This is an introducton to basic hypothesis testing in R. We have shown that, with a certain set of assumptions, the difference between the OLS estimator and the true parameter vector is distributed normally as shown in expression (2.63):

$$(\mathbf{b} - \beta)|\mathbf{X} \sim N(\mathbf{0},\ \sigma^2 \cdot (\mathbf{X}'\mathbf{X})^{-1})$$

We have also shown that $s^2 = \mathbf{e}'\mathbf{e}/(n-k)$ is an unbiased estimator of σ^2 in Section 2.3.4 of the lecture notes. The purpose of the section is not to rehash the lectures, but instead to use the results to practice indexing in R.

```
data <- read.csv("../data/auto.csv", header=TRUE)
names(data) <- c("price", "mpg", "weight")
y <- matrix(data$price)
X <- cbind(1, data$mpg, data$weight)
```

For reference, consider the regression output, using data we've seen before:

```
res <- lm(price ~ 1 + mpg + weight, data=data)
summary(res)
```

```

Call:
lm(formula = price ~ 1 + mpg + weight, data = data)

Residuals:
   Min     1Q Median     3Q    Max
 -3332  -1858   -504   1256   7507

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 1946.0687  3597.0496   0.541  0.59019
mpg          -49.5122    86.1560  -0.575  0.56732
weight         1.7466     0.6414   2.723  0.00813 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2514 on 71 degrees of freedom
Multiple R-squared: 0.2934,   Adjusted R-squared: 0.2735
F-statistic: 14.74 on 2 and 71 DF,  p-value: 4.425e-06
```

In order to perform individual t-tests, we will first have to identify the standard errors for each coefficient, noting the distribution in (2.63). The variance of the error, σ^2, can be numerically estimated, as shown below:

```
n <- nrow(X); k <- ncol(X)
P <- X %*% solve(t(X) %*% X) %*% t(X)
e <- (diag(n) - P) %*% y
s2 <- t(e) %*% e / (n - k)
print(s2)
```

```
        [,1]
 [1,] 6320340
```

The vector of standard errors matches those reported from R's canned routine `lm()`, which is encouraging.

```
vcov.mat <- as.numeric(s2) * solve(t(X) %*% X)
se <- sqrt(diag(vcov.mat))
print(se)
```

```
[1] 3597.0495988   86.1560389    0.6413538
```

We can now use the vector of standard errors to perform the individual t-tests.

```
b <- solve(t(X) %*% X) %*% t(X) %*% y
apply(b / se, 1, function(t) {2*pt(-abs(t), df=n-k)})
```

```
[1] 0.590188628 0.567323727 0.008129813
```

Great! We have replicated the `Pr(>|t|)` column of the canned output. Now let's try to replicate the full regression F-statistic. This is a joint test of coefficient significance; are the coefficients jointly different from a zero vector? Max has a great description as to why this is different from three separate tests of significance. For now, note that we are testing joint significance by setting

$$\mathbf{R} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \text{and} \quad \mathbf{r} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \tag{1}$$

This is great. This simplifies the hell out of equation (2.81), which is fairly daunting at first:

$$F = \frac{(\mathbf{Rb} - \mathbf{r})'[\mathbf{R}(\mathbf{X}'\mathbf{X})^{-1}\mathbf{R}']^{-1}(\mathbf{Rb} - \mathbf{r})/J}{s^2} = \frac{\mathbf{b}'(\mathbf{X}'\mathbf{X})\mathbf{b}/J}{s^2} \tag{2}$$

```
F <- t(b) %*% (t(X) %*% X) %*% b / (s2*3)
print(F)
```

```
         [,1]
[1,] 158.1714
```

Well shit. This is much larger than the reported F-statistic of 14.74. What happened? The problem is that we also included the intercept, whereas `R` assumes that this shouldn't be included in the joint test. Simplification failed. Let's try again.

```
R <- rbind(c(0, 1, 0), c(0, 0, 1)); J <- 2
select.var <- solve(R %*% solve(t(X) %*% X) %*% t(R))
F <- t(R %*% b) %*% select.var %*% (R %*% b) / (s2 * J)
print(c(F, pf(F, 2, 71, lower.tail=FALSE)))
```

```
[1] 1.473982e+01 4.424878e-06
```

It worked! And the probability of observing the F-statistic with degrees of freedom $J = 2$ and $n - k = 71$ is printed as well.