

Unit 7: Multiple linear regression

3. Transformations & case study

STA 104 - Summer 2017

Duke University, Department of Statistical Science

Prof. van den Boom

<http://www2.stat.duke.edu/courses/Summer17/sta104.001-1/>

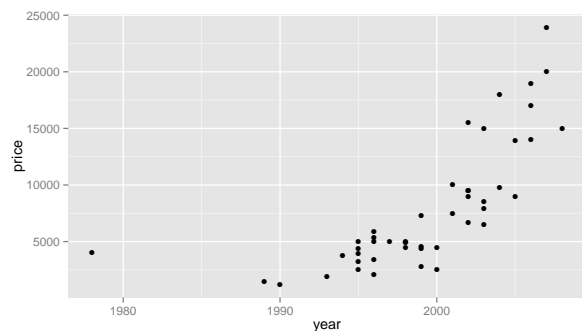
Slides posted at

- ▶ Poster session / project due Monday – during our regular lab time
- ▶ After this deck of slides, lecture are mainly for review for final exam: Bring questions you have or suggest topics you want me to go over.

1

Truck prices

The scatterplot below shows the relationship between year and price of a random sample of 43 pickup trucks. Describe the relationship between these two variables.



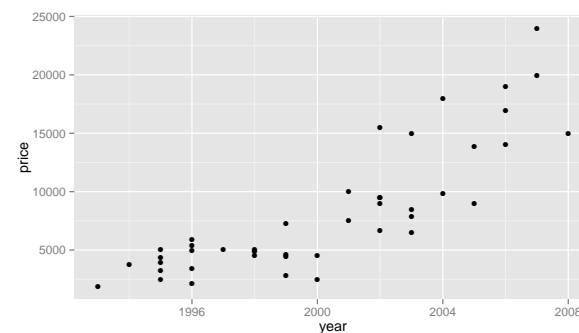
From: <http://faculty.chicagobooth.edu/robert.gramacy/teaching.html>

2

Remove unusual observations

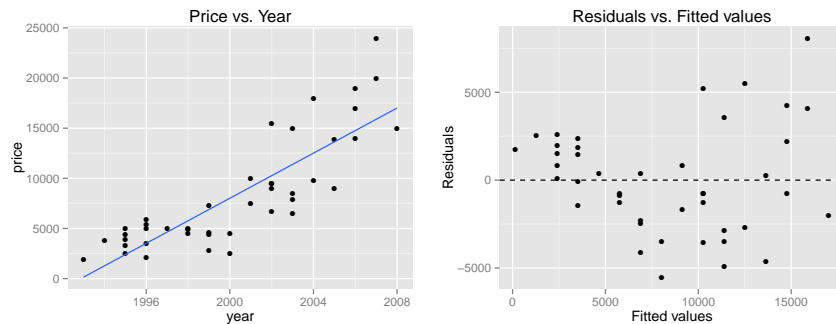
Let's remove trucks older than 20 years, and only focus on trucks made in 1992 or later.

Now what can you say about the relationship?



3

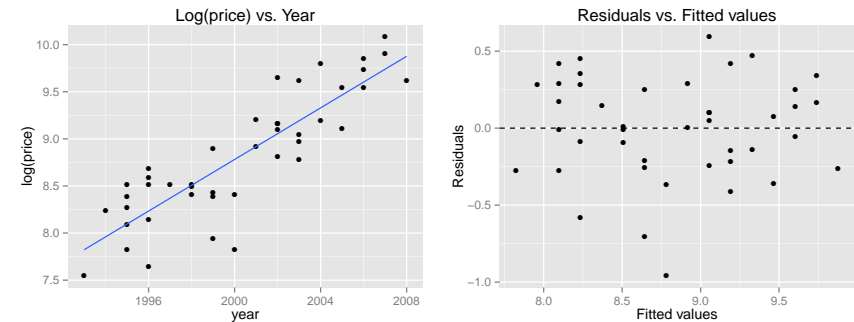
$$\text{Model: } \widehat{\text{price}} = b_0 + b_1 \text{ year}$$



The linear model doesn't appear to be a good fit since the residuals have non-constant variance.

4

$$\text{Model: } \log(\widehat{\text{price}}) = b_0 + b_1 \text{ year}$$



We applied a log transformation to the response variable. The relationship now seems linear, and the residuals no longer have non-constant variance.

5

Interpreting models with log transformation

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	-265.073	25.042	-10.585	0.000
year	0.137	0.013	10.937	0.000

$$\text{Model: } \log(\widehat{\text{price}}) = -265.073 + 0.137 \text{ year}$$

- ▶ For each additional year the car is newer (for each year decrease in car's age) we would expect the log price of the car to increase on average by 0.137 log dollars.
- ▶ which is not very useful...

6

Working with logs

- ▶ Subtraction and logs: $\log(a) - \log(b) = \log\left(\frac{a}{b}\right)$
- ▶ Natural logarithm: $e^{\log(x)} = x$
- ▶ We can use these identities to “undo” the log transformation

7

The slope coefficient for the log transformed model is 0.137, meaning the log price difference between cars that are one year apart is predicted to be 0.14 log dollars.

$$\begin{aligned}\log(\text{price at year } x + 1) - \log(\text{price at year } x) &= 0.137 \\ \log\left(\frac{\text{price at year } x + 1}{\text{price at year } x}\right) &= 0.137 \\ e^{\log\left(\frac{\text{price at year } x + 1}{\text{price at year } x}\right)} &= e^{0.137} \\ \frac{\text{price at year } x + 1}{\text{price at year } x} &= 1.15\end{aligned}$$

For each additional year the car is newer (for each year decrease in car's age) we would expect the price of the car to increase on average *by a factor of 1.15*.

8

- ▶ Non-constant variance is one of the most common model violations, however it is usually fixable by transforming the response (y) variable
- ▶ The most common variance stabilizing transform is the log transformation: $\log(y)$, especially useful when the response variable is (extremely) right skewed.
- ▶ When using a log transformation on the response variable the interpretation of the slope changes:
 - For each unit increase in x, y is expected on average to decrease/increase by a factor of e^{b_1} .
- ▶ Another useful transformation is the square root: \sqrt{y} , especially useful when the response variable is counts.
- ▶ These transformations may also be useful when the relationship is non-linear, but in those cases a polynomial regression may also be needed.

9

Data from the ACS

1. **income**: Yearly income (wages and salaries)
2. **employment**: Employment status, not in labor force, unemployed, or employed
3. **hrs_work**: Weekly hours worked
4. **race**: Race, White, Black, Asian, or other
5. **age**: Age
6. **gender**: gender, male or female
7. **citizens**: Whether respondent is a US citizen or not
8. **time_to_work**: Travel time to work
9. **lang**: Language spoken at home, English or other
10. **married**: Whether respondent is married or not
11. **edu**: Education level, hs or lower, college, or grad
12. **disability**: Whether respondent is disabled or not
13. **birth_qtrtr**: Quarter in which respondent is born, jan thru mar, apr thru jun, jul thru sep, or oct thru dec

10

Load and subset data

```
acs_emp <- acs %>%
  filter(employment == "employed", income > 0)
```

11

```
acs_emp %>%
  select(employment) %>%
  table()
```

```
not in labor force      unemployed      employed
0                      0              787
```

```
acs_emp <- droplevels(acs_emp) # overwrite acs_emp

acs_emp %>%
  select(employment) %>%
  table()
```

```
employed
787
```

12

Suppose we only want to consider the following explanatory variables: hrs_work, race, age, gender, citizen.

```
m_full = lm(income ~ hrs_work + race + age + gender
+ citizen, data = acs_emp)
```

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	-17215.60	11399.81	-1.51	0.13
hrs_work	1251.31	153.14	8.17	0.00
raceblack	-13202.39	6373.05	-2.07	0.04
raceasian	32699.34	8903.66	3.67	0.00
raceother	-12032.88	7556.78	-1.59	0.11
age	760.99	129.71	5.87	0.00
genderfemale	-17246.91	3887.17	-4.44	0.00
citizenyes	-9537.20	8360.85	-1.14	0.25

13

Diagnostics -- code

```
# residuals vs. fitted
qplot(data = m_full, y = .resid, x = .fitted, geom = "point") +
  geom_hline(yintercept = 0, linetype = "dashed") +
  xlab("Fitted values") +
  ylab("Residuals") +
  ggtitle("Residuals vs. Fitted values")

# histogram of residuals
qplot(data = m_full, x = .resid, geom = "histogram") +
  xlab("Residuals") +
  ggtitle("Histogram of residuals")

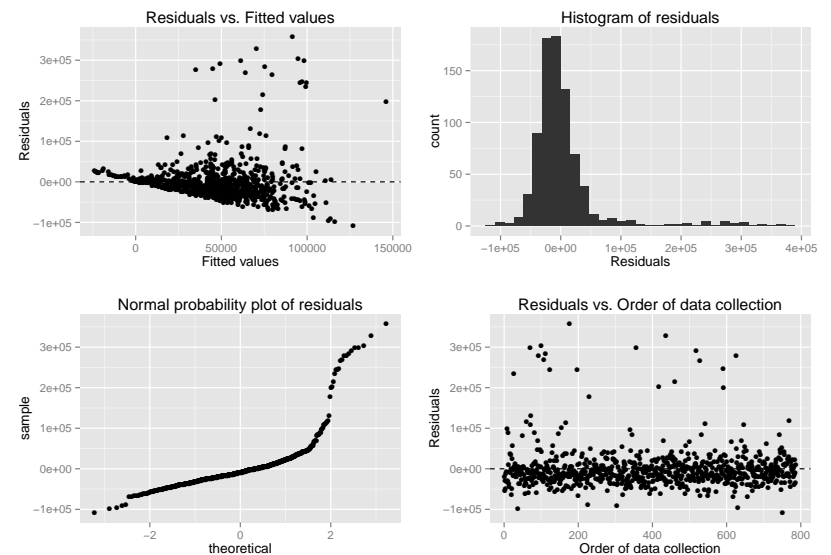
# normal prob plot of residuals
qplot(data = m_full, sample = .resid, stat = "qq") +
  ggtitle("Normal probability plot of residuals")

# order of residuals
qplot(data = m_full, y = .resid) +
  geom_hline(yintercept = 0, linetype = "dashed") +
  ylab("Residuals") +
  xlab("Order of data collection") +
  ggtitle("Residuals vs. Order of data collection")
```

14

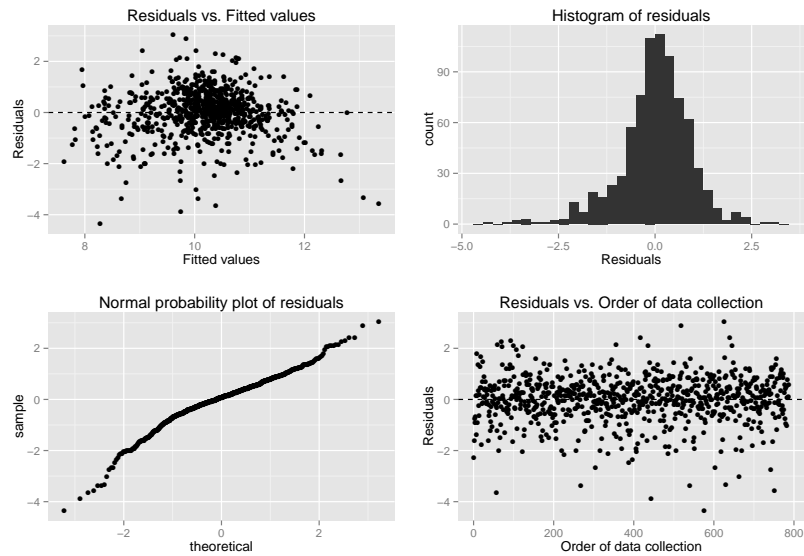
Diagnostics

What do you think?



15

```
m_full_log = lm(log(income) ~ hrs_work + race + age  
+ gender + citizen, data = acs_emp)
```



16

Application exercise: 7.2 Interpreting models with a transformed response

See course website for more details

17