Chickens vs. Eggs: Replicating Thurman and Fisher (1988)

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1. Introduction

This exercise lays out the procedure for testing Granger Causality as discussed in the celebrated paper of Thurman and Fisher (*American Journal of Agricultural Economics,* 1988) entitled "Chickens, Eggs, and Causality, or Which Came First?". This is inspired by Roger Koenker of University of Illinois.

2. Granger Causality, Cointegration and Unit Roots

2.1. Data and Variables

The data used in this part was originally provided by Thurman and adjusted by Koenker. It is available from R website. It consists of annual time series 1930-83 for the U.S. egg production in millions of dozens and U.S.D.A estimate of the U.S. chicken population.

Table 1: Descriptive statistics

Variables	No. of Obs.	Arith. mean	Std.	Min	Max	Median
Eggs	54	4986.463	884.9662	3081	5836	5379.5
Chickens	54	419504	46406.94	364584	582197	403818.5
Year	54	1956.5	-	1930	1983	1956.5

2.2. Testing the Granger Causality: "Which Came First, Chicken or Egg?"

The following general equations with k = 1, 2, 3 and 4 were used for testing Granger-Causality to reproduce the comparable test statistics with Thurman and Fisher (1988)'s work.

$$Eggs_t = \mu + \sum_{k=1}^{p} \alpha_i Eggs_{t-k} + \sum_{k=1}^{p} \beta_k Chickens_{t-k} + \varepsilon_t \tag{2.2.1}$$

$$Chickens_t = \mu + \sum_{k=1}^{p} \alpha_i Chickens_{t-k} + \sum_{k=1}^{p} \beta_k Eggs_{t-k} + \varepsilon_t \tag{2.2.2}$$

2.2.1. Did the Chicken Come First?

To test whether "Chickens" do not Granger-cause "Eggs", we first estimated the four variants (with different no. of lags in the RHS equation) of equation 2.2.1. Then we carried out the F-test as follows

Ho: $\beta_1 = ... = \beta_k = 0$ (Chickens do not Granger cause Eggs)
Ha: At least one of β_k is not zero (Chickens Granger cause Eggs)

The results of *F*-test under Ho are presented as follows.

Table 2. *F*-test Results under Ho: "Chickens do not Granger cause Eggs".

k = no. of lags	df	*F*-statistic	*p*-value	Adj. R^2 of the regression
1	(1, 50)	0.05	0.8292	0.9612
2	(2, 47)	0.88	0.4815	0.9650
3	(3, 44)	0.59	0.6238	0.9629
4	(4, 41)	0.39	0.8125	
0.9573				

We see that **the above *F*-statistic results failed to reject our null hypothesis** at 5% level in all four variants of regression model 2.2.1.

2.2.2. <u>Did the "Eggs" Come First?</u>

To test whether "Eggs" do not Granger cause "Chickens", we first estimated the four variants (with different no. of lags in the RHS equation) of equation 2.2.2. Then we carried out the *F*-test as follows:

Ho: $\beta_1 = ... = \beta_k = 0$ (Eggs do not Granger cause Chickens)
Ha: At least one of β_k is not zero (Eggs Granger cause Chickens)

The *F*-test results presented as follows:

Table 3. *F*-test Results under Ho: "Eggs do not Granger cause Chickens".

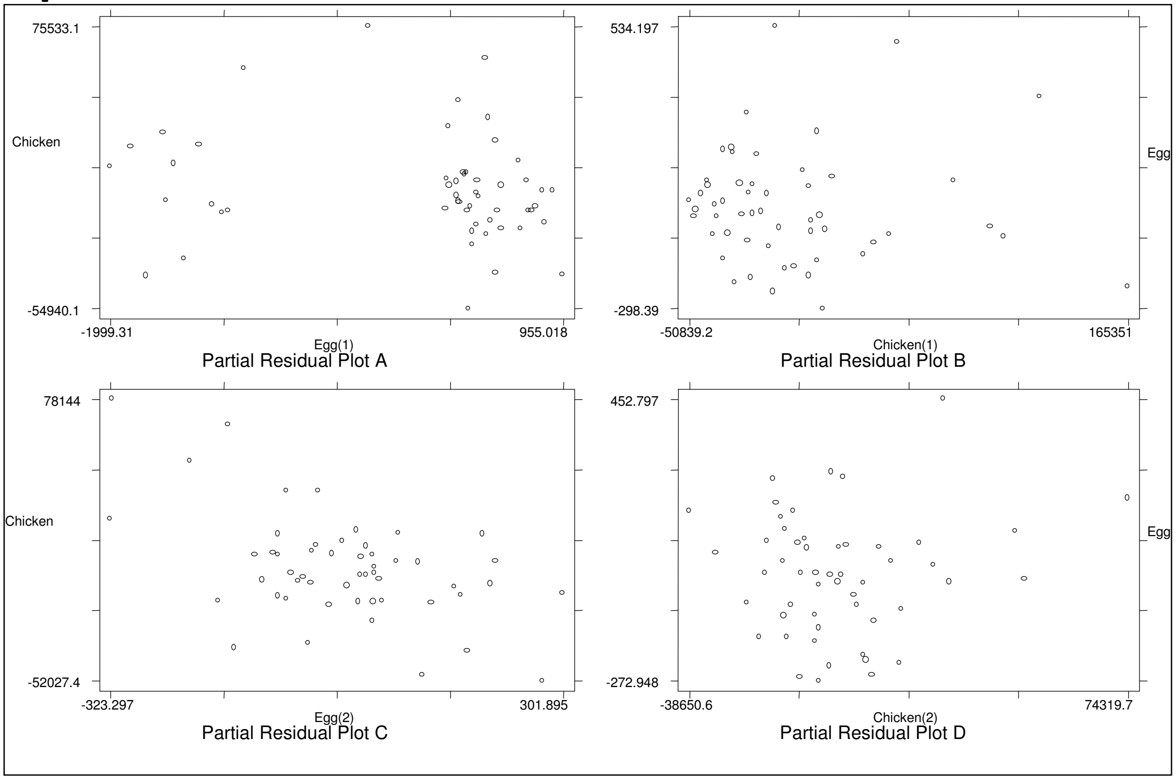
k = no. of lags	df	*F*-statistic	*p*-value	Adj. R^2 of the regression
1	(1, 50)	1.21	0.2772	0.7140
2	(2, 47)	8.42	0.0006	0.7794
3	(3, 44)	5.40	0.0030	0.7831
4	(4, 41)	4.26	0.0057	
0.7802				

Our *F*-test result above provided the empirical **evidence against our null hypothesis** "Eggs do not Granger cause chickens".

In summary, our conclusion from Granger causality test results found to be consistent with the results shown by Thurman and Fisher (1988) despite the difference between their and our calculated *F*-test statistics. The difference may be due to the difference in the number of observations.

Observing the patterns of partial residuals may help to explain further the rather striking results above. We graph these patterns as follows:

Graph 1. Partial Residual Plots

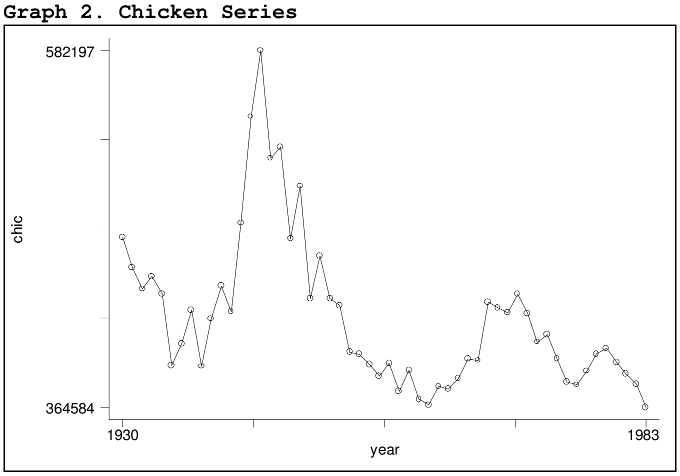


However, we see that the partial residual plots above do not seem to support the hypothesis of "Eggs Grainger-cause chickens". Therefore, we need to proceed on conducting necessary tests on the series used.

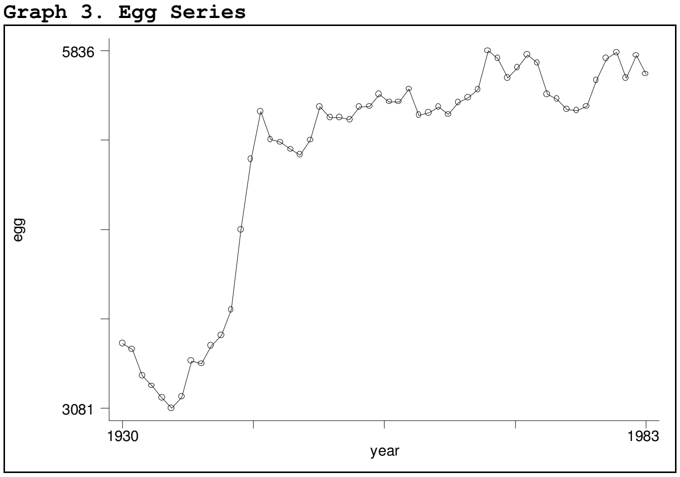
3. Test for Unit Roots

In order to be able to confirm our conjecture in the previous section, we need to conduct tests for unit roots on the two series. Before doing so, we observe the pattern of the series against time as follows:

Graph 2. Chicken Series



Graph 3. Egg Series



The graphs above show that there was no systematic pattern of chicken series, while there seems to be a relatively systematic pattern of egg series, esp. after the first quarter of the observations. However, we should not rely solely on such rough graphs. Therefore, we need to test the non-stationarity formally. That is, we employed the augmented Dicky-Fuller (ADF) tests on the both series.

3.1 Augmented Dicky-Fuller Equations for "Chickens"

The three equations below represent our testing model for (i) random walk behavior, (ii) random walk with drift, and (iii) random walk with drift and trend, respectively.

$$\Delta Chickens_t = (\rho - 1)Chickens_{t-1} + \sum_{k=1}^{p} \delta_k \Delta Chickens_{t-k} + \varepsilon_t \quad (3.1.1)$$

$$\Delta Chickens_t = \text{Constant} + (\rho - 1)Chickens_{t-1} + \sum_{k=1}^{p} \delta_k \Delta Chickens_{t-k} + \varepsilon_t \quad (3.1.2)$$

$$\Delta Chickens_t = \text{Constant} + (\rho - 1)Chickens_{t-1} + \gamma trend_t + \sum_{k=1}^{p} \delta_k \Delta Chickens_{t-k} + \varepsilon_t$$

(3.1.3)

3.2 Augmented Dicky-Fuller equations for "Eggs"

Similarly, the equations for testing the egg series are:

$$\Delta Eggs_t = (\rho - 1)Eggs_{t-1} + \sum_{k=1}^{p} \delta_k \Delta Eggs_{t-k} + \varepsilon_t \quad (3.2.1)$$

$$\Delta Eggs_t = \text{Constant} + (\rho - 1)Eggs_{t-1} + \sum_{k=1}^{p} \delta_k \Delta Eggs_{t-k} + \varepsilon_t \quad (3.2.2)$$

$$\Delta Eggs_t = \text{Constant} + (\rho - 1)Eggs_{t-1} + \gamma trend_t + \sum_{k=1}^{p} \delta_k \Delta Eggs_{t-k} + \varepsilon_t \qquad (3.2.3)$$

Before estimating the ADF equations from 3.1.1 to 3.2.3, we first determine the value of *k*. For this purpose we arbitrarily selected *k* = 1, 2, 3 and 4 and estimated four variants of those equations. Then we carried out the *F*-test to test the joint Ho: $\delta_1 = ... = \delta_k = 0$ against Ha: At least one of the δ_k is not zero. In case that the *F*-test provided the empirical evidence against Ho, we then computed the Schwarz's Information Criterion (SIC) using equation 3.2.4 below for those estimated equations.

$$SIC_j = \log \hat{\sigma}_j^2 + (k_j / n) \log n \qquad (3.2.4)$$

where *n* is the number of observations, *k* is the number of parameters, and $\hat{\sigma}^2$ is the residual sum of squares estimated from OLS divided by *n*.

Our results for SIC for different lag structure in equation 3.1.1 to 3.2.3 are summarized as follows:

Table 5. SIC values for variants of Equations (3.1.1) to (3.2.3)

Equation	SIC values corresponding to ADF equations			
	No. of lags (k)	No constant, no trend	No trend	With constant and trend
Chicken	1	20.404335	20.432374	-
	2	20.459487	20.461065	-
	3	20.554433	20.553202	-
	4	20.639749	20.603449	-
Eggs	1	10.305644	10.311814	-
	2	10.373362	10.3429	-
	3	10.472166	10.429575	-
	4	10.56682	10.483637	-

As a decision rule we chose *k* number of lags that minimized the SIC for each equation. If we follow this rule for SIC value we should use *k* = 1 in ADF equations for "Chicken" and "Eggs" (section 3.1 and 3.2) for the purpose of testing unit roots. However, for pedagogical purpose, we estimated ADF equations for all four different *k* values, ranging from 1 to 4.

3.3 <u>Hypothesis Testing for Nonstationarity</u>

We first estimated the ADF equations from 3.1.1 to 3.2.3 with *k* = 1, 2, 3, 4 and tested the following hypothesis in each equation to determine whether there is a unit root in the given time series.

Ho: $\rho = 1$ (There is unit root in the series)
Ha: $\rho < 1$ (There is no unit root in the series)

The test results and corresponding test statistics are presented as follows:

Table:6 Augmented Dickey-Fuller Tests for Chicken Series

Ho: Unit-root presents   Ha: Unit-root does not present

Lag	Cons Trend	Test Statistic	1% Critical Value	5% Critical Value	p-value	Reject Ho
Z(1)	c t	-1.998	-4.146	-3.498	0.6030	No
	c -	-1.618	-3.577	-2.928	0.4737	No
	- -	-0.712	-2.619	-1.950	-	No
Z(2)	c t	-2.547	-4.148	-3.499	0.3056	No
	c -	-1.969	-3.579	-2.929	0.3005	No
	- -	-0.560	-2.620	-1.950	-	No
Z(3)	c t	-2.543	-4.150	-3.500	0.3075	No
	c -	-1.982	-3.580	-2.930	0.2945	No
	- -	-0.616	-2.620	-1.950	-	No
Z(4)	c t	-3.172	-4.159	-3.504	0.0901	No
	c -	-2.340	-3.587	-2.933	0.1593	No
	- -	-0.545	-2.622	-1.950	-	No

Based on the results presented in Table 6, we failed to reject our Ho, hence confirmed that time series observations for "Chickens" is nonstationary.

Table: 7 Augmented Dickey-Fuller Tests for Eggs Series

Ho: Unit-root presents   Ha: Unit-root does not present

Lag	Cons Trend	Test Statistic	1% Critical Value	5% Critical Value	p-value	Reject Ho
Z(1)	c t	-1.634	-4.146	-3.498	0.7781	No
	c -	-1.715	-3.577	-2.928	0.4232	No
	- -	0.762	-2.619	-1.950	-	No
Z(2)	c t	-1.720	-4.148	-3.499	0.7415	No
	c -	-2.112	-3.579	-2.929	0.2398	No
	- -	0.902	-2.620	-1.950	-	No
Z(3)	c t	-1.702	-4.150	-3.500	0.7493	No
	c -	-2.202	-3.580	-2.930	0.2055	No
	- -	0.936	-2.620	-1.950	-	No
Z(4)	c t	-1.777	-4.159	-3.504	0.7151	No
	c -	-2.535	-3.587	-2.933	0.1072	No
	- -	1.033	-2.622	-1.950	-	No

In the same fashion, based on the results presented in Table 7, we also failed to reject the associated Ho, hence confirmed that time series observations for "Eggs" is also nonstationary.

Thus we confirmed that **both "Chickens" and "Eggs" series are nonstationary**. That is, they exhibit the presence of unit-root or I(1) process. This implies a violation to the classical iid conditions for residuals in equation (2.1.1) and (2.1.2). In other words, our prior conclusion that "Eggs Grainger-cause chickens" is somehow weakened, in the sense that our *F*-statistics in Table 2 might have been overstated.

To re-check the result we can impose first difference on both series in order to make them follow I(0) process. Therefore, our new models for causality tests are:

$$\Delta Eggs_t = \mu + \sum_{k=1}^{p} \alpha_i \Delta Eggs_{t-k} + \sum_{k=1}^{p} \beta_k \Delta Chickens_{t-k} + \varepsilon_t \tag{3.3.1}$$

$$\Delta Chickens_t = \mu + \sum_{k=1}^{p} \alpha_i \Delta Chickens_{t-k} + \sum_{k=1}^{p} \beta_k \Delta Eggs_{t-k} + \varepsilon_t \tag{3.3.2}$$

The associated results are presented in the following table:

Table 8. F-test Results under Ho: "Chickens do not Granger cause Eggs" (Stationary)

k = no. of lags	df	*F*-statistic	*p*-value	Adj. R^2 of the regression
1	(1,49)	0.54	0.4646	0.1086
2	(2,46)	0.39	0.6816	0.0698
3	(3,43)	0.22	0.8788	0.0184
4	(4,40)	0.28	0.8881	-0.0219

Table 9. F-test Results under Ho: "Eggs do not Granger cause Chickens" (Stationary)

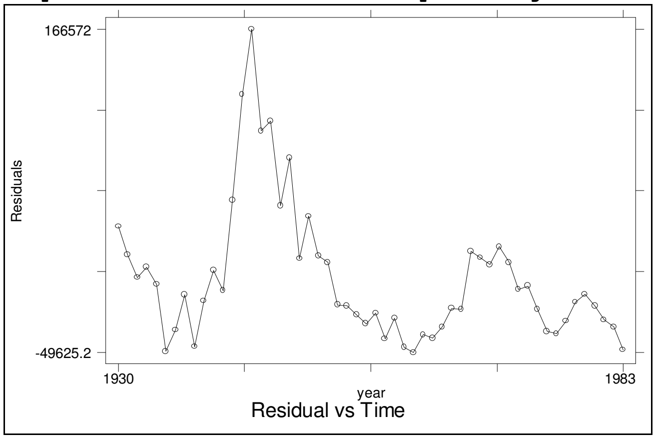
k = no. of lags	df	*F*-statistic	*p*-value	Adj. R^2 of the regression
1	(1,49)	10.37	0.0023	0.1681
2	(2,46)	3.92	0.0268	0.136
3	(3,43)	2.93	0.0441	0.1229
4	(4,40)	4.18	0.0064	0.2281

It turns out that the results in Table 8 and Table 9 **provide support to our conclusion that "Eggs Grainger-cause Chickens"**. In addition, after correcting for nonstationarity, we found that even the model with lag-one of eggs in chickens-eggs equation is significant.

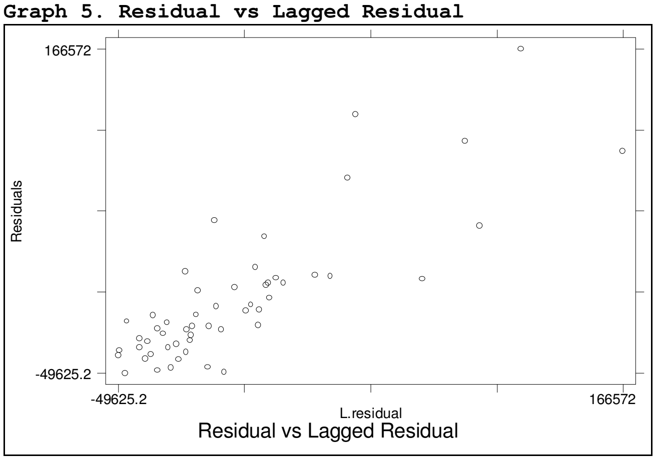
3.4. Tests for Cointegration

We confirmed from Table 6 and 7 that both variables "Chickens" and "Eggs" are nonstationary meaning that they showed the presence of unit roots. To test whether those series are cointegrated, we first observe the relationships between the residuals and time and between the residual with its lag as follows:

Graph 4. Residual from Chicken Equation Against Time



Graph 5. Residual vs Lagged Residual



There are not many inferences we can get from Graph 4. On the other hand, Graph 5 suggests a weak positive relation between residual and its lag.

Next, we estimated the following long run equilibrium equation (3.4.1) for Chicken-Egg processes.

$$Chickens_t = \beta_1 + \beta_2 Eggs_t + \nu_t \quad \text{and} \quad \nu_t \sim iidN\left(0, \sigma^2 I_T\right) \tag{3.4.1}$$

Then we estimated the following augmented Engle-Graenger (AEG)[1] equations 3.4.2-3.4.4 for testing the presence of unit roots in residuals of equation (3.41).

$$\Delta \hat{\nu}_t = (\rho - 1)\hat{\nu}_{t-1} + \sum_{k=1}^{p} \delta_k \Delta \hat{\nu}_{t-k} + \varepsilon_t \tag{3.4.2}$$

$$\Delta \hat{\nu}_t = \text{Constant} + (\rho - 1)\hat{\nu}_{t-1} + \sum_{k=1}^{p} \delta_k \Delta \hat{\nu}_{t-k} + \varepsilon_t \tag{3.4.3}$$

[1] The procedure is similar to ADF. The only difference here is that we impose the test on residual series. This is why this test is also called "residual-based test".

$$\Delta \hat{v}_t = \text{Constant} + (\rho - 1)\hat{v}_{t-1} + \gamma trend_t + \sum_{k=1}^{p} \delta_k \Delta \hat{v}_{t-k} + \varepsilon_t \qquad (3.4.4)$$

We tested the following hypothesis for the presence of unit roots in the above three AEG equations.

Ho: $\rho = 1$ (There is unit root in the estimated residuals of equation 3.4.1)
Ha: $\rho < 1$ (There is no unit root in the estimated residuals of equation 3.4.1)

Our Dicky-Fuller test statistics are presented as follows:

Table 10. Augmented Dickey-Fuller Tests for Residuals Series

Ho: Unit-root presents   Ha: Unit-root does not present

Lag	Cons Trend	Test Statistic	1% Critical Value	5% Critical Value	p-value	Reject Ho
Z(0)	c t	-2.291	-4.143	-3.497	0.4404	No
	c -	-2.120	-3.576	-2.928	0.2364	No
	- -	-2.146	-2.619	-1.950	-	Yes (5%)
Z(1)	c t	-2.025	-4.146	-3.498	0.5885	No
	c -	-1.810	-3.577	-2.928	0.3756	No
	- -	-1.834	-2.619	-1.950	-	No
Z(2)	c t	-2.619	-4.148	-3.499	0.2714	No
	c -	-2.282	-3.579	-2.929	0.1778	No
	- -	-2.311	-2.620	-1.950	-	Yes (5%)
Z(3)	c t	-2.583	-4.150	-3.500	0.2885	No
	c -	-2.251	-3.580	-2.930	0.1884	No
	- -	-2.282	-2.620	-1.950	-	Yes (5%)
Z(4)	c t	-3.163	-4.159	-3.504	0.0919	No
	c -	-2.659	-3.587	-2.933	0.0814	No
	- -	-2.695	-2.622	-1.950	-	Yes (5%)

This implies that estimated residuals from equation 3.4.1 exhibits nonstationary. We also found that both estimated parameters for models with trend and drift were statistically insignificant at 5% level in all three equations from 3.4.2-3.4.4. With the exception of cases without both constant and trend, in general, we failed to reject the null. This means, **the eggs and chickens series were not cointegrated**.

4. Notes

You can do all the above procedure on Stata in a pretty straightforward way. Better yet, this is probably a good way to start using R. Koenker has made the data available in R.