Stationarity and Cointegration of Vegetable Oils

FRE530 Assignment 1 (12.5 points)
Due in Canvas *before* midnight (11:59pm) on xx

1 Background

This assignment has three main objectives: (1) reinforce the time series topics covered in class, (2) build your intuition about time series in economics within the FRE sector, and (3) build your R toolkit.

In the labs, we have been exploring the linkage between diesel prices and soybean oil. In this assignment, you will explore the linkage between 3 vegetable oils - palm oil, soybean oil, and rapeseed oil. You will submit the rendered PDF or html file that includes your codes, output, and answers.

2 Data Download and Cleaning (1 point)

- Download the World Bank Commodity Markets "Pink Sheet" Data (Monthly Prices, XLS) here
- You may find the following packages useful to conduct the cleaning and analysis: `pacman::p_load(here, readxl, dplyr, janitor, xts, lubridate, urca, forecast)`.
- Using `read_excel()`, load the Commodity Price Data and call this object `cmo`. *Hint: You can add `skip = 4, na = ".."` to skip the first four lines and ask R to read ".." as missing. You can also use the `clean_names()` function right away to fix the variable names.*
  - If you used `clean_names()`, rename `x1` to `date`
  - Use the `dplyr::select()` function to select the following columns only: `date, palm_oil, soybean_oil, rapeseed_oil`.
  - Use `filter()` to keep only the non-missing data for `date` and `rapeseed_oil`
  - You will notice that the date is stored as YYYYM01 format. R needs "a day", as in 1 for January 1, for a year-month date to be recognize as a date. Use `mutate(date = as.Date(paste0(date, "01"), "%YM%m%d"))` to recode the current `date` column into a date format that R can recognize.
  - Use `filter()` to keep only observations from January 1, 2003 to December 1, 2020, inclusive.
  - Use `mutate()` to take the natural log of each price series. Name these columns `lnpalm`, `lnsoy`, and `lnrapeseed`, respectively.
- Use `xts()` to create a new time series object called `vegoils`. This object should only contain `lnpalm`, `lnsoy`, and `lnrapeseed`.
- The first 5 rows of your `vegoils` dataframe should match the output below.

```
##              lnpalm    lnsoy lnrapeseed
## 2003-01-01 6.186435 6.292902   6.435702
## 2003-02-01 6.167412 6.258491   6.372910
## 2003-03-01 6.117106 6.258663   6.313403
## 2003-04-01 6.093615 6.293234   6.322960
## 2003-05-01 6.117701 6.308536   6.408809
```

```
## [1] "xts" "zoo"
```

3 Testing for Stationarity (8 points)

a) Perform a Dickey-Fuller (DF) test (i.e., no constant, no trend, no lags) to determine whether each price series is stationary or not. Be clear and concise in explaining how you concluded whether the price series is stationary or not. To be clear, you will do 3 separate tests; all tests are done with log prices. (2 point)

b) In recent years, an Augmented Dickey Fuller (ADF) test has been developed to account for potential autocorrelation in the residuals.

- Use a partial autocorrelation plot and the `selectlags()` function to explain how many lag terms you would include your ADF test **for log soybean oil prices only**. (1 point).
- Follow the Stationarity Testing flow chart to test for the stationarity of **log soybean oil prices only**. Use the same number of lags in these tests based on your previous answer. Make sure you explain what the different test statistics mean per specification when you discuss your results. (2 points)
- In 2-3 sentences, explain why it is important to go through the flow chart and use different specifications of the ADF test when testing for stationarity. (1 point)

c) Perform an ADF test whether the first difference of each log price series is stationary or not. For each ADF test, control for autocorrelation by using 4 lags for palm, 1 lag for soybean oil, and 1 lag for rapeseed oil. Discuss your ADF test results. In your answers, briefly explain why it would have been acceptable to begin the flow chart at stage 3 rather than stage 1 (i.e., omit testing for a unit root in the presence of a time trend). *Hint: Think about what happens to a time trend when you take a first difference. Also, compare plots of your data with and without differencing.* (1 point)

d) In 1-2 sentences, explain why we took the first difference of each price series and conducted an ADF test on the first difference? (1 point)

Suggested Answers

a) DF tests:

- DF_{palm}: t-statistic is 0.735 and the critical values are -2.58, -1.95, -1.62. We fail to reject the null hypothesis of a unit root. Palm price is not stationary.
- DF_{soy}: t-statistic is 0.855 and the critical values are -2.58, -1.95, -1.62. We fail to reject the null hypothesis of a unit root at any significance level. Soybean oil price is not stationary.
- $DF_{rapeseed}$: t-statistic is 0.754 and the critical values are -2.58, -1.95, -1.62. We fail to reject the null hypothesis of a unit root at any significance level. Rapeseed price is not stationary.

b) ADF tests:

- Visual inspection of the partial autocorrelation plot suggests we include two lags to the ADF test of soybeans. Only 1 lag is included in the final specification if we select lags based on the lowest AIC. The answers below only include 1 lag in the ADF tests.
- The first step is to use the specification `type = c("trend")` in R. Since the τ_3 test statistic is -2.361 and the critical values are -3.99, -3.43, -3.13, we fail to reject the null hypothesis of a unit root.
- The next step looks at the significance of the trend term. The test statistic of ϕ_3 is 2.871 and the critical values are 8.43, 6.49, 5.47, so we fail to reject the joint null hypothesis of no unit root and trend.
- We now specify the ADF test to include the constant term only, i.e. use the `type = c("drift")` specification. The τ_2 test statistic is -2.384 and the critical values are 6.52, 4.63, 3.81, so we fail to reject the null hypothesis of a unit root, which is consistent with our earlier finding. The ϕ_2 test statistic is 3.069 and the critical values are 6.52, 4.63, 3.81, so we fail to reject the null hypothesis of a significant constant term.

- Finally, we just estimate the model without any trend or drift terms. The τ_1 test statistic is 0.572 and the critical values are -2.58, -1.95, -1.62, so we fail to reject the null hypothesis of a unit root.

- The different specifications of the ADF test confirm that log soybean oil price has a unit root and is therefore non-stationary.

- It is important to go through the different specifications to ensure that we do not incorrectly reject the unit root hypothesis and conclude the data is stationary when it is not. The converse is also true. If one applies linear regression models to non-stationary data because of an incorrectly specified ADF test, one will get spurious results.

c) In the ADF test of the first difference of palm oil, soybean oil, and rapeseed oil, the τ_1 test statistics are -6.3078, -7.6416, -8.5303, respectively. The critical values are -2.58, -1.95, -1.62. We reject the null hypothesis of a unit root for each of the price series and conclude that each price series is integrated of the order 1. While it is acceptable to go through the full flow chart exercise for the first difference, it is simply not required because the time trend has been eliminated through differences. The conclusion that the first difference of the price series is stationary remains the same, with or without going through steps 1 and 2.

d) As noted in the lectures and readings, one method to make a non-stationary time series stationary is to take the first difference, as it helps stabilize the time series by reducing trend and seasonality. We conducted an ADF test on the first difference of each price series because we need the price series to be integrated of the same order before we can proceed with the test for cointegration.

4 Testing for Cointegration (3.5 points)

- Use the 2-step Engle-Granger test to determine if palm-soybean, palm-rapeseed, soybean-rapeseed are cointegrated or not. As we have done in the labs, do not add trend or drift terms to the second stage of the ADF test on residuals. For this part, specify `lags = 0` for the second stage ADF test on residuals. Use the `englegranger()` function we used in the lab to determine the appropriate critical values for the ADF test on residuals. Discuss your results. (1 points)

- Do the Step 2 of Engle-Granger test again but now add lags to your ADF test specification. Specifically, add 1 lag to palm-soybean, 2 lags to soybean-rapeseed, and 2 lags to soybean-rapeseed. Discuss your results and the importance of lag length selection in conducting the ADF test on residuals. (1.5 points)

- In a few sentences, explain why certain countries are interested in determining whether there exists a cointegrating relationship among vegetable oils, and why? (1 point)

Suggested Answers

- With `var = 2, trend = 0, n = 215`, the critical values are `-3.949745`, `-3.365648`, `-3.06525`, at the 1%, 5%, and 10%, respectively.

- Palm-Soy: When we do not control for autocorrelation, the t-statistic is -3.8729. Compared to the critical values provided, we can only reject the null hypothesis of a unit root at the 5% level. When we add 1 lag to the model to control for autocorrelation, the t-statistic is -5.11, so we reject the null hypothesis of a unit root at the 1% level. We have evidence that palm and soy are cointegrated.

- Palm-Rapeseed: When we do not control for autocorrelation, the t-statistic is -3.1712. Compared to the critical values provided, we can only reject the null hypothesis at the 10% level. When we add 2 lags to the model to control for autocorrelation, the t-statistic is -3.7066, so we reject the null hypothesis of a unit root at the 5% level. We have weak evidence that palm and rapeseed are cointegrated.

- Soy-Rapeseed: When we do not control for autocorrelation, the t-statistic is -3.5813. Compared to the critical values provided, we can only reject the null hypothesis at the 5% level. When we add 2 lags to the model to control for autocorrelation, the t-statistic is -2.9199, we fail to reject the null hypothesis of a unit root at any significance level. We have conflicting evidence that soy and rapeseed are cointegrated.

- Based from this exercise, we observe that conclusions about cointegration are sensitive to the selection of the number of lags to include in the test. For example, soy and rapeseed appear to the cointegrated at the 5% level when no lags were included, but does not appear to be cointegrated when lags were included.
- Some countries such as Indonesia and Malaysia are big producers of palm oil. For example, 4.5% of Indonesia's GDP comes from palm oil (UNDP). If there is a shock to palm oil prices, Indonesia's welfare may be affected, so it it is important from a public policy perspective to investigate if the price of palm oil continues to be impacted by other vegetable oils. For example, if the Indonesian government observes more volatile soybean oil prices, they may start thinking about policies to help producers of palm oil.

5 Code and Output

5.1 Data Cleaning

```
cmo <- read_excel(here("data", "CMO-Historical-Data-Monthly.xlsx"),
                  sheet = "Monthly Prices", skip = 4, na = "..") %>%
  clean_names()

cmo <- cmo %>%
  rename(date = x1) %>%
  dplyr::select(date, palm_oil, soybean_oil, rapeseed_oil) %>%
  filter(!is.na(date) & !is.na(rapeseed_oil)) %>%
  mutate(date = as.Date(paste0(date, "01"), "%YM%m%d")) %>%
  filter(date >= "2003-01-01" & date <= "2020-12-01") %>%
  mutate(lnpalm = log(as.numeric(palm_oil)),
         lnsoy = log(as.numeric(soybean_oil)),
         lnrapeseed = log(as.numeric(rapeseed_oil)))

# saveRDS(cmo, here("data", "vegoils.RDS"))

vegoils <- xts(cmo[,c("lnpalm", "lnsoy", "lnrapeseed")], order.by = cmo$date)
```

5.2 Testing for Stationarity

```
# a
df_palm <- ur.df(vegoils$lnpalm, type = c("none"), lags = 0)
df_soy <- ur.df(vegoils$lnsoy, type = c("none"), lags = 0)
df_rapeseed <- ur.df(vegoils$lnrapeseed, type = c("none"), lags = 0)

summary(df_soy)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.245266 -0.027247 -0.001851  0.030113  0.121865
##
## Coefficients:
##          Estimate Std. Error t value Pr(>|t|)
## z.lag.1 0.0004100  0.0004796   0.855    0.394
##
## Residual standard error: 0.04735 on 214 degrees of freedom
## Multiple R-squared:  0.003404,   Adjusted R-squared:  -0.001253
```

```
## F-statistic: 0.7308 on 1 and 214 DF,  p-value: 0.3936
##
##
## Value of test-statistic is: 0.8549
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

```
summary(df_palm)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.264998 -0.031463  0.000374  0.031544  0.188192
##
## Coefficients:
##          Estimate Std. Error t value Pr(>|t|)
## z.lag.1 0.0004741  0.0006446   0.735    0.463
##
## Residual standard error: 0.06224 on 214 degrees of freedom
## Multiple R-squared:  0.002521,   Adjusted R-squared:  -0.00214
## F-statistic: 0.5408 on 1 and 214 DF,  p-value: 0.4629
##
##
## Value of test-statistic is: 0.7354
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

```
summary(df_rapeseed)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1)
##
## Residuals:
```

```
##       Min        1Q    Median        3Q       Max
## -0.176404 -0.028815  0.000478  0.032060  0.129314
##
## Coefficients:
##          Estimate Std. Error t value Pr(>|t|)
## z.lag.1 0.0003577  0.0004741   0.754    0.451
##
## Residual standard error: 0.04728 on 214 degrees of freedom
## Multiple R-squared:  0.002652,   Adjusted R-squared:  -0.002008
## F-statistic: 0.5691 on 1 and 214 DF,  p-value: 0.4514
##
##
## Value of test-statistic is: 0.7544
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

```
# b
adf_soy <- ur.df(vegoils$lnsoy, type = c("none"), lags = 2, selectlags = c("AIC"))
summary(adf_soy)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1 + z.diff.lag)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.199480 -0.022503 -0.002604  0.022678  0.111788
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## z.lag.1    0.0002394  0.0004365   0.548    0.584
## z.diff.lag 0.4381492  0.0621114   7.054 2.45e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.04283 on 211 degrees of freedom
## Multiple R-squared:  0.1939, Adjusted R-squared:  0.1863
## F-statistic: 25.38 on 2 and 211 DF,  p-value: 1.326e-10
##
##
## Value of test-statistic is: 0.5484
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

```r
adf_soy_trend <- ur.df(vegoils$lnsoy, type = c("trend"), lags = 1)
summary(adf_soy_trend)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression trend
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 + 1 + tt + z.diff.lag)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.188763 -0.026225 -0.002532  0.025345  0.114819
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.783e-01  7.404e-02   2.408   0.0169 *
## z.lag.1     -2.644e-02  1.120e-02  -2.361   0.0192 *
## tt           1.435e-05  4.905e-05   0.293   0.7701
## z.diff.lag   4.463e-01  6.157e-02   7.250 7.87e-12 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.04236 on 210 degrees of freedom
## Multiple R-squared:  0.2119, Adjusted R-squared:  0.2007
## F-statistic: 18.83 on 3 and 210 DF,  p-value: 7.476e-11
##
##
## Value of test-statistic is: -2.3607 2.0654 2.8713
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau3 -3.99 -3.43 -3.13
## phi2  6.22  4.75  4.07
## phi3  8.43  6.49  5.47
```

```r
adf_soy_drift <- ur.df(vegoils$lnsoy, type = c("drift"), lags = 1)
summary(adf_soy_drift)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression drift
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 + 1 + z.diff.lag)
##
## Residuals:
```

```
##       Min        1Q    Median        3Q       Max
## -0.189801 -0.025837 -0.002744  0.026142  0.113952
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.17343    0.07200   2.409   0.0169 *
## z.lag.1     -0.02548    0.01069  -2.384   0.0180 *
## z.diff.lag   0.44512    0.06129   7.262 7.22e-12 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.04227 on 211 degrees of freedom
## Multiple R-squared:  0.2116, Adjusted R-squared:  0.2041
## F-statistic: 28.32 on 2 and 211 DF,  p-value: 1.275e-11
##
##
## Value of test-statistic is: -2.3836 3.0687
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau2 -3.46 -2.88 -2.57
## phi1  6.52  4.63  3.81
```

```
adf_soy_lag <- ur.df(vegoils$lnsoy, type = c("none"), lags = 1)
summary(adf_soy_lag)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1 + z.diff.lag)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.199655 -0.022442 -0.002208  0.022348  0.111679
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## z.lag.1    0.0002487  0.0004346   0.572    0.568
## z.diff.lag 0.4370807  0.0618901   7.062 2.31e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.04274 on 212 degrees of freedom
## Multiple R-squared:  0.1935, Adjusted R-squared:  0.1859
## F-statistic: 25.44 on 2 and 212 DF,  p-value: 1.253e-10
##
##
## Value of test-statistic is: 0.5723
##
## Critical values for test statistics:
```

```
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

```r
# c
adf_palm_diff <- ur.df(diff.xts(vegoils$lnpalm, na.pad = F), type = c("none"), lags = 4)
summary(adf_palm_diff)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1 + z.diff.lag)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.216730 -0.032589  0.003165  0.032271  0.180101
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## z.lag.1     -0.67451    0.10693  -6.308 1.71e-09 ***
## z.diff.lag1  0.16835    0.10393   1.620  0.10679
## z.diff.lag2  0.01526    0.09144   0.167  0.86759
## z.diff.lag3 -0.01826    0.07832  -0.233  0.81592
## z.diff.lag4  0.19860    0.06937   2.863  0.00463 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.05571 on 205 degrees of freedom
## Multiple R-squared:  0.3459, Adjusted R-squared:   0.33
## F-statistic: 21.69 on 5 and 205 DF,  p-value: < 2.2e-16
##
##
## Value of test-statistic is: -6.3078
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

```r
adf_soy_diff <- ur.df(diff.xts(vegoils$lnsoy, na.pad = F), type = c("none"), lags = 1)
summary(adf_soy_diff)
```

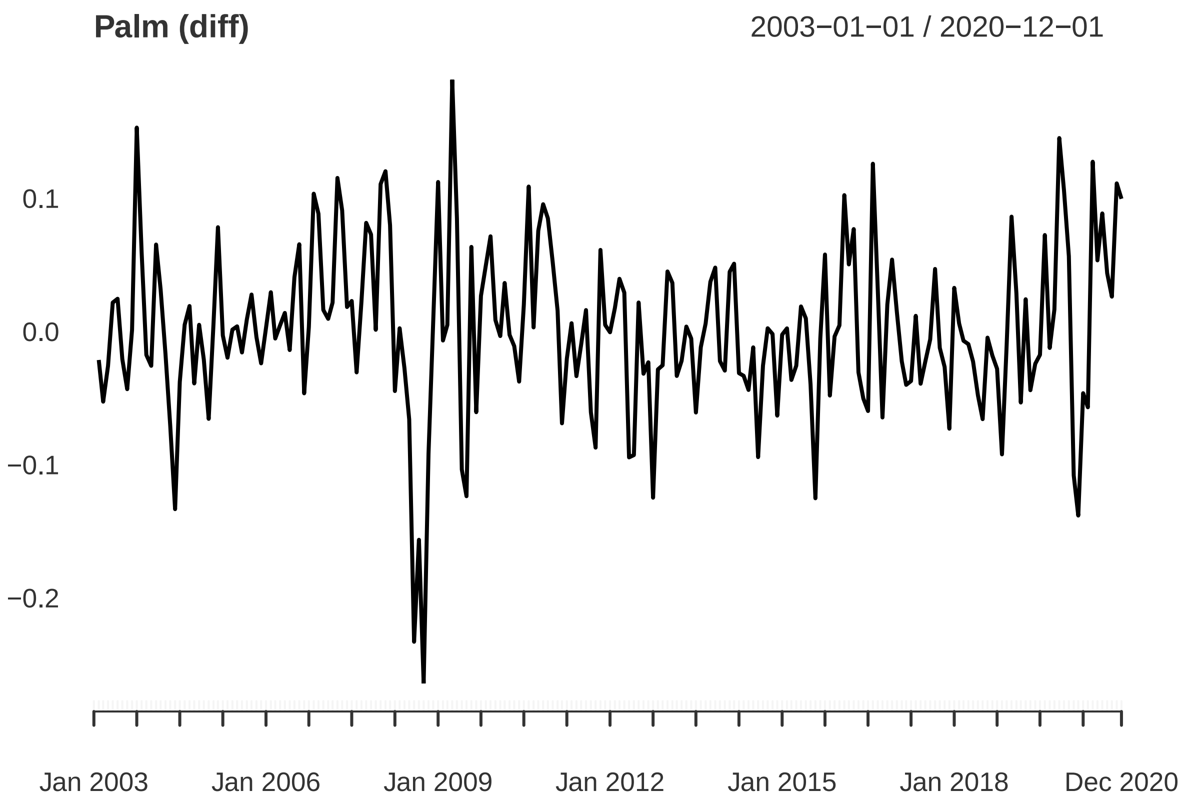
```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
```

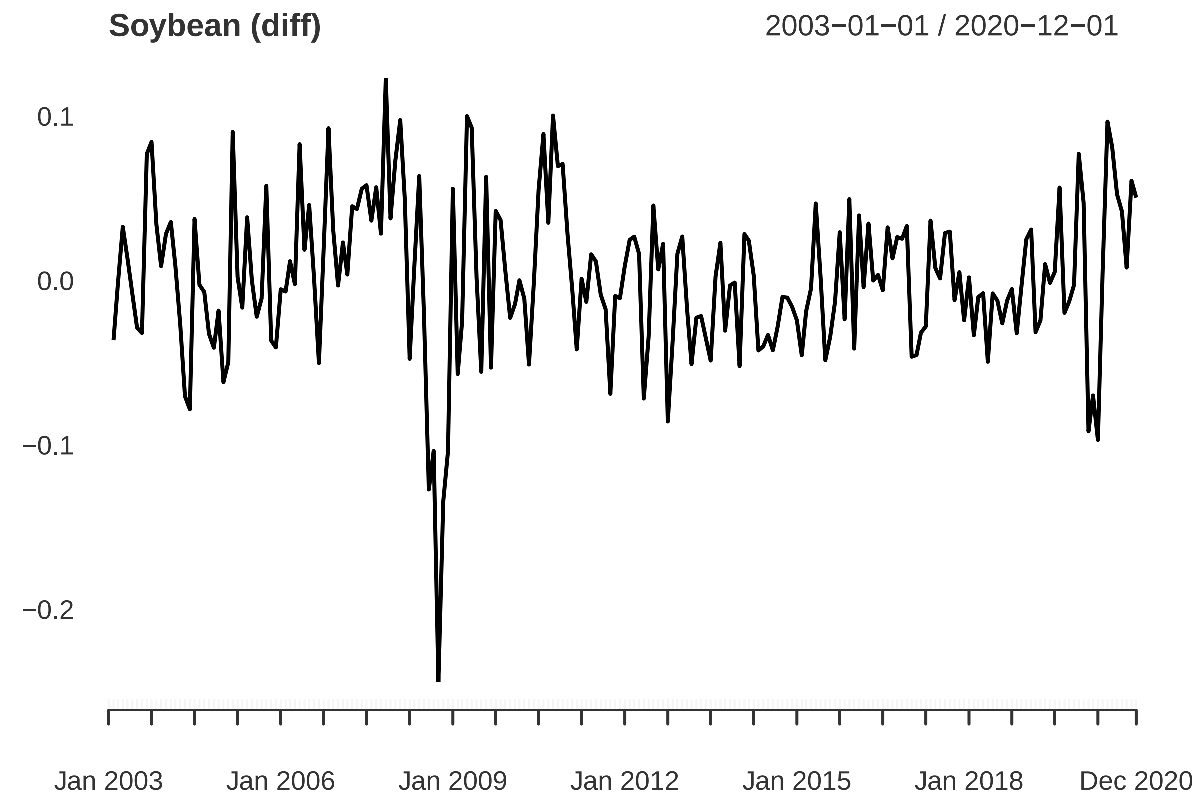
```
## lm(formula = z.diff ~ z.lag.1 - 1 + z.diff.lag)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.197673 -0.020938 -0.000968  0.024162  0.113323
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## z.lag.1    -0.560455   0.073343  -7.642 7.42e-13 ***
## z.diff.lag  0.001369   0.069075   0.020    0.984
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.04286 on 211 degrees of freedom
## Multiple R-squared:  0.2784, Adjusted R-squared:  0.2716
## F-statistic: 40.71 on 2 and 211 DF,  p-value: 1.12e-15
##
##
## Value of test-statistic is: -7.6416
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

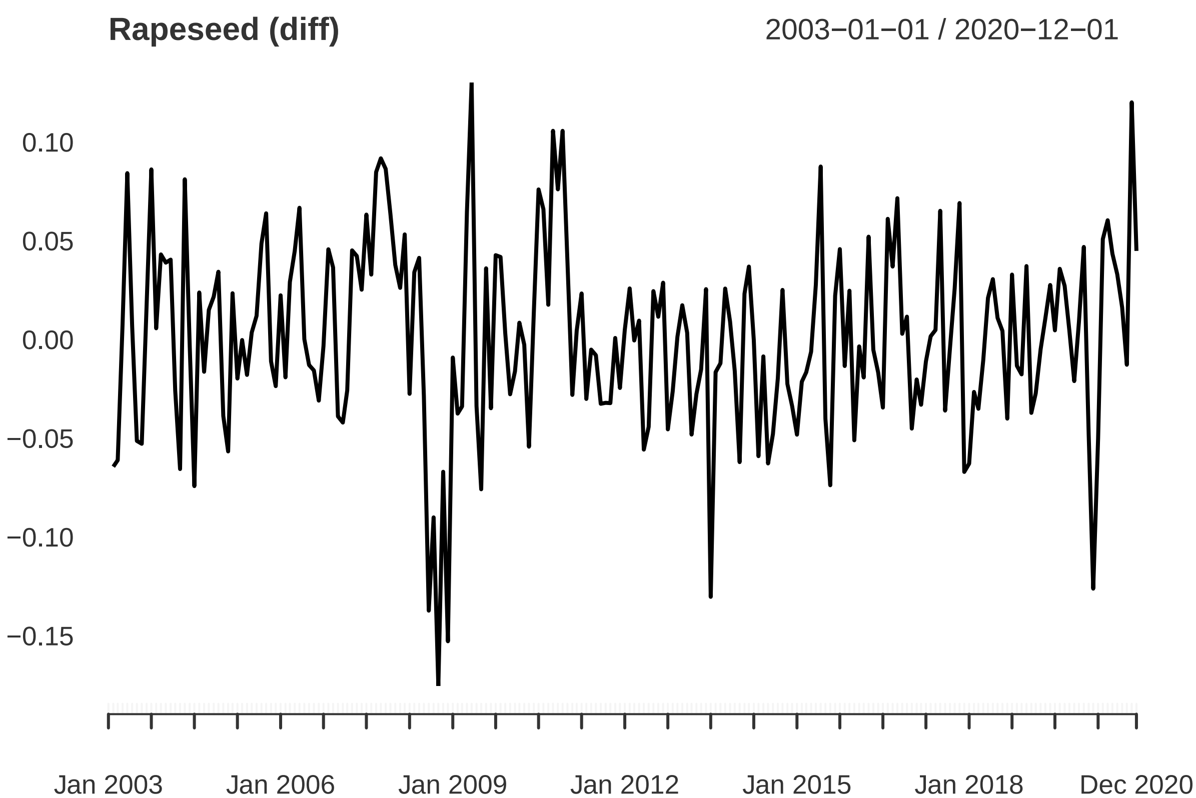
```
adf_rapeseed_diff <- ur.df(diff.xts(vegoils$lnrapeseed, na.pad = F), type = c("none"), lags = 1)
summary(adf_rapeseed_diff)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1 + z.diff.lag)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.146443 -0.025392  0.002477  0.031108  0.126322
##
## Coefficients:
##            Estimate Std. Error t value Pr(>|t|)
## z.lag.1    -0.67262    0.07885  -8.530 2.84e-15 ***
## z.diff.lag  0.03279    0.06949   0.472    0.637
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.0443 on 211 degrees of freedom
## Multiple R-squared:  0.327,  Adjusted R-squared:  0.3206
## F-statistic: 51.26 on 2 and 211 DF,  p-value: < 2.2e-16
##
##
## Value of test-statistic is: -8.5303
##
```

```
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```




Soybean (diff)
2003−01−01 / 2020−12−01
0.1
0.0
−0.1
−0.2
Jan 2003
Jan 2006
Jan 2009
Jan 2012
Jan 2015
Jan 2018
Dec 2020


Rapeseed (diff)
2003−01−01 / 2020−12−01
0.10
0.05
0.00
−0.05
−0.10
−0.15
Jan 2003
Jan 2006
Jan 2009
Jan 2012
Jan 2015
Jan 2018
Dec 2020

5.3 Testing for Cointegration

```
englegranger <- function(var, trend, n){
  if (var == 2 & trend == 0){
    print(list(crit1 = -3.9001-10.534/n-30.03/n^2,
               crit5 = -3.3377-5.967/n-8.98/n^2,
               crit10 = -3.0462-4.069/n-5.73/n^2))
  } else if (var == 2 & trend == 1){
    print(list(crit1 = -4.326-15.531/n-34.03/n^2,
               crit5 = -3.7809-9.421/n-15.06/n^2,
               crit10 = -3.4959-7.203/n-4.01/n^2))
  } else if (var == 3 & trend == 0){
    print(list(crit1 = -4.2981-13.79/n-46.37/n^2,
               crit5 = -3.7429-8.352/n-13.41/n^2,
               crit10 = -3.4518-6.241/n-2.19/n^2))
  } else if (var == 3 & trend == 1){
    print(list(crit1 = -4.6676-18.492/n-18.492/n^2,
               crit5 = -4.1193-12.024/n-12.024/n^2,
               crit10 = -3.8344-9.188/n-9.188/n^2))
  } else {
    print('Beyond the scope of FRE530')
  }
}

palm_soy <- lm(lnpalm ~ lnsoy, vegoils)
palm_soy_resid <- resid(palm_soy)
adf_palm_soy <- ur.df(palm_soy_resid, type = c("none"), lags = 0)
adf_palm_soy_l <- ur.df(palm_soy_resid, type = c("none"), lags = 1)

palm_rapeseed <- lm(lnpalm ~ lnrapeseed, vegoils)
palm_rapeseed_resid <- resid(palm_rapeseed)
adf_palm_rapeseed <- ur.df(palm_rapeseed_resid, type = c("none"), lags = 0)
adf_palm_rapeseed_l <- ur.df(palm_rapeseed_resid, type = c("none"), lags = 2)

soy_rapeseed <- lm(lnsoy ~ lnrapeseed, vegoils)
soy_rapeseed_resid <- resid(soy_rapeseed)
adf_soy_rapeseed <- ur.df(soy_rapeseed_resid, type = c("none"), lags = 0)
adf_soy_rapeseed_l <- ur.df(soy_rapeseed_resid, type = c("none"), lags = 2)

summary(adf_palm_soy)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.111727 -0.024341  0.001646  0.026213  0.133435
```

```
##
## Coefficients:
##         Estimate Std. Error t value Pr(>|t|)
## z.lag.1 -0.13538    0.03496  -3.873 0.000143 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.03899 on 214 degrees of freedom
## Multiple R-squared:  0.0655, Adjusted R-squared:  0.06113
## F-statistic:    15 on 1 and 214 DF,  p-value: 0.0001429
##
##
## Value of test-statistic is: -3.8729
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

```
summary(adf_palm_soy_l)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1 + z.diff.lag)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.103233 -0.025492  0.000605  0.024038  0.119746
##
## Coefficients:
##            Estimate Std. Error t value Pr(>|t|)
## z.lag.1    -0.17814    0.03486  -5.110 7.17e-07 ***
## z.diff.lag  0.29409    0.06598   4.457 1.34e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.03742 on 212 degrees of freedom
## Multiple R-squared:  0.1467, Adjusted R-squared:  0.1387
## F-statistic: 18.23 on 2 and 212 DF,  p-value: 4.953e-08
##
##
## Value of test-statistic is: -5.11
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

```
summary(adf_palm_rapeseed)
```

```
##
```

```
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.149891 -0.034549  0.002377  0.037249  0.157404
##
## Coefficients:
##         Estimate Std. Error t value Pr(>|t|)
## z.lag.1 -0.09148    0.02885  -3.171  0.00174 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.0514 on 214 degrees of freedom
## Multiple R-squared:  0.04488,    Adjusted R-squared:  0.04042
## F-statistic: 10.06 on 1 and 214 DF,  p-value: 0.001741
##
##
## Value of test-statistic is: -3.1712
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

```
summary(adf_palm_rapeseed_l)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1 + z.diff.lag)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.160901 -0.033212  0.002434  0.034666  0.150155
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## z.lag.1     -0.10849    0.02927  -3.707 0.000269 ***
## z.diff.lag1  0.34453    0.06652   5.179  5.2e-07 ***
## z.diff.lag2 -0.11115    0.06876  -1.616 0.107498
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## Residual standard error: 0.04866 on 210 degrees of freedom
## Multiple R-squared:  0.1553, Adjusted R-squared:  0.1432
## F-statistic: 12.87 on 3 and 210 DF,  p-value: 9.457e-08
##
##
## Value of test-statistic is: -3.7066
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

```
summary(adf_soy_rapeseed)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.143660 -0.022603  0.001676  0.023579  0.109973
##
## Coefficients:
##         Estimate Std. Error t value Pr(>|t|)
## z.lag.1  -0.1128     0.0315  -3.581 0.000423 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.03602 on 214 degrees of freedom
## Multiple R-squared:  0.05654,    Adjusted R-squared:  0.05214
## F-statistic: 12.83 on 1 and 214 DF,  p-value: 0.0004232
##
##
## Value of test-statistic is: -3.5813
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```

```
summary(adf_soy_rapeseed_l)
```

```
##
## ###############################################
## # Augmented Dickey-Fuller Test Unit Root Test #
## ###############################################
##
## Test regression none
##
##
```

```
## Call:
## lm(formula = z.diff ~ z.lag.1 - 1 + z.diff.lag)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.141750 -0.019546  0.002605  0.019350  0.094712
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## z.lag.1     -0.09506    0.03255  -2.920  0.00388 **
## z.diff.lag1  0.08212    0.06654   1.234  0.21852
## z.diff.lag2 -0.22055    0.06728  -3.278  0.00122 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.03498 on 210 degrees of freedom
## Multiple R-squared:  0.1098, Adjusted R-squared:  0.0971
## F-statistic: 8.635 on 3 and 210 DF,  p-value: 1.977e-05
##
##
## Value of test-statistic is: -2.9199
##
## Critical values for test statistics:
##       1pct  5pct 10pct
## tau1 -2.58 -1.95 -1.62
```