Ch 3.1: More Linear Regression

Lecture 5 - CMSE 381

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Last time:

- Started 3.1 - Simple linear regression (least squares)

Announcements:

- Homework #1 Due Sun, Sep 7
- Homework #2 Due Sun, Sep 14

Covered in this lecture

- Confidence interval, hypothesis test, and p-value for coefficient estimates
- Residual standard error (RSE)
- R squared

Section 1

Last time

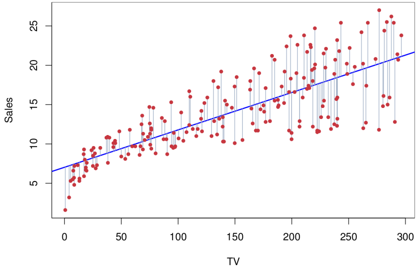
Setup

- Predict Y on a single predictor variable X

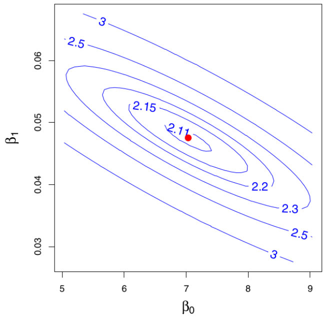
$$Y \approx \beta_0 + \beta_1 X$$

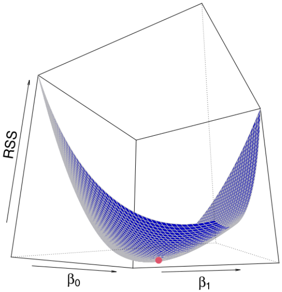
- "$\approx$" .... "is approximately modeled as"

- Given $(x_1, y_1), \cdots, (x_n, y_n)$
- Let $\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_i$ be prediction for Y on ith value of X.
- $e_i = y_i - \hat{y}_i$ is the ith residual



Least squares criterion: RSS





Residual sum of squares RSS is

$$RSS = e_1^2 + \cdots + e_n^2$$
$$= \sum_i (y_i - \hat{\beta}_0 - \hat{\beta}_1 x_i)^2$$

Least squares criterion

Find β_0 and β_1 that minimize the RSS.

$$\hat{\beta}_1 = \frac{\sum_{i=1}^n (x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^n (x_i - \overline{x})^2}$$
$$\hat{\beta}_0 = \overline{y} - \hat{\beta}_1 \overline{x}$$

Section 2

Assessing Coefficient Estimate Accuracy

Bias in estimation

Analogy with mean

- Assume a true value μ^*
- An estimate from training data $\hat{\mu}$
- The estimate is unbiased if $E(\hat{\mu} = \mu^*)$

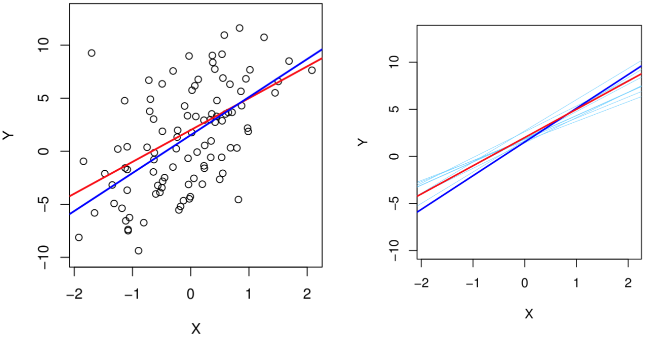
- Sample mean is unbiased for population mean:

$$E(\hat{\mu}) = E\left(\frac{1}{n}\sum_i X_i\right) = \mu$$

- Standard variance estimate is biased

$$E(\hat{\sigma}^2) = E\left[\frac{1}{n}\sum_i (X_i - \overline{X})^2\right] \neq \sigma^2$$

Linear regression is unbiased



Variance in estimation

Continuing analogy with mean

- True value μ^*
- Estimate from training data $\hat{\mu}$
- Variance of sample mean
  $\mathrm{Var}(\hat{\mu}) = \mathrm{SE}(\hat{\mu})^2 = \frac{\sigma^2}{n}$

Variance of linear regression estimates

- Variance of linear regression estimates:

$$\mathrm{SE}(\hat{\beta}_0)^2 = \sigma^2 \left[\frac{1}{n} + \frac{\overline{x}^2}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \right]$$

$$\mathrm{SE}(\hat{\beta}_1)^2 = \frac{\sigma^2}{\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

where $\sigma^2 = \mathrm{Var}(\varepsilon)$

- Residual standard error is an estimate of σ

$$RSE = \sqrt{RSS/(n-2)}$$

Coding group work

Run the section titled “Simulating data”

Confidence Interval

The 95% confidence interval for β_1 approximately takes the form

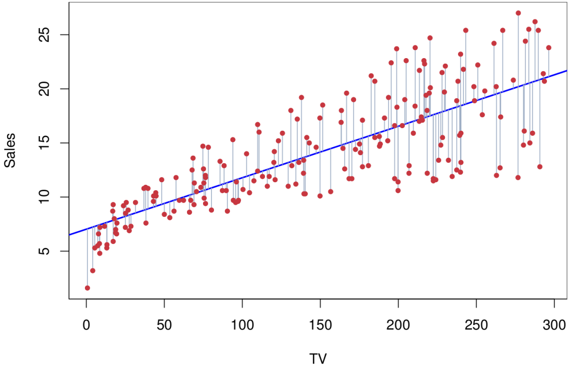
$$\hat{\beta}_1 \pm 2 \cdot \mathrm{SE}(\hat{\beta}_1)$$

Interpretation:
There is approximately a 95% chance that the interval

$$\left[\hat{\beta}_1 - 2 \cdot \mathrm{SE}(\hat{\beta}_1), \hat{\beta}_1 + 2 \cdot \mathrm{SE}(\hat{\beta}_1)\right]$$

will contain β_1 where we repeatedly approximate $\hat{\beta}_1$ using repeated samples.

CI in Advertising data



For the advertising data set, the 95% CIs are:

- β_1 :: $[0.042, 0.053]$
- β_0 :: $[6.130, 7.935]$

Hypothesis testing

H_0: There is no relationship between X and Y

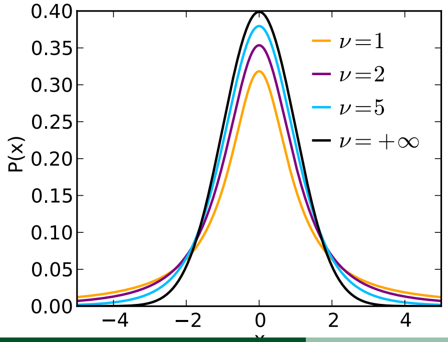
H_1: There is some relationship between X and Y

Test statistic and p-value

Test statistic:

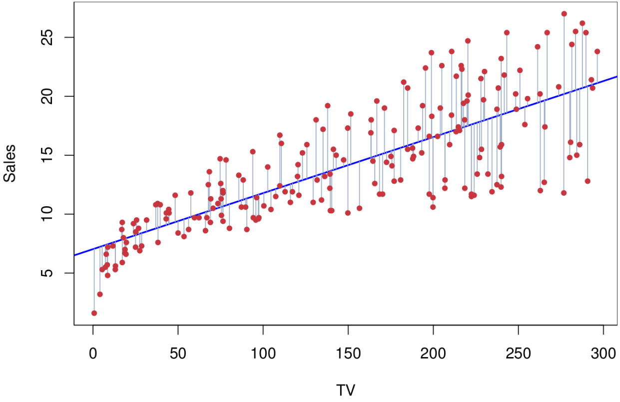
$$t = \frac{\hat{\beta}_1 - 0}{\mathrm{SE}(\hat{\beta}_1)}$$

t-distribution with $n-2$ degrees of freedom



Advertising example

	Coefficient	Std. error	t-statistic	p-value
`Intercept`	7.0325	0.4578	15.36	< 0.0001
`TV`	0.0475	0.0027	17.67	< 0.0001



Assessing the accuracy of the module: RSE

Residual standard error (RSE):

$$
\begin{aligned}
RSE &= \sqrt{\frac{1}{n-2} RSS} \\
&= \sqrt{\frac{1}{n-2} \sum_i (y_i - \hat{y}_i)^2}
\end{aligned}
$$

Assessing the accuracy of the module: R^2

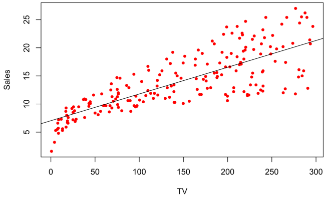
R squared:

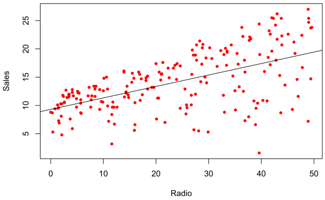
$$R^2 = \frac{TSS - RSS}{TSS} = 1 - \frac{RSS}{TSS}$$

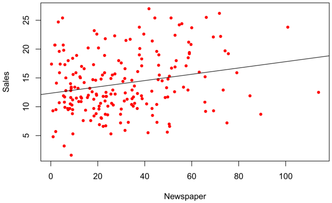
where total sum of squares is

$$TSS = \sum_i (y_i - \overline{y})^2$$

Advertising example







$R^2 = 0.61$ $R^2 = 0.33$ $R^2 = 0.05$

Coding group work

Run the section titled "Assessing Coefficient Estimate Accuracy"

Next time

CMSE381_F2025_Schedule : Schedule

Lec #	Date		Topic	Reading	HW
1	M	8/25	Intro / Python Review	1	
2	W	8/27	What is statistical learning	2.1	
3	F	8.29	Assessing Model Accuracy	2.2.1, 2.2.2	
	M	9/1	Labor Day - No Class		
4	W	9/3	Linear Regression	3.1	
5	F	9/5	More Linear Regression	3.1	HW #1 Due Sun 9/7
6	M	9/8	Multi-linear Regression	3.2	
7	W	9/10	Probably More Linear Regression	3.3	
8	F	9/12	Last of the Linear Regression		HW #2 Due Sun 9/14
9	M	9/15	Intro to classification, Bayes classifier, KNN classifier	2.2.3	
10	W	9/17	Logistic Regression	4.1, 4.2,	

Announcements

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