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THE PROBLEM OF AGGREGATION IN
SPATIAL CAUSALITY ANALYSIS

BY

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and
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Abstract

Aggregation across time has major implications for interpretation of causality tests. Empirical tests for three corn markets reveal one-way causality to be "fragile" with respect to changes in the level of time aggregation in data. Dynamic multipliers are discussed as one method of checking model specification.

Keywords: causality tests, corn prices, dynamic multipliers, time series, aggregation across time, specification error

THE PROBLEM OF AGGREGATION IN SPATIAL CAUSALITY ANALYSIS

Testing for Granger causality between markets is the focus of a growing body of literature. Frequently this econometric technique is used to examine pricing efficiency and relationships between markets and commodities (Brorsen, et al.; Beutler and Brorsen; Lee and Cramer; Spriggs, Kaylen and Bessler). Causality tests have also been used to define geographic markets (Uri and Rifken). The attractiveness of this technique is due partly to the supposition that price data will reveal causal relationships between markets and commodities.

However, the validity of the econometric techniques used in testing Granger causality has been questioned recently. The arguments against the technique have ranged from the general point that correlation does not imply causality, to specific econometric criticisms of the Granger model (Zellner; Ziemer and Collins; Jacobs, Leamer, and Ward; Conway, et al.; Bessler and Kling). Repeatedly, specification error has been suggested as a major problem when Granger causality tests are applied to economic time series.

Aggregation across time is a major source of specification error in economic time series analysis because it involves missing information (Hannan, Wei). Although aggregation of time series has been analyzed for its implications to economic modeling since the 1950's, empirical literature on Granger causality has used data sets containing daily, one day of the week, weekly average and monthly average prices. The implications of such aggregation to the empirical results has largely been an ignored issue.

The central purpose of this paper, therefore, is to examine the effects of aggregation across time on Granger causality tests in spatial equilibrium analysis. First, implications of using this technique for spatial equilibrium analysis are raised. Second, the procedure frequently used by agricultural economists is presented. Finally, three major commodity market price series are analyzed to demonstrate how aggregation can affect Granger tests and the dynamic properties of estimated models.

Market Identification, Aggregation, and Causality

Commodity marketing involves arbitrage of space and time utility, implying that spatial equilibrium theory can provide insights into expected characteristics of dynamic price relationships between markets. The arbitrage process places limits on dynamic characteristics of causality models and provides guidance on the "appropriateness" of hypotheses being tested.

Expectations concerning temporal dynamics of equilibrium depend on distance as well. For example, analyzing two commodity markets 15 miles apart involves evaluating the ability of two organizations to arbitrage and compete in the same spatial market. If the commodity is undifferentiated, price changes in destination markets should cause identical instantaneous adjustments in both markets (Schmiesing, Blank, and Gunn). In contrast, two markets 5,000 miles apart have different destination markets and, therefore, lack the interdependence of the previous case. Identical instantaneous adjustments would not be expected, any reaction would be dependent upon the degree of integration between the two markets. Price changes in each distant market are the result of a distinct set of economic parameters. Statistical analysis of such distant market prices can measure their simple correlation, but economic models representing Granger causality between them are suspect.

The critical questions are: What are the "true" differences in various levels of aggregation, and what are their implications for the interpretation of causality tests? Analyzing daily cash price changes involves evaluating actual ability to arbitrage between markets. Analyzing cash price changes over longer periods, such as a month, involves looking at adjustment processes in spatial equilibria between markets or evaluating specification error. It is not surprising, for example, that Uri and Rifkin concluded that Los Angeles, Kansas City and New York were part of a single national flour market when they found instantaneous causality in their "adjusted" weekly data. Arbitrage between those distant markets requires less than one week.

Analysts should attempt to identify the decision process of economic agents being studied, especially in applications of Granger causality tests because the emphasis is on identification of information dissemination processes. For example, estimates of adjustment periods in the grain marketing complex based on causality models have recently produced contradictory results. Adjustment periods were estimated to range from days to months between commodities and spatial markets, with a much more rapid adjustment period being found when using less aggregated data (Beutler and Brorsen; Brorsen, et al.). As is the case with Granger causality tests, estimates of adjustment periods are subject to problems implied by data aggregation, raising the question: what do these adjustment periods actually measure -- market efficiency, specification error, or spatial adjustments between markets?

Aggregation Across Time

Intuitively, it is clear that data aggregation can be a problem in market and price analysis. In a commodity market where price adjustment occurs in a day or less, utilization of weekly price data might disguise the true nature of temporal relationships (Engle and Liu).

Problems of aggregation across time can arise from missing information. In analyzing price series with distributed-lag or autoregressive models, the missing data problem can evidence itself as either a skipped sampling (using only one day of the week) or time aggregates (average for a period) (Maddala). Zellner and Montmarquette summarized the problems of aggregation to include distortion of parameter estimation, lower power of tests, inability to make short-run forecasts, and inability to discover new hypotheses about the short run behavior of data. Therefore, the question is how to deal with aggregation in causality testing.

Leamer suggested the addition of two words to econometric discourse. The two words are "whimsy" and "fragile". According to Leamer:

> "In order to draw inferences from data as described by econometric texts, it is necessary to make whimsical assumptions. The professional audience consequently and properly withholds belief until an inference is shown to be adequately insensitive (not fragile) to the choice of assumptions."

In causality tests a large number of distributional assumptions must be made in order to estimate the models. Data aggregation can cause considerable disruption of these assumptions. So there is a need to examine whether the inferences associated with causality tests are insensitive to the choice of assumptions when dealing with empirical data.

The concept of "fragile" refers to whether conclusions drawn from a model hold up if the model is changed. If conclusions are sensitive to prior assumptions or model specification, the model's credibility is in question. Leamer's approach to judging validity is used in the analysis which follows.

Granger Causality

Testing for Granger-type causality between specified markets is frequently done using tests refined by Geweke based on one- and two-sided distributed lag regressions for each bivariate relationship specified. This approach is not a test of exogenity but rather of "informativeness". Jacobs, Leamer and Ward define "informativeness" as the usefulness of one variable in predicting another. This form of the test is used here because it is among the most common type applied.

To test the null hypothesis that X does not predict Y, ordinary least squares (OLS) is used in this procedure. The test for one-way causality is based upon the following specification:

$$(1)\quad Y_t = a_1 + \sum_{j=1}^{p} a_{1j} Y_{t-j} + e_{1t}$$

$$(2)\quad Y_t = a_2 + \sum_{j=1}^{p} a_{2j} Y_{t-j} + \sum_{k=1}^{q} b_{2k} X_{t-k} + e_{2t}$$

where p and q are the number of lags specified by Akaike's final prediction error (FPE), as described by Bessler and Brandt. The residuals (e_{it}) are independent, serially uncorrelated random variables with zero means and finite variances for all time periods. The F-test used for testing the informativeness of X on Y is

$$(3)\quad [(SSE_1 - SSE_2)/q] \,/\, [SSE_1 \,/\, (T-p-q-1)].$$

SSE refers to the sum of squared errors of the equation and T refers to the number of observations. A significant F-test implies the existence of information in X about Y. A similar test is used to evaluate the informativeness of Y on X (Ziemer and Collins).

A test of no instantaneous causality is used also, which is based on the residuals from equation 2 and those from

$$(4)\quad Y_t = a_3 + \sum_{j=1}^{p} a_{3j} Y_{t-j} + \sum_{k=o}^{q} b_{3k} X_{t-k} + e_{3t}\ .$$

The F-test in this case is redefined to be

$$(5)\quad (SSE_2 - SSE_4) \,/\, [SSE_2 \,/\, (T-p-q-2)].$$

A significant F-test implies instantaneous causality exists between the two markets (Bessler and Brandt).

If the original price series is found not to be stationary, a first difference filter is frequently applied to remove the linear trend (Granger and Newbold). However, Sims (1980) and Litterman argued that stationarity may be unnecessary. Therefore, this study follows Granger's principle that series need only to be consistent (all either stationary or nonstationary) (Bessler and Kling).

An Empirical Example

To demonstrate the importance of aggregation in causality analysis, Granger tests are applied to eight aggregated data sets based on the same original price series. The results will indicate whether Granger causality tests are "fragile" to changes in assumptions about data aggregation required for the analysis, as implied by the discussion above.

Data Set

Daily price data for No. 2 yellow corn were collected for the Minneapolis, Chicago and St. Louis markets for October 1980 through May 1985 from the USDA's "Grain and Feed Market News". The mid point of each daily range was used.

The markets were selected because of their close spatial linkage and their significance for the undifferentiated commodity analyzed. It is expected that any causality evidenced in the price series for such markets would more likely be based upon actual interaction than that found in more distant spatial markets.

The daily price data were transformed using methods appearing in the literature to develop seven additional data sets. Five data sets consisted of daily prices for a specific day of the week. For example, the Monday price data set consisted of the daily corn prices that occurred on all Mondays during the specified time period. The other two series, the weekly and monthly data sets, were simple averages of the daily prices for the relevant periods.

FPE Results

Presented in Table 1 are the appropriate number of lags as specified by Akaike's FPE technique. All the price series were first differenced to remove the determinate part of the price series before the FPE technique was applied.

The lag structure for a specific market was affected greatly by the level of time aggregation. For example, the Minneapolis results indicate that aggregating the data may have created a lag structure where none existed before. The daily data had a zero lag structure, but a <u>three month</u> lag appeared using monthly average data. Also, using different days of the week generated lag structures ranging from three to seven weeks for the same Minneapolis data. Also, there was no consistency in results between markets. Clearly, this phenomena is caused by something other than inefficiency in the corn markets analyzed.

Granger Causality Test Results

In the estimated autoregressive models p and q were assumed to be equal (Bessler and Brandt). The longest lag structure, as identified by the FPE results, was used to determine the length of the lag structure for each model. The Q-statistics for the specified autoregressive models revealed that whitening was achieved for all the price series except the daily data.

The Q-statistic was used to determine if the residuals were generated by a white noise process (i.e., independently distributed random variables). The Q-statistic tests the joint hypothesis that all of the autocorrelation coefficients are zero. The statistic is approximately distributed as chi-square, therefore, a large Q-statistic implies that the null hypothesis of the residuals being white noise must be rejected (Pindyck and Rubinfeld).

All the Q-statistics were highly significant for the daily price series estimations. To correct for this problem, lag structures for the daily data were expanded to 5 lags and the resulting Q-statistics indicated that whitening was achieved. Also, subsequent estimates of dynamic multipliers were more consistent with theoretical expectations. Results from these revised daily price models are reported in Tables 2-4.

The hypothesis of instantaneous causality was accepted for all types of aggregation, but one-way causality tests were more fragile to levels of time aggregation (Table 2). Five of the six specified one-way causalities were significant for the daily price data. This significance level is partly attributable to the large sample size used in the daily price analysis (Jacobs, Leamer, and Ward). The one day of the week analysis found one-way causality tests to be very sensitive to which day of the week was selected. Friday-only prices provided no evidence of one-way causality. The remaining days all had at least one significant result. In general, inconsistent conclusions were very prevalent in the one-way tests.

These results should not be too surprising. If a strong instantaneous price relationship exists between two markets, this implies that a majority of the price adjustment is accomplished in the same day. Therefore, price changes between weeks should strongly reflect the instantaneous nature of the price adjustment process.

Also, lead-lag relationships are often more dependent upon price movements between days than between weeks. For example, a price change on Friday is probably more dependent upon the price change on Thursday of the same week than the price change on Friday of the previous week. Using only one day per week in a price analysis places a restriction on the distributed lag structure of zero coefficients for all the other days of the week.

Results for the simple weekly and monthly price averages also indicate an instantaneous price adjustment process (Table 2); no significant one-way causality was found. These results appear to support the theoretical expectation of information loss due to aggregation.

Economic Dynamics

Brorsen, et al. proposed using causality models to study the dynamic properties of markets to better understand the transmission of information. They estimated total long-run and intermediate multipliers.

To evaluate this proposed use of causality models, the current analysis also estimated long term and intermediate multipliers for the instantaneous models using the simulation approach suggested by Pindyck and Rubinfeld. Unlike the previously cited analysis, the multipliers were estimated here by assuming a one cent change in the specified exogenous market. The total long-run multiplier is defined to measure the total long-run price change in the endogenous market resulting from a one cent change in the exogenous market.

The speed of the adjustment process is measured by how rapidly the intermediate multiplier approaches the value of the long-run multiplier. Following the example of Brorsen, et al., the process was defined to continue for the number of periods required for the intermediate multiplier to stabilize within five percent of the long-run multiplier.

In a spatial equilibrium model based on the "one-price" theory, the long-run multiplier is not expected to be significantly different from one. If all other factors are constant, it is expected that a price change in one market would be matched by a competing market. Brorsen, et al. argued that long adjustment periods may also indicate economic inefficiency.

In this study, the estimated long-run multipliers again indicate the problems associated with using aggregated data in a spatial analysis (Table 3). The daily data produced long-run multipliers that were very close to one. However, the size of long-run multipliers appeared to increase with increasing levels of aggregation. The relationship between Minneapolis and Chicago, particularly, reflected this tendency.

Length of Adjustment Period

The length of adjustment period was affected significantly by the level of time aggregation (Table 4), as hypothesized in the dynamic multiplier literature. The adjustment process was quite rapid using daily data, requiring four days or less. When the stabilization level was set at 10 percent, the adjustment period was one day or less. These results support many empirical studies, such as that by Garcia, and indicate market efficiency.

If the adjustment process for price changes does occur in less than a week, results for analyses using longer time aggregates should indicate instantaneous adjustment periods. If such results were obtained it would be reasonable to conclude that analysis of the dynamic adjustment process was not "fragile".

Using weekly average data, the Minneapolis and St. Louis pairing had an adjustment period estimated to be instantaneous. Their close proximity, plus both being on the Mississippi River system, probably contributed to this rapid adjustment. However, the monthly data for the pair of markets reflected a much different level of efficiency, with a three month adjustment period. The length of adjustment period varied for the other pairs of markets, but ranged up to three months also.

These adjustment periods appear to indicate pricing inefficiency in the grain marketing system. But is it inefficiency or a reflection of a fragile technique suffering from aggregation? Brorsen, et al. found extremely long adjustment periods in their analysis of spatial equilibria of grain prices using a one-day per week price series. Such assertions of inefficiency appear questionable when based on aggregated data. Identifying evidence of instantaneous causality may represent one way of determining whether much confidence should be placed in findings of long adjustment periods. This would be consistent with the recommendations of Judge, et al. that if the actual adjustment process is much shorter than the aggregated data observation period, the model should not be specified as dynamic.

Concluding Comments

Aggregation across time should not be ignored when evaluating the results of Granger causality. Previous theoretical analyses indicate that specification errors can develop when estimating autoregressive and distributed lag models. Data should be consistent with both the relationships specified by economic theory and the actual decision rules of the economic agents involved. Spatial equilibrium theory does, under certain conditions, guide expectations of price behavior between various markets for identical products.

The nature of both the arbitrage process and the physical movement of the product may provide additional guidance in selecting appropriate time aggregated data. If a commodity is merchandised primarily to local markets with little import or export, it is expected that prices will be less responsive to changes in other markets and more aggregated data could be used. If all markets for a product are linked electronically, attention has to be directed at the information dissemination process. In such a market, intra-day pricing information may be required to identify true causal patterns.

One-way Granger causality appears rather fragile. Significant one-way causality did not appear consistently in the eight forms of data aggregation analyzed in the empirical example. In contrast, the instantaneous causality was significant in all eight groups of data series. This indicates that identification of instantaneous causality may imply a need for further disaggregation of data if valid one-way causalities are to be identified.

Incorporating more stringent theoretical considerations and applying alternative econometric techniques to data analyzed for Granger causality are necessary to improve the validity of causal hypothesis testing. For example, theoretical expectations about the characteristics of dynamic multipliers may indicate the adequacy of a model's specification. Also, Blank and Schmiesing proposed combining path analysis with causality tests to more adequately assess prices in a spatial equilibrium model.

In general, a price analyst has many options when attempting to deal with the problem of time aggregation. As noted above, this paper argues that the best approach is to assure that data is consistent with both the relationships specified by economic theory and the actual decision rules of the economic agents involved.

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Table 1. Minimum Lag Determined by Final Predication Error (FPE) for Selected Markets With Specified Aggregation of Corn Prices.

Level of Price Aggregation	Corn Markets Analyzed: Minneapolis	Chicago	St. Louis
	Number of lags using:		
	ALL AVAILABLE PRICE DATA (Lags Expressed in Days)		
1. Daily Prices	0	1	1
	PRICES FOR ONLY ONE DAY PER WEEK (Lags Expressed in Weeks)		
2. Monday Prices	4	3	3
3. Tuesday Prices	7	0	1
4. Wednesday Prices	3	3	3
5. Thursday Prices	4	3	2
6. Friday Prices	3	3	0
	AVERAGE PRICE FOR SPECIFIED PERIOD (Lags Expressed in Weeks)		
7. Weekly	4	3	3
8. Monthly[a/]	12	12	12

a/ Reported figures assumed 4 weeks per month so actual lags were 3 months for all relationships.

Table 2. F-Tests[a/] for Granger Type Causality Tests Based on Different Levels of Aggregation of the Corn Price Data.

Causality Tested	Daily Prices[b/]	Prices for Only One Day of the Week					Average Price for Period	
		Mon.	Tues.	Wed.	Thurs.	Fri.	Weekly	Monthly
1. Number of Observations	1144	206	226	227	223	218	229	46
2. Mpls ⟵ Chicago	1.28	1.36	0.56	2.74+	0.82	1.48	0.45	0.64
═	1386.02+	512.33+	586.00+	497.10+	476.04+	723.88+	749.82+	349.35+
⟶	4.09+	0.50	0.82	2.24*	2.26*	1.42	1.39	0.05
3. Mpls ⟵ St. Louis	5.21+	0.62	0.21	0.18	1.59	1.13	0.11	1.71
═	1417.50+	581.88*	859.25+	674.30+	650.25+	689.14+	1041.87+	427.68+
⟶	3.66+	0.55	0.76	1.44	0.50	0.18	0.80	0.63
4. St. Louis ⟵ Chicago	7.14+	2.04*	4.01+	2.07*	1.84	1.16	1.09	1.64
═	1176.33+	548.58+	549.03+	597.22+	529.92+	721.39+	935.00+	530.05+
⟶	1.98+	0.91	0.00	0.81	4.72+	1.56	0.99	0.95

a/ The F-statistics marked with a "*" are significant at the 10 percent level while a "+" indicates significance at the 5 percent level.

b/ Because the Q-statistic was significant for all the estimated models, using the FPE lag structure. The number of lags was expanded to 5. The reported statistics are for these expanded models. Also, the estimated multipliers were more consistent with theoretical expectations based on these models.

Note: An arrow (⟶) indicates one-way causality hypothesized as moving in the direction shown. An equal (═) indicates hypothesized instantaneous causality between the two markets.

Table 3. Long-Run Multiplier for the Specific Endogenous Market Prices when the Exogenous Market Price Increased by One Cent Per Bushel.

Level of Price Aggregation	Causal Relationship: Minneapolis and Chicago	Minneapolis and St. Louis	St. Louis and Chicago
		ALL AVAILABLE PRICE DATA	
1. Daily Prices	0.89	0.98	1.04
		PRICES FOR ONLY ONE DAY PER WEEK	
2. Monday Prices	1.26	0.99	1.09
3. Tuesday Prices	1.35	1.00	0.92
4. Wednesday Prices	1.19	1.04	1.09
5. Thursday Prices	1.25	1.21	1.12
6. Friday Prices	1.36	1.14	1.16
		AVERAGE PRICE FOR SPECIFIED PERIOD	
7. Weekly	1.24	1.00	1.17
8. Monthly	1.48	1.47	1.18

Table 4. Number of Periods Required Before Intermediate Multipliers are within 5 Percent of the Long-Run Multiplier.

Level of Price Aggregation	Causal Relationship: Minneapolis and Chicago	Minneapolis and St. Louis	St. Louis and Chicago
	NUMBER OF PERIODS USING:		
	ALL AVAILABLE PRICE DATA (Periods expressed in days)		
1. Daily Prices	2	3	4
	PRICES FOR ONLY ONE DAY PER WEEK (Periods expressed in weeks)		
2. Monday Prices	2	0	3
3. Tuesday Prices	4	0	0
4. Wednesday Prices	2	0	2
5. Thursday Prices	2	2	2
6. Friday Prices	2	2	2
	AVERAGE PRICE FOR SPECIFIED PERIOD (Periods expressed in weeks)		
7. Weekly	3	0	2
8. Monthly*	12	12	12

* Reported figures assumed 4 weeks per month, so actual adjustment periods were all 3 months.