GRANGER CAUSALITY AND U.S. CROP AND LIVESTOCK PRICES

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Abstract

Agricultural economists have recently been attracted to procedures suggested by Granger and others which allow observed data to reveal causal relationships. Results of this study indicate that "causality" tests can be ambiguous in identifying behavioral relationships between agricultural price variables. Caution is suggested when using such procedures for model choice.

Key words: Granger causality, causality tests, autoregressive processes

Economists have long been concerned with the issue of causality versus correlation. Even beginning economics students are constantly reminded that economic variables can be correlated without being causally related. Recently, testable definitions of causality have been suggested by Granger (1969, 1980), Sims and others. These causality tests have been applied by agricultural economists in livestock markets (Bessler and Brandt; Miller; Spreen and Shonkwiler) and other agricultural markets (Bessler and Schrader; Heien; and Weaver). The appeal of Granger-like procedures is that the investigator can allow the data to reveal causal relationships. Thus, if theory is ambigous regarding model specification, statistical causality procedures may appear attractive.

The validity of causality tests in the Granger spirit has been recently questioned. Pierce found that a number of theoretically related economic time series failed to exhibit causality in the Granger sense. Alternatively, Sheehan and Grieves found causality to exist between seemingly unrelated time series. In this paper, the Granger causality test is applied to a number of agricultural crop and livestock price series. Additionally, some irrelevant time series are considered to shed some light on the robustness of the Granger technique when applied to agricultural prices. In the following section, causality in the "Granger sense" is defined. Statistical considerations are then addressed. Results for agricultural prices and irrelevant time series are then discussed. Finally, some concluding remarks are offered.

CAUSALITY: TESTABLE DEFINITIONS

Can observed correlations be used to suggest or infer causality? This question lies at the heart of the recent causality literature. Jacobs et al. contend that the null hypothesis commonly tested is necessary but not sufficient to imply that one variable "causes" another. Furthermore, the authors show that exogenity is not empirically testable and that "informativeness" is the only testable definition of causality. This testable definition is commonly known as causality in the Granger sense. Although Granger (1969) never suggested that this testable definition of causality could be used to infer exogenity, many researchers think of exogenity when seeing the common parlance "test for casuality."Granger (1980) and Zellner provide further discussion of definitions of "causality" and Engle et al. offer a formal treatment of the concept of exogeneity.

A variable x is said to cause y in the Granger sense if current values of y can be better predicted using past values of x than if only past values of y are used to predict current values of y. The test for causality in the Granger sense is commonly based on the equations:

$$(1) \qquad Y_t = \alpha_o + \sum_{j=1}^{m} \alpha_j Y_{t-j} + u_t$$

$$(2) \qquad Y_t = \beta_o + \sum_{j=1}^{m} \beta_j Y_{t-j} + \sum_{i=1}^{n} \gamma_i x_{t-i} + v_t$$

where u_t and v_t are independent, serially uncorrelated random variables with zero means and finite variances for all $t = 1, \ldots, T$, and the α's, β's, and γ's are parameters. If equation (2) is a better predictor of Y_t than equation (1), x is said to cause Y in the Granger sense. Given such a notion, a test of causality can be based on a test of the hypothesis that $\gamma_1 = \gamma_2 = \ldots = \gamma_n = 0$. This is a one-directional test for whether or not x causes y as opposed to a test of whether y causes x or a test of

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instantaneous causation (Granger, 1969). It is emphasized that this procedure is not a test for exogenity rather one for "prediction" (Granger, 1969) or "informativeness" (Jacobs et al.).

STATISTICAL CONSIDERATIONS

Given equations (1) and (2), an immediate question involves the choice of the lag length parameters m and n. Since these parameters are usually unknown in practice, they will have to be estimated to make the Granger test operational. A number of simple procedures for determining the length of autoregressive processes, such as partial autocorrelations, are available. An attractive mechanical method can be based on Akaike's final prediction error (FPE) criterion which is used in a study of agricultural prices by Bessler and Binkley. For lag length ℓ, consider the function:

$$(3) \quad A(\ell) = (T+\ell+1)\left[\sum_{t=\ell+1}^{T} (Y_t - \hat{Y}_t(\ell))^2/T\right] / (T-\ell-1)$$

where $\hat{Y}_t(\ell)$ is the predicted value of y_t from an autoregression of order ℓ. The FPE criterion is to choose ℓ such that $A(\ell)$ is a minimum. Inspection of equation (3) reveals that part of the function rewards precision in estimating Y_t while part rewards parsimony in the choice of the lag length ℓ.

A check to see if the chosen autoregressive order ℓ is appropriate can be based on the Portmanteau test statistic for white noise (Box and Pierce):

$$(4) \quad Q = T\left(\sum_{i=1}^{K} r_i^2\right)$$

where the r_i's are estimated autocorrelation coefficients and $K > \ell$.[1] Q has a $\chi^2_{(K-\ell)}$ distribution if the null hypothesis of no autocorrelation (i.e. white noise) is true.

Once the lag length parameters m and n have been determined, the Granger test for causality can be based on the statistic:

$$(5) \quad \delta = [(T\text{-}m\text{-}n\text{-}1)(SSE_1\text{-}SSE_2)] / (n\, SSE_2)$$

where SSE_i is the ordinary least squares sum of squared residuals from equation i = 1, 2. The statistic δ (which is easily computed from the output generated by standard computer regression routines) has an $F_{(n,T-m-n-1)}$ distribution if the null hypothesis that $\gamma_1 = \gamma_2 = \ldots = \gamma_n = 0$ (i.e. x does not cause y) is true.[2]

AN APPLICATION TO AGRICULTURAL PRICES

To test the robustness of the Granger procedure and shed some light on the validity of Granger causality when applied to agricultural time series, seven annual agricultural price series and three annual irrelevant time series are considered. The agricultural price series, which were not deflated, are corn ($/bu.), wheat ($/bu.), barley ($/bu.), oats ($/bu.), cotton (¢/lb.), beef ($/cwt.) and hogs ($/cwt.).[3] The irrelevant series are annual Wolf sunspot numbers (Zurich observatory), worldwide sperm whale catch and number of automobile registrations (mil.) in the U.S.[4] After appropriate lag lengths for each time series were determined, fifty-nine annual observations for the period 1921-79 were used for the causality test.

In Table 1, the appropriate lag lengths for each time series, as determined by the Akaike FPE criterion (see equation 3), are shown. In addition, the Portmanteau statistic for each autoregression given $K = \ell + 10$, where ℓ is the chosen autoregressive order, is presented for each time series (see equation 4). Given a χ^2_{10} ($\alpha = .05$) = 18.81 critical value, all lag lengths

TABLE 1. AUTOREGRESSIVE ORDER AND PORTMANTEAU STATISTIC FOR SELECTED VARIABLES

Item	Autoregressive order[a]	Portmanteau statistic[b]
Corn	5	3.48
Wheat	4	2.44
Barley	2	4.78
Oats	1	2.38
Cotton	8	5.60
Beef	5	4.17
Hogs	3	4.30
Sunspots	9	7.19
Whale catch	1	5.50
Vehicle registrations	3	2.43

[a]Based on Akaike FPE criterion.
[b]χ^2_{10} (α=.05) = 18.81.

[1] To compute Q, note that a common estimate of autocorrelations is: $r_i = c_i/c_o$ where:

$$c_i = T^{-1} \sum_{t=1}^{T-i} (Y_t - \bar{Y})(Y_{t+i} - \bar{Y}), \text{ for } i = 1, \ldots, K.$$

For the Q-statistic, K is chosen sufficiently large to encompass any suspected relationships.

[2] Sometimes it is suggested that the data series for y and x be transformed ("filtered") *before* causality tests are performed (for example, see Belongia and Dickey).

[3] All agricultural price series were graciously provided by Don Mellon, U.S.D.A., Statistical Reporting Service.

[4] Sunspot numbers were obtained from Gnevyshev and Oi (up to 1968), *Sky and Telescope* (1969) and *Schatten*(1970-79). Whale catch numbers were obtained from McHugh (up to 1970) and *U.N. Statistical Yearbook* (1971-79). Automobile registrations for all years are from the U.S. Department of Transportation, *Highway Statistics.*

are appropriately long to filter each series. In other words, the null hypothesis that the residuals from each fitted autoregression are white noise cannot be rejected.

Given the lag lengths presented in Table 1, Granger causality tests, based on the test statistic in equation (5), were performed for all time series considered. Results are shown in Table 2; causal variables are read from left to right while dependent variables are read from top to bottom. Asterisks indicate a rejection of the null hypothesis of no causality. Since the degrees of freedom for the Granger F-test are generally different in each case (i.e. the lag lengths m and n are different), the numbers chosen to present are the probabilities of observing a larger value of the test statistic δ under the null hypothesis (i.e., p-values). For example, for the test that wheat prices cause corn prices, the probability of observing a larger value of δ is .0584. Consequently, the null hypothesis of no causality can be rejected given a 10 percent significance level but not a 5 percent significance level. Similarly, the null hypothesis that corn prices do not cause wheat prices can be rejected at a .01 significance level since the probability of observing a larger value of δ is .0041.

For the irrelevant (non-agricultural) variables, the results presented in Table 2 indicate that the null hypothesis of no causality can be rejected in 11 out of 48 cases given a .10 significance level. This result raises some concern regarding the validity of the Granger causality test since only about 5 rejections of no causality would be expected due to sampling error given a .10 significance level for the test. For the agricultural variables the number of expected rejections of the null hypothesis of no causality is more difficult to determine since causality is *theoretically* expected between certain agricultural prices. For example, few agricultural economists would argue that corn prices are not causally related to beef and hog prices. However, some argument would certainly be aroused over the existence of causation between beef and cotton prices.

Based upon a review of previous studies, the number of theoretically expected rejections of the no causality hypothesis was determined, Table 3. A determination of "causality" between two agricultural price variables was made if one of the variables was modeled as a function of the other in one or more of the studies considered, see Table 3, footnote 'a'. Corn, beef, and hog prices have generally been modeled in causal manner since corn is a primary feedstock for livestock products. In previous studies, causal relationships have also been assumed among the small grains (wheat, barley, and oats) since these field crops are grown together in similar regions of the United States. However, with the exception of wheat none of the prices were found to be specified as causally related to cotton. Among the agricultural price variables, previous studies suggested 22 out of 42 possible cases as causally related. However, the Granger test results depicted in Table 2 show that among the agricultural prices, the null hypothesis of no causality is rejected in 31 out of 42 cases. In addition, a comparison of tables 2 and 3 indicates 14 incorrect rejections of the null hypothesis of no causality (type I error) and 5 incorrect acceptances of the no causality hypothesis (type II error). Hence, even considering sampling error, these results raise some concern as to the validity of the Granger technique when applied to agricultural prices.

As a further application, the lag lengths m and n were increased by 5 over those suggested by the Akaike FPE criterion, Table 1.[5] It was thought that this procedure would better ensure that the residuals of equations (1) and (2) were white noise and decrease the possibility of spurious causality findings. As evidenced in Table 4, the additional lag lengths appeared to give improved results for the Granger tests. First, for the irrelevant time series, the null hypothesis

TABLE 2. GRANGER CAUSALITY RESULTS (P-VALUES) BASED ON AKAIKE FPE LAG LENGTH CRITERION[a]

Dependent variable[b]	Causal variables[c] Corn	Wheat	Barley	Oats	Cotton	Beef	Hogs	Sunspots	Whale catch	Vehicle reg.
Corn	———	.0584*	.6640*	.9870	.2305	.0287**	.0336**	.9202	.7137	.0537*
Wheat	.0041***	———	.1449	.1091	.0299**	.0267**	.0008***	.3274	.7092	.0790*
Barley	.0000***	.0018***	———	.7974	.1337	.0010***	.0000***	.9632	.4180	.0354**
Oats	.0227**	.0031***	.0567*	———	.1169	.0062***	.0005***	.9545	.5853	.0952*
Cotton	.0414**	.0860*	.0336**	.0131**	———	.0005***	.0002***	.8246	.2572	.0678*
Beef	.0290**	.0303**	.5858	.9482	.5865	———	.0005***	.0543*	.0387**	.4091
Hogs	.0000***	.0056***	.0001***	.0012***	.0037***	.0020***	———	.8508	.4252	.0443**
Sunspots	.2122	.3674	.9094	.9367	.7719	.0285**	.6318	———	.2290	.5916
Whale catch	.0889*	.6670	.3304	.2780	.6859	.7609	.1527	.2775	———	.0653*
Vehicle reg.	.4081	.5633	.3337	.7358	.4589	.4579	.3015	.6429	.7273	———

[a] The lag lengths m and n for the Granger causality tests are depicted in Table 1.
[b] Causal variables are read from left to right and dependent variables are read from top to bottom.
[c] Asterisks represent rejection of the null hypothesis of no causality for significance level α, where α=.10 (*); α=.05 (**) and α=.01 (***).

[5] The whale catch lag length could not be increased due to historical data limitations.

of no causality can be rejected in only 5 out of the 48 possible cases given a .10 significance level, a result which could be attributed solely to sampling error (this compares to 11 rejections based on the Akaike FPE lag lengths; Table 2).

In addition, for the agricultural price series, the increased lag lengths resulted in 26 out of 42 possible rejections of the null hypothesis of no causality given a .10 significance level. However, although this is 5 less rejections than obtained using the Akaike FPE lag lengths, a comparison of tables 3 and 4 reveals that little gain in terms of correct causality predictions was achieved by using the extended lag lengths. For instance, only one less (13 versus 14) incorrect rejection of the null hypothesis of no causality was obtained. Furthermore, 7 (versus 5) incorrect acceptances of the null hypothesis were obtained. Thus, type I error was not notably reduced while type II error actually increased using the extended lag lengths. In sum, although arbitrarily extending the Akaike FPE lag lengths resulted in improved performance in terms of predicting causality among the irrelevant time series, no improvement was achieved in terms of correctly predicting causality among the agricultural price series.

TABLE 3. EXPECTED CAUSAL RELATIONSHIPS BASED ON PREVIOUS STUDIES[a]

Dependent variable[b]	Causal variables[b] Corn	Wheat	Barley	Oats	Cotton	Beef	Hogs
Corn	—	YES	YES	YES	NO	YES	YES
Wheat	YES	—	YES	YES	YES	NO	NO
Barley	YES	YES	—	YES	NO	NO	NO
Oats	YES	YES	YES	—	NO	NO	NO
Cotton	NO	YES	NO	NO	—	NO	NO
Beef	YES	YES	NO	NO	NO	—	YES
Hogs	YES	YES	NO	NO	NO	YES	—

[a]The studies reviewed include Arzac and Wilkinson; Freebairn and Rausser; Salathe, Price and Gadson; Ray and Richardson; and Collins and Taylor.
[b]YES and NO are respectively causally related and not causally related.

CONCLUDING REMARKS

Agricultural economists have recently been attracted to procedures suggested by Granger and others which allow observed data to reveal causal relationships between economic variables. These procedures are appealing since they offer a statistical means to model specification and theory is often not clear regarding the choice between alternative economic models. However, the results of this study indicate that Granger causality tests can be ambiguous in identifying behavioral relationships among agricultural price variables. Although the results may have limited applicability to agricultural variables other than prices, it is suggested that researchers be cautious when using Granger-like procedures as a vehicle in the choice of model specification.

Of course, the nature of the results as well as the conclusion is not without precedent. Many authors have pointed out problems in the statistical testing of Granger-causality among economic variables. For example, as noted by Granger and Newbold and recently demonstrated by Bessler and Kling, causality tests can be highly dependent on the autoregressive properties of the data. Thus, Granger and Newbold suggest differencing to obtain stationary time series before applying usual causality tests. Recently, Granger (1980) and others have emphasized the use of post-sample data to test for causality, the logic in this argument being that the definition of causality requires evidence of improved forecasts. Finally, beginning econometrics students are repeatedly told of the importance of economic theory in properly specifying econometric models. Thus, many individuals might argue that causality tests which only involve two variables inherently suffer from specification error. Indeed, a number of authors have expressed concern with causality tests that only involve two variables without taking into account the relevance of other "causal" variables (for example, see Pierce; and Zellner).

Obviously, we do not intend to address these problems based on the results of the analysis discussed here. However, we do hope that our results demonstrate that one should be skeptical of causality tests that involve variables for which there is little reason to expect to be causally

TABLE 4. GRANGER CAUSALITY RESULTS (P-VALUES) BASED ON EXTENDED AKAIKE LAG LENGTH CRITERION[a]

Dependent variable[b]	Causal variables[c] Corn	Wheat	Barley	Oats	Cotton	Beef	Hogs	Sunspots	Whale catch	Vehicle reg.
Corn	—	.2691	.5634	.4610	.1684	.0491**	.0452**	.9382	.5660	.2052
Wheat	.0151**	—	.0823*	.0354**	.0587*	.1296	.0005***	.4398	.5916	.2507
Barley	.3850	.0134**	—	.6717	.2555	.0041***	.0067***	.8828	.6318	.1005
Oats	.1130	.0049***	.2398	—	.1419	.0065***	.0018***	.9749	.6076	.3403
Cotton	.0269**	.0887*	.0071*	.1279	—	.0153**	.0002***	.7475	.3634	.1914
Beef	.0009***	.0328**	.0017***	.0011***	.1173	—	.0018***	.1098	.0042***	.6194
Hogs	.0001***	.0050***	.0003***	.0018***	.1060	.0129**	—	.7441	.7504	.1264
Sunspots	.2713	.5718	.4010	.5512	.9538	.0901*	.3633	—	.0899*	.1189
Whale catch	.1583	.4017	.3361	.4025	.8520	.7746	.3072	.1191	—	.0932*
Vehicle reg.	.3293	.2136	.1331	.0549*	.5174	.6536	.2295	.8172	.8185	—

[a] The lag lengths m and n for the Granger causality tests are depicted in Table 1 and were increased by 5.
[b] Causal variables are read from left to right and dependent variables are read from top to bottom.
[c] Asterisks represent rejection of the null hypothesis of no causality for significance level α, where $\alpha = .10$ (*); $\alpha = .05$ (**) and $\alpha = .01$ (***).

related given available *a priori* information. It seems senseless to conclude that U.S. automobile registrations cause corn prices or that the world whale catch causes beef prices, regardless of the outcome of a statistical causality test. Zellner (p.51) notes this in his statement that, *"The mechanical application of causality tests is an extreme form of 'measurement without theory' . . ."*. Operationally, our advice is to use causality tests carefully, and only as an additional piece of information in conjunction with economic theory to aid in model choice. We do not advise that one *choose* an econometric model solely on the basis of a statistical causality test, unless of course, you are willing to accept the notion that sunspots cause . . .

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