

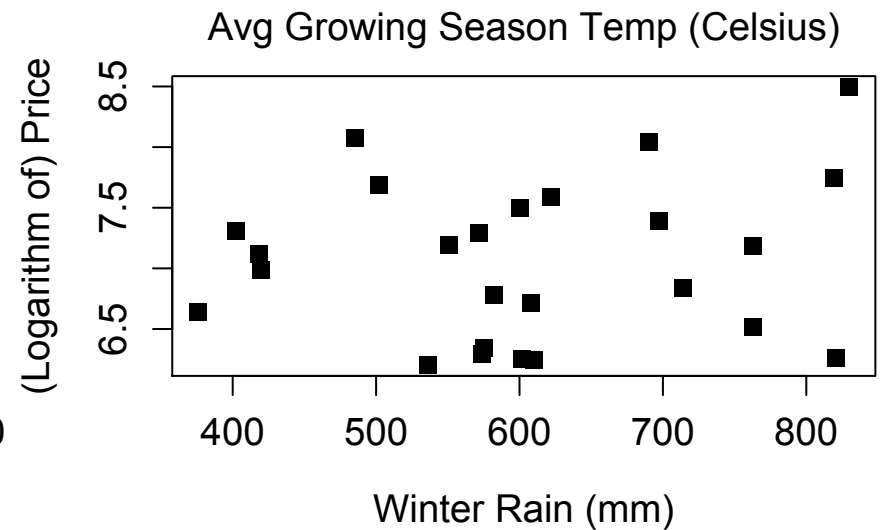
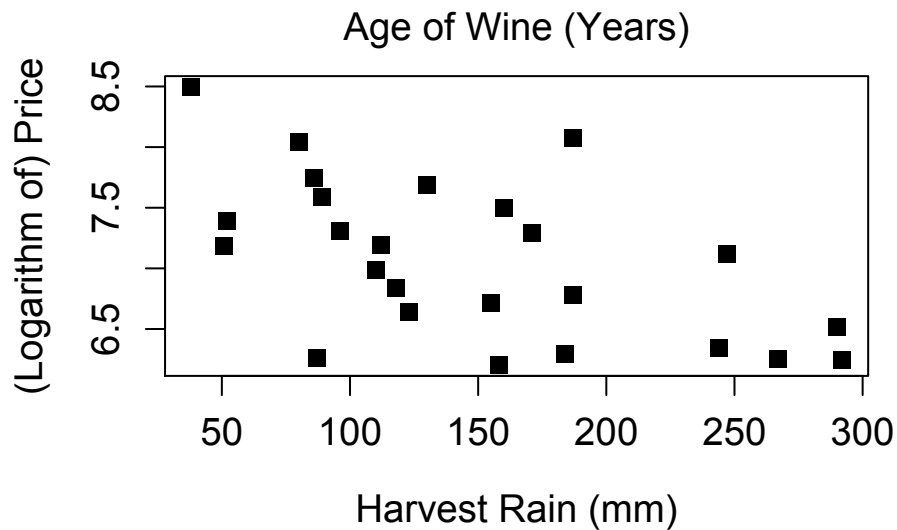
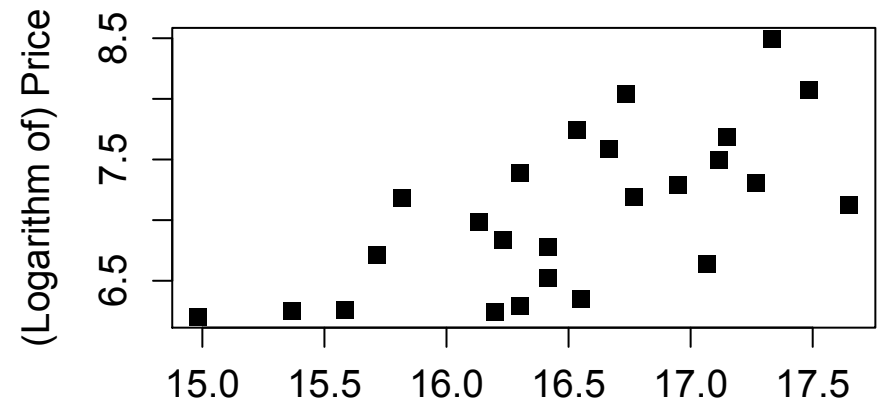
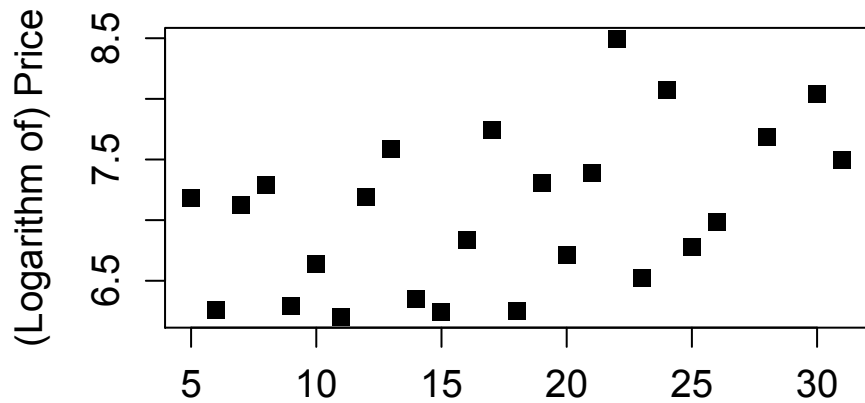
- March 1990 - Orley Ashenfelter, a Princeton economics professor, claims he can predict wine quality without tasting the wine



Building a Model

- Ashenfelter used a method called **linear regression**
 - Predicts an outcome variable, or *dependent variable*
 - Predicts using a set of *independent variables*
- Dependent variable: typical price in 1990-1991 wine auctions (approximates quality)
- Independent variables:
 - Age – older wines are more expensive
 - Weather
 - Average Growing Season Temperature
 - Harvest Rain
 - Winter Rain

The Data (1952 – 1978)

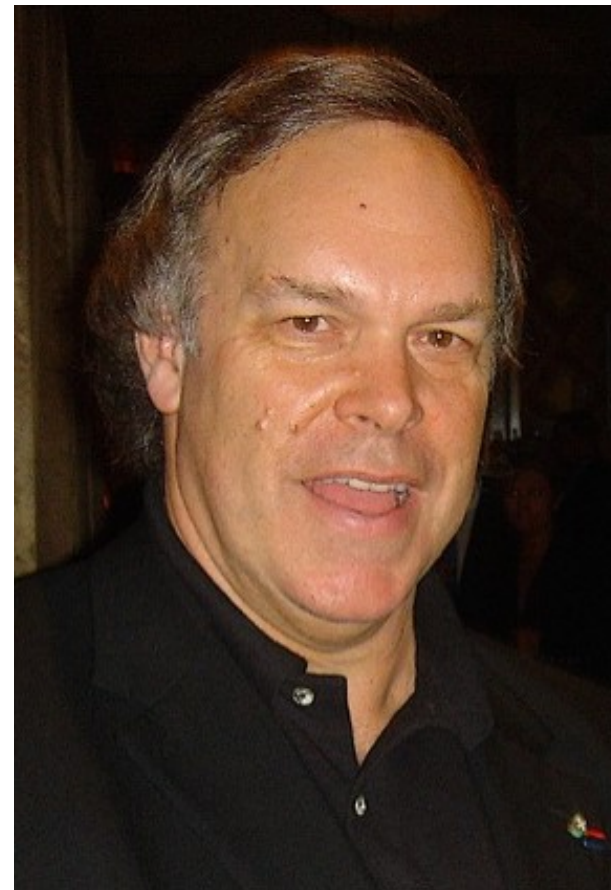


The Expert's Reaction

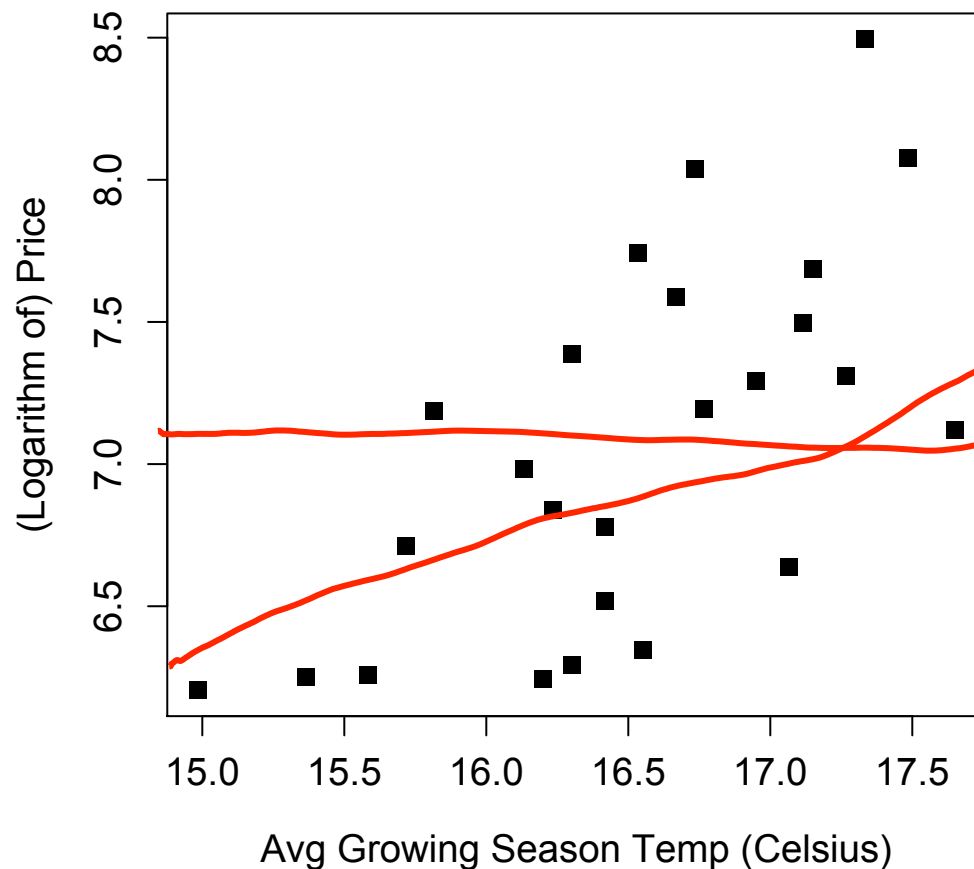
Robert Parker, the world's most influential wine expert:

“Ashenfelter is an absolute total sham”

“rather like a movie critic who never goes to see the movie but tells you how good it is based on the actors and the director”



One-Variable Linear Regression



$$y = 7.07$$

$$y = 0.5(AGST) - 1.25$$

The Regression Model

- One-variable regression model

$$y^i = \beta_0 + \beta_1 x^i + \epsilon^i$$

y^i = dependent variable (wine price) for the i^{th} observation

x^i = independent variable (temperature) for the i^{th} observation

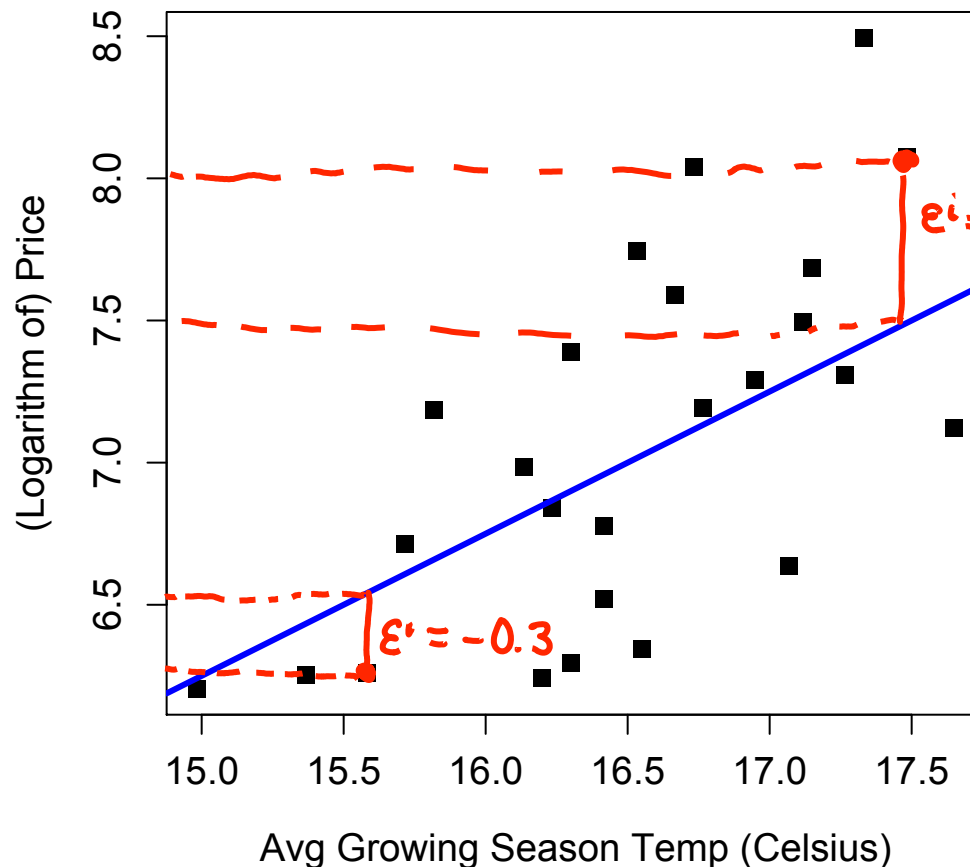
ϵ^i = error term for the i^{th} observation

β_0 = intercept coefficient

β_1 = regression coefficient for the independent variable

- The best model (choice of coefficients) has the smallest error terms

Selecting the Best Model

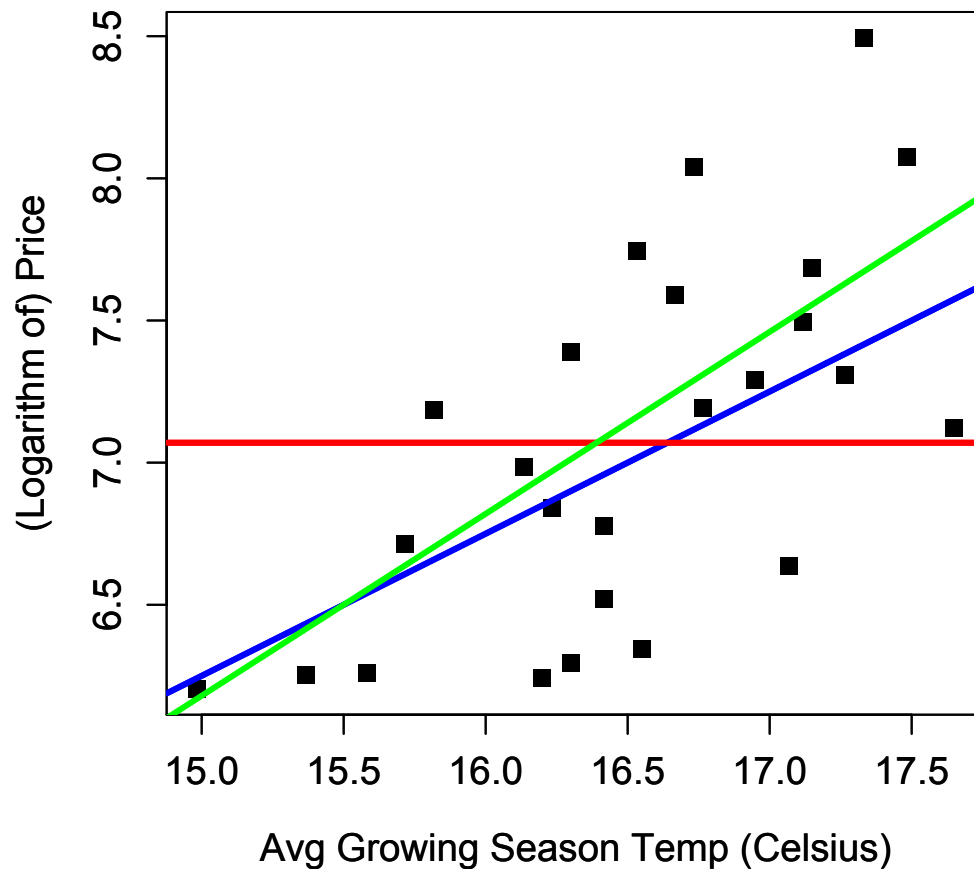


SSE

$$= (\epsilon^1)^2 + (\epsilon^2)^2 + \dots + (\epsilon^N)^2$$

$N = \# \text{data points}$

Selecting the Best Model



$$\text{SSE} = 10.15$$

$$\text{SSE} = 6.03$$

$$\text{SSE} = 5.73$$

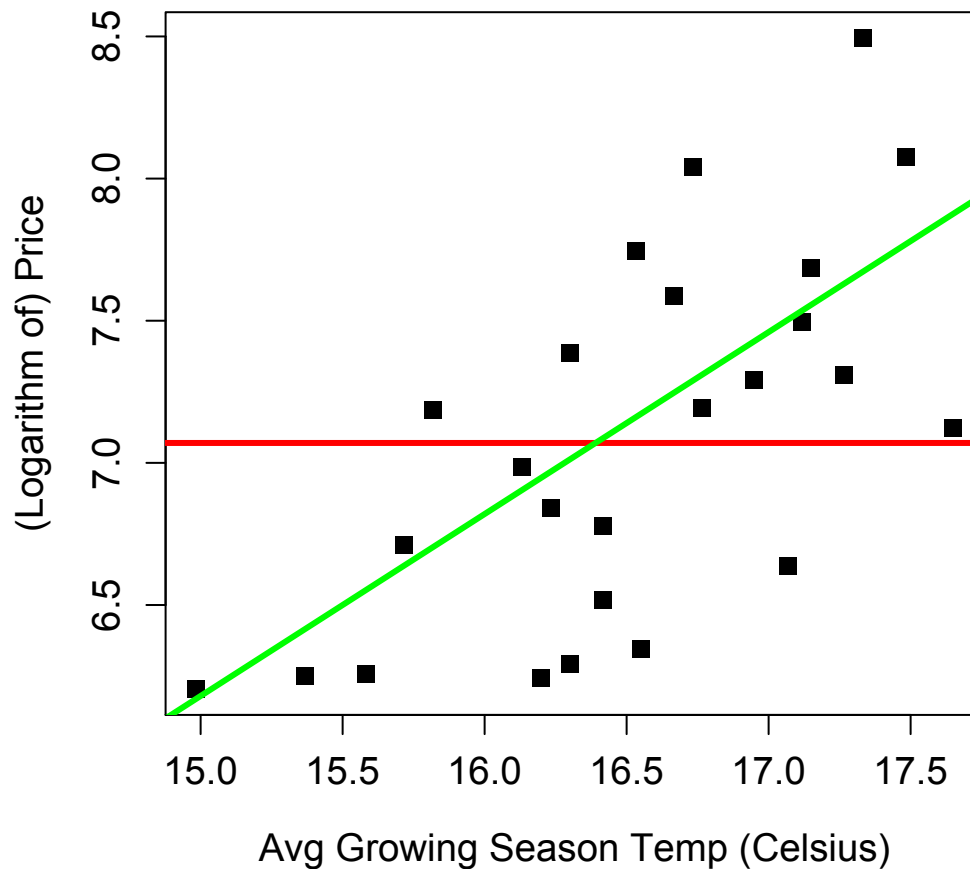
Other Error Measures

- SSE can be hard to interpret
 - Depends on N
 - Units are hard to understand
- Root-Mean-Square Error (RMSE)

$$RMSE = \sqrt{\frac{SSE}{N}}$$

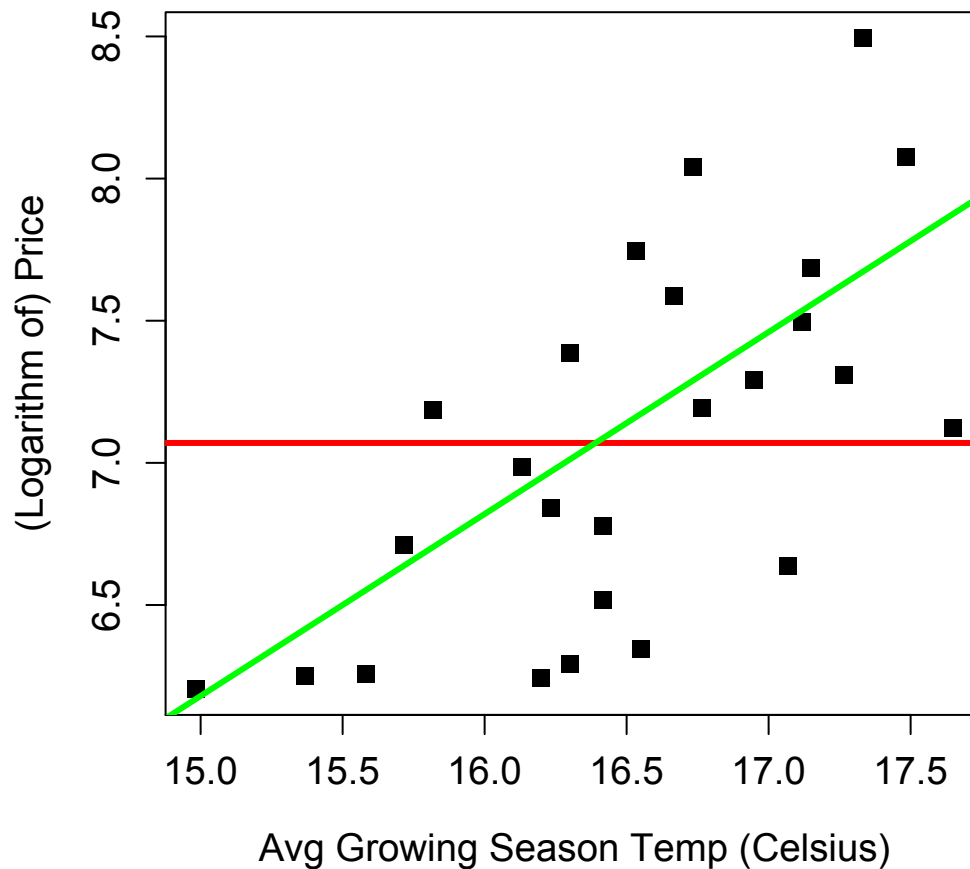
- Normalized by N, units of dependent variable

$$R^2$$



- Compares the best model to a “baseline” model
- The **baseline model** does not use any variables
 - Predicts same outcome (price) regardless of the independent variable (temperature)

R^2



$$SSE = 5.73$$

$$SST = 10.15$$

$$R^2 = 1 - \frac{SSE}{SST}$$

$$= 1 - \frac{5.73}{10.15}$$

$$= 0.44$$

Interpreting R^2

$$R^2 = 1 - \frac{SSE}{SST}$$

$0 \leq SSE \leq SST$
 $0 \leq SST$

- R^2 captures value added from using a model
 - $R^2 = 0$ means no improvement over baseline
 - $R^2 = 1$ means a perfect predictive model
- Unitless and universally interpretable
 - Can still be hard to compare between problems
 - Good models for easy problems will have $R^2 \approx 1$
 - Good models for hard problems can still have $R^2 \approx 0$

Available Independent Variables



- So far, we have only used the Average Growing Season Temperature to predict wine prices
- Many different independent variables could be used
 - Average Growing Season Temperature
 - Harvest Rain
 - Winter Rain
 - Age of Wine (in 1990)
 - Population of France

Multiple Linear Regression

- Using each variable on its own:
 - $R^2 = 0.44$ using Average Growing Season Temperature
 - $R^2 = 0.32$ using Harvest Rain
 - $R^2 = 0.22$ using France Population
 - $R^2 = 0.20$ using Age
 - $R^2 = 0.02$ using Winter Rain
- Multiple linear regression allows us to use all of these variables to improve our predictive ability

The Regression Model

- Multiple linear regression model with k variables

$$y^i = \beta_0 + \beta_1 x_1^i + \beta_2 x_2^i + \dots + \beta_k x_k^i + \epsilon^i$$

y^i = dependent variable (wine price) for the i^{th} observation

x_j^i = j^{th} independent variable for the i^{th} observation

ϵ^i = error term for the i^{th} observation

β_0 = intercept coefficient

β_j = regression coefficient for the j^{th} independent variable

- Best model coefficients selected to minimize SSE

Adding Variables

Variables	R^2
Average Growing Season Temperature (AGST)	0.44
AGST, Harvest Rain	0.71
AGST, Harvest Rain, Age	0.79
AGST, Harvest Rain, Age, Winter Rain	0.83
AGST, Harvest Rain, Age, Winter Rain, Population	0.83

- Adding more variables can improve the model
- Diminishing returns as more variables are added

Selecting Variables

- Not all available variables should be used
 - Each new variable requires more data
 - Causes *overfitting*: high R^2 on data used to create model, but bad performance on unseen data
- We will see later how to appropriately choose variables to remove

Understanding the Model and Coefficients

Coefficients:		<u>Estimate</u> <u>Std. Error</u>		t value	Pr(> t)	
	Estimate	Std. Error				
(Intercept)	-4.504e-01	1.019e+01		-0.044	0.965202	
AvgGrowingSeasonTemp	6.012e-01	1.030e-01		5.836	1.27e-05	***
HarvestRain	-3.958e-03	8.751e-04		-4.523	0.000233	***
Age	5.847e-04	7.900e-02		0.007	0.994172	
WinterRain	1.043e-03	5.310e-04		1.963	0.064416	.
FrancePopulation	-4.953e-05	1.667e-04		-0.297	0.769578	

→ Signif. codes:	0	***	0.001	**	0.01	* 0.05 . 0.1 ' ' 1

Correlation



A measure of the linear relationship between variables

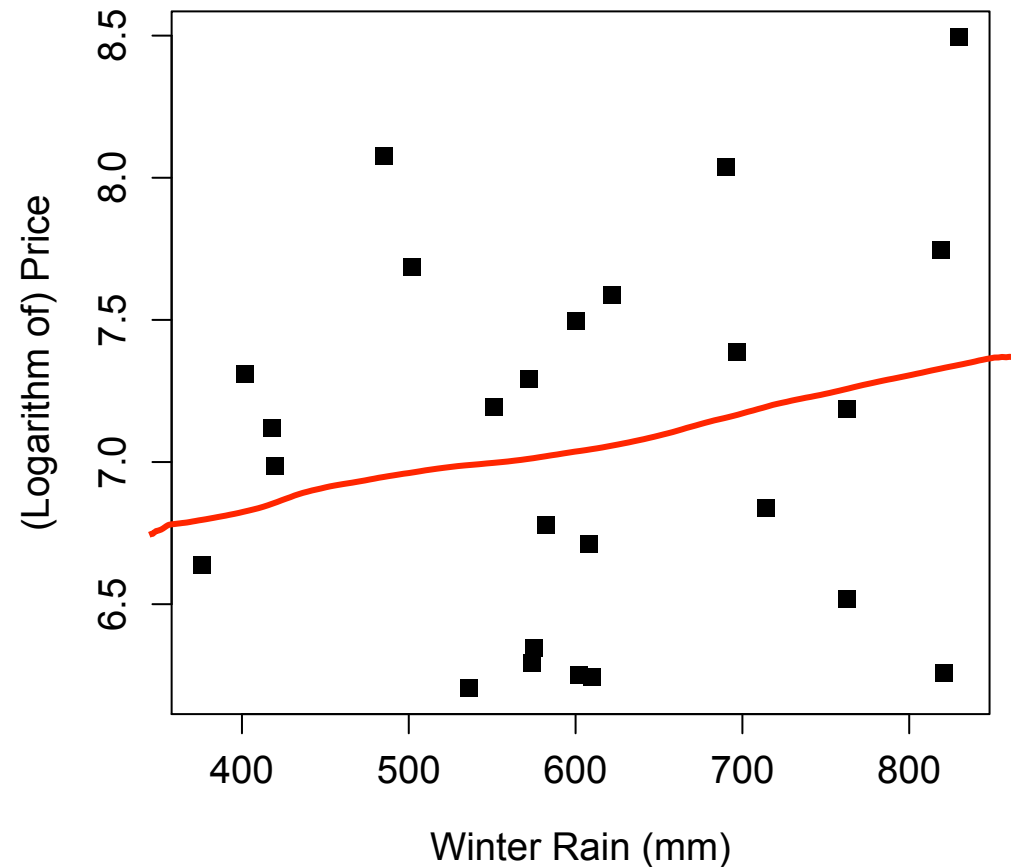
+1 = perfect positive linear relationship

0 = no linear relationship

-1 = perfect negative linear relationship

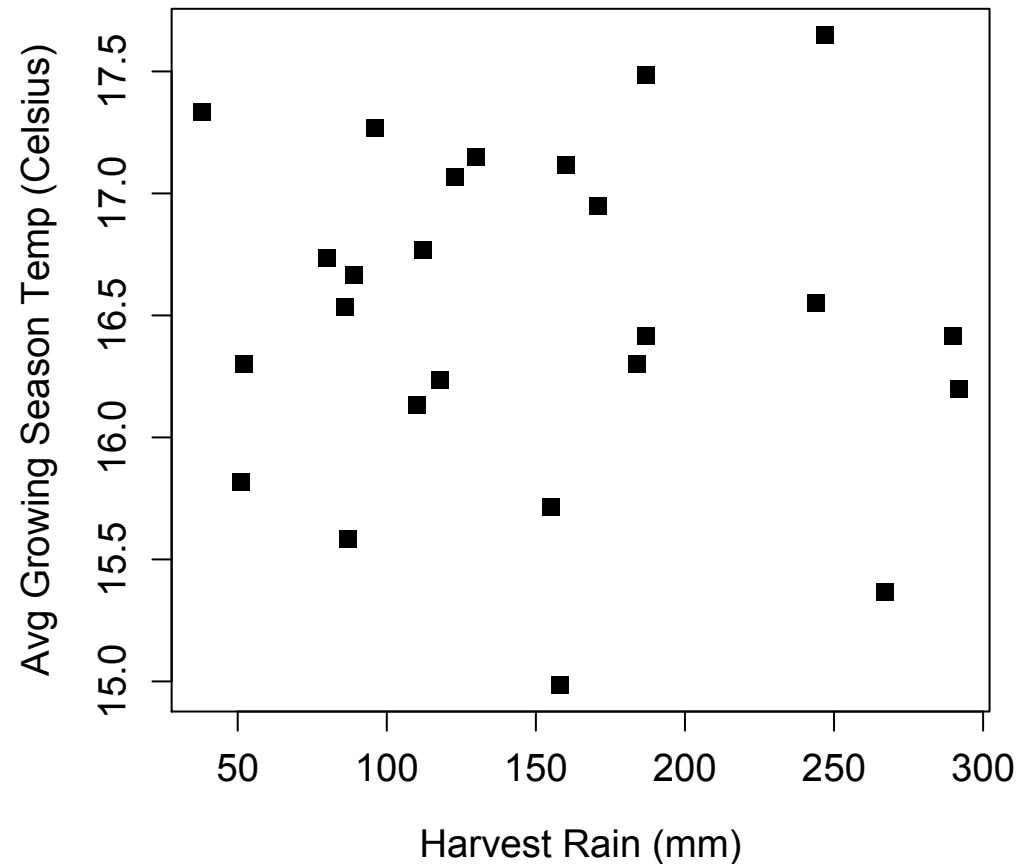
Examples of Correlation

cor
= 0.14

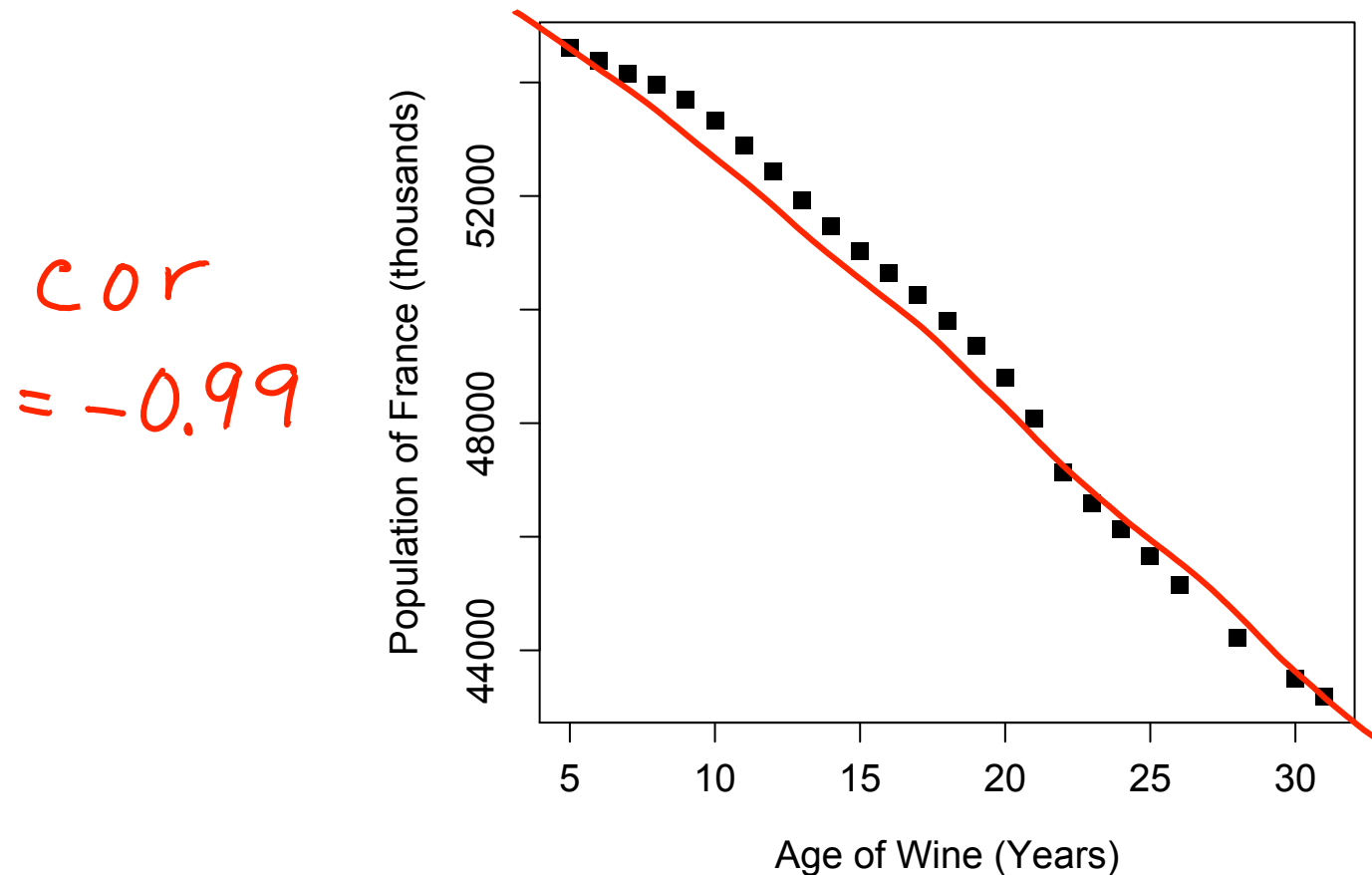


Examples of Correlation

cor
 $= -0.06$



Examples of Correlation



Predictive Ability

- Our wine model had a value of $R^2 = \underline{0.83}$
- Tells us our accuracy on the data that we used to build the model
- out-of-sample*
- But how well does the model perform on new data?
 - Bordeaux wine buyers profit from being able to predict the quality of a wine years before it matures

Out-of-Sample R^2

Variables	Model R^2	Test R^2
Avg Growing Season Temp (AGST)	0.44	0.79
AGST, Harvest Rain	0.71	-0.08
AGST, Harvest Rain, Age	0.79	0.53
AGST, Harvest Rain, Age, Winter Rain	<u>0.83</u>	<u>0.79</u>
AGST, Harvest Rain, Age, Winter Rain, Population	0.83	0.76

- Better model R^2 does not necessarily mean better test set R^2
- Need more data to be conclusive
- Out-of-sample R^2 can be negative!

The Results

- **Parker:**
 - 1986 is “very good to sometimes exceptional”
- **Ashenfelter:**
 - 1986 is mediocre
 - 1989 will be “the wine of the century” and 1990 will be even better!
- In wine auctions,
 - 1989 sold for more than twice the price of 1986
 - 1990 sold for even higher prices!
- Later, Ashenfelter predicted 2000 and 2003 would be great
- Parker has stated that “2000 is the greatest vintage Bordeaux has ever produced”

The Analytics Edge



- A linear regression model with only a few variables can predict wine prices well
- In many cases, outperforms wine experts' opinions
- A quantitative approach to a traditionally qualitative problem