Causality analysis in agricultural economics: a review of theoretical and empirical issues

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Cahiers d'économie et sociologie rurales, n° 34-35, 1995

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L'analyse de causalité en économie agricole : revue des questions théoriques et empiriques

Résumé – Les travaux de recherche menés en économie agricole comprennent souvent une analyse de causalité. Comme la théorie économique donne peu d'indications précises sur ce type de question, Granger a proposé en 1969 une approche statistique permettant de tester des hypothèses de causalité. Elle a été largement utilisée par les économistes agricoles et cet article présente un survol des analyses qu'ils ont réalisées dans ce domaine depuis les années 70.

Une première partie est consacrée à une brève discussion des relations entre la causalité au sens de Granger et divers concepts d'exogénéité. Vient ensuite une description des méthodes permettant de tester des hypothèses de causalité dans les modèles traditionnels VAR bivariés non contraints et dans des systèmes cointégrés. Elle est complétée par la présentation critique d'un certain nombre d'applications de ces méthodes en économie agricole. Malgré l'usage très répandu qui en est fait dans ce domaine, les tests de Granger, de Sims (ordinaire et modifié) et de Haugh-Pierce donnent des résultats contradictoires. Leurs résultats sont très sensibles au préfiltrage, à l'existence de variables manquantes et au choix de la longueur des retards. De plus, il est difficile d'en donner une interprétation correcte en termes de causalité. Alors que l'utilisation de modèles VAR non contraints permet de résoudre le problème des variables manquantes, les résultats des modèles VAR en niveau peuvent prêter à discussion, à cause des contraintes d'identification imposées pour l'estimation.

La non-stationarité et l'existence de racines unitaires dans les séries de données peuvent aussi être à l'origine de difficultés. Si le modèle VAR comprend des variables incluant une tendance stochastique et s'il y a une possibilité de cointégration, le test de Wald utilisé pour tester la causalité au sens de Granger dans les modèles VAR en niveau peut ne pas avoir une distribution de probabilité limite, ce qui invalide le test. Si le système comprend des variables non-stationnaires dont certaines peuvent être liées par des relations de long terme, la méthode de cointégration permet alors d'analyser la causalité de Granger d'une façon appropriée. Quelle que soit la méthode employée, la plupart des recherches faites sur la causalité en économie agricole a porté sur l'analyse des prix des produits. Un nombre croissant de travaux s'intéresse aussi aux effets macroéconomiques sur l'agriculture. Enfin, l'analyse de la causalité menée à l'aide des systèmes cointégrés a permis le réexamen d'un certain nombre de paradigmes bien établis de l'économie agricole. Compte tenu des avantages et des inconvénients des diverses méthodes, l'auteur propose d'utiliser une approche séquentielle basée sur la méthode du maximum de vraisemblance de Johansen pour tester la causalité au sens de Granger dans le cas des systèmes cointégrés comprenant des variables à tendance stochastique.

Mots-clés :
causalité de Granger, modèles traditionnels bivariés, modèles VAR non contraints, systèmes cointégrés, économie agricole

Causality analysis in agricultural economics : a review of theoretical and empirical issues

Summary – *This paper provides an overview of causality analysis in agricultural economics. The relationships between Granger causality and various concepts of exogeneity are discussed. Four traditional causality tests developed for testing Granger causality are described and their applications in agricultural economics are critically appraised. Causality analysis in vector autoregressive and cointegrated systems along with their applications in agricultural economics are discussed. Irrespective of the methodology, commodity price analysis received most of the applications of causality analysis in agricultural economics. In view of the strengths and weaknesses of different approaches, a sequential approach for testing Granger causality based Johansen's maximum likelihood method is suggested for systems involving variables with stochastic trends and cointegration.*

Key-words :
agricultural economics, Granger causality, unrestricted VAR models, cointegrated systems, traditional bivariate models

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THE concept of causality is central to any scientific inquiry. Although it is a widely used concept in agricultural economics, the literature on causality does not lack in controversy. Even the meaning of the term itself is under dispute (Holland, 1986; Basmann, 1988). While the origin of the term 'causality' can be traced back to the writings of Aristotle, a renowned Greek philosopher, its meaning has evolved through time in the writings of prominent philosophers like Locke, Hume, Mill and Suppes. There is a lack of consistency in the literature as to how these philosophers defined the term and whether or not it is measurable in practice. Despite occasional debates among themselves the philosophers did not produce a precise definition of causality that a majority can accept, nor did they produce an operational definition that is useful in economic analysis (Granger, 1980; Prioier, 1988)*.

Empirical research in agricultural economics often requires some causal issues to be resolved. In many occasions, economic theory provides no precise guidance in this regard. As a consequence, the resolution of various causal issues had been judgemental (Thurman, 1987). Granger (1969) introduced a statistical approach to confront causal hypothesis in economics. According to this approach, a variable X_t is said to cause another variable, Y_t, if the lagged values of X_t provide information useful for predicting Y_t. Notice that this simple notion of causality is firmly rooted in statistics and has little relation to the philosophical notion of "cause and effect". This, however, has not stopped Granger causality tests from becoming a standard tool in commodity price analysis since the early 1980s.

A concept closely related to causality is exogeneity. A clear understanding of the relationship between causality and exogeneity is essential for the evaluation of causality results and their interpretation. Exogeneity plays a fundamental role in econometric estimation and statistical inference. The exogeneity of a variable depends on whether it can be treated as "given" in a model without loosing information for the purpose of research at hand. In essence, it depends on two critical factors: (i) the parameters of interest to the investigator, and (ii) the purpose of the model, whether it is for statistical inference, forecasting or policy analysis. The objectives of research define the parameters of interest while the three purposes for modelling define three types of exogeneity called weak, strong, and super (Engle *et al.*, 1983). If two variables, X_t and Y_t are jointly normally distributed and are serially independent, then X_t is said to be weakly exogenous if inference on the parameters of interest

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* I would like to thank four reviewers of the journal for their helpful comments. I am particularly grateful to the third reviewer whose extensive comments significantly improved the paper. Any remaining errors are, of course, my responsibility.

conditional on X_t involves no loss of relevant information. The weak exogeneity implies that a precise specification of the marginal distribution of X_t is not necessary for the analysis. If in addition to being weakly exogenous, X_t is not Granger caused by Y_t, then X_t is called strongly exogenous. Finally, if there is a structural change causing changes to the underlying data generating mechanism for X_t, the observed values of X_t and its dispersion will change. If the conditional relationship between Y_t and X_t remains unaffected despite these changes (*i.e.*, if the parameters of interest are variant to the structural change), then X_t is said to be super exogenous. While weak exogeneity is essential for conducting statistical inference, Granger noncausality is required for valid conditional forecasting. The condition that Y_t does not Granger cause X_t is neither necessary nor sufficient for the weak exogeneity of X_t(1).

A number of alternative procedures have been developed in the 1970s to conduct Granger causality test in bivariate models. Conflicting causality results in agricultural economics have been obtained from these tests. Misspecification inherent in most bivariate causality models along with conflicting results from alternative causality tests have generated considerable controversy. The misspecification issue has been addressed in multivariate vector autoregressive (VAR) models since the mid 1980s. Impulse responses from these models are used to generate causal inferences. While the introduction of causality analysis in a VAR framework represents a significant improvement over the traditional causality analysis in bivariate models, it has been realized in recent years that causal inferences from VAR models can also be misleading. This is particularly true for variables which have stochastic trends in their univariate representations. Unconstrained VAR modelling with such variables can be problematic and causality results from such models can be controversial.

It is well known that most economic time series are not stationary in their levels. That is, both the mean and variance of these series are not constant over time. The error terms resulting from standard regression analysis of nonstationary variables do not follow a standard normal distribution even asymptotically. Consequently, the conventional statistical tests such as *t*, *Z*, *F* etc. are not valid. These revelations led most recent studies in agricultural economics to derive causal inferences from cointegrated or constrained VAR models. Cointegration is a statistical property which can describe the long-run behaviour of economic time series. The point of departure of cointegration theory is the proposition that if the nonstationary variables are integrated of order one, then it is possible that some linear combination of these nonstationary variables are stationary. If this is true, then the variables are called cointegrated. When some economic variables are cointegrated, they cannot move too far

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(1) For a more rigorous treatment of the concepts of exogeneity, Granger noncausality and predeterminedness, see Engle *et al.* (1983) and Ericsson (1992).

apart from each other in the long-run, although their levels seem to fluctuate widely in the short-run. This property of the cointegrated variables fits perfectly with the theoretical notion of a long-run relationship among economic variables. Cointegration analysis, therefore, links the concept of equilibrium relationships among economic variables embedded in economic theory to a statistical model of equilibrium among those variables. As it turns out, in doing so, it provides a theoretically consistent and econometrically more efficient approach to test causal relationships among economic variables than has been the case with bivariate models or with unconstrained VARs.

The major objective of this paper is to provide an overview of testing causal hypotheses in agricultural economics and to identify potential avenues for improvements in causality analysis. The balance of the paper is organized as follows. The first section provides a brief exposition of four traditional causality tests. The second one concentrates on the applications of traditional causality analysis in agricultural economics and their limitations. Section three focuses on causality analysis in VAR models, applications in agricultural economics and their limitations. Section four deals with nonstationarity, cointegration and causality analysis. This section also provides an overview of major agricultural economics applications of causality analysis in cointegrated systems. The limits of causality analysis in cointegrated systems and possible future directions of causality analysis in agricultural economics are also discussed. The final section summarizes the main points and concludes the paper.

TRADITIONAL CAUSALITY TESTS: AN EXPOSITION

The statistically testable notion of causality introduced by Granger led to the development of four major causality tests: the Granger test, the Sims test, the modified Sims test and the Haugh-Pierce test. Each of these tests investigates three alternative causal hypotheses: (i) Y_t causes X_t, or, (ii) X_t causes Y_t, or, (iii) there is a feedback relationship between Y_t and X_t. The following is a brief exposition of these tests.

The Granger test

The Granger test involves regressing a variable, Y_t, on lagged values of itself and on lagged values of the other variable of interest, X_t, such that:

$$Y_t = \alpha_0 + \sum_{j=1}^{J} \beta_j Y_{t-j} + \sum_{i=1}^{M} \gamma_i X_{t-i} + e_t \qquad (1)$$

Where α_0 is the intercept, β's and γ's are regression coefficients and e is the error term$^{(2)}$. The assumption on the error term requires that the variables are stationary and there is no autocorrelation. The null hypothesis that X_t does not cause Y_t (*i.e.*, H_0: $\gamma_1 = \gamma_2 = \ldots\ldots = \gamma_j = 0$) is tested using an F-test calculated from the residuals of the restricted and unrestricted forms of eq. (1). The above procedure can be repeated reversing the roles of Y_t and X_t to test the null hypothesis that Y_t does not cause X_t. These F-tests will also determine if there is any feedback relationship between the two variables. Note that the Lagrange multiplier (LM) test can also be used to test the above causal hypotheses.

The Sims test

An alternative formulation of Granger causality test was introduced by Sims (1972). Suppose, Y_t and X_t represent a jointly covariance-stationary stochastic process. According to Sims, if X causes Y then in the regression of Y on past and future values of X, the future values of X as a group should have coefficients statistically not different from zero. Thus, the Sims test is based on the following regression equation:

$$Y_t = \alpha_0 + \sum_{j=-LF}^{LP} \alpha_j X_{t-j} + e_t \tag{2}$$

where LF and LP are the lengths of leading and lagged values respectively.

The test of the null hypothesis that Y does not Granger cause X is equivalent to testing the constraint: $\alpha_j = 0$, for all $j = -1, -2, \ldots, -LF$. The joint significance or lack thereof of these future coefficients provides the basis for the Sims test. The restricted and unrestricted forms of equation (2) are estimated and the residuals from these equations are used to test the null hypothesis.

The Modified Sims test

A useful modification of the Sims test is proposed by Geweke *et al.* (1983). The modification involves the inclusion of lagged dependent variable in the regression to purge serial correlation from the estimated residuals. Consequently, there is no need to use an ad hoc quadratic prefiltering or a generalized least squares (GLS) procedure as suggested by Sims (1972). Thus the modified Sims test is based on the following equation:

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(2) In addition to the intercept, α_0, one can also include a time trend and seasonal dummy variables in equation (1). A time trend and seasonal dummy variables may also be included in Sims' and modified Sims' tests.

$$Y_t = \alpha_0 + \sum_{j=-LF}^{LP} \alpha_j X_{t-j} + \sum_{k=1}^{P} \beta_k Y_{t-k} + e_t \qquad (3)$$

Here also, the test of the null hypothesis that Y does not cause X is equivalent to testing the joint significance of the constraints $\alpha_j = 0$, for all $j = -1, -2, ..., -LF$. The residuals from the restricted and unrestricted forms of eq. 3 are used to compute an F-statistic to test this hypothesis.

The Haugh-Pierce test

This test involves a two step procedure; the first step involves estimation of an autoregressive integrated moving average (ARIMA) model for each variable. The residuals from the first step are used to estimate cross-correlation functions in the second stage. The test for causality between Y and X is based on the significance of these cross-correlations (Pierce and Haugh, 1978).

Suppose $P(B)$ and $L(B)$ are two previously chosen filters for series Y_t and X_t respectively, so that, $U_t = P(B)Y_t$, and $V_t = L(B)X_t$. There is no serial correlation in either of the error terms U_t and V_t. The causality pattern between two original series, Y_t and X_t, can be assessed by cross-correlating U_t and V_t such that:

$$\rho_{uv}(k) = \frac{E(U_{t-k}, V_t)}{[E(U_t^2) \cdot E(V_t^2)]^{1/2}} \qquad (4)$$

where k is the lag length.

Since both series are white noise, the cross-correlation procedure is symmetric. Consequently, a single estimate is sufficient to characterize causality in both directions. In practice, $\rho_{uv}(k)s$ are unknown and are estimated as residual cross-correlations. Once the residual cross-correlations are estimated, each individual estimate is tested for its statistical significance and only the significant cross-correlations are used to determine the causal patterns. Finally, the causal hypotheses are tested using a U-test which has an asymptotic χ^2 distribution.

Pierce and Haugh (1978) have shown, in terms of linear predictability, the theoretical equivalence of the above causality testing procedures. Despite their apparent theoretical equivalence, however, these causality tests have generated inconsistent causal conclusions in empirical applications (Conway *et al.*, 1984).

APPLICATIONS & LIMITATIONS OF TRADITIONAL CAUSALITY ANALYSIS

All of the traditional causality tests described above have been used extensively by agricultural economists since the early 1980s. Commodity price analysis experienced a flurry of activity in Granger causality testing during the 1980s. For example, 13 out of 16 causality studies summarized in table 1 investigated some lead-lag relationships between various price series. Note that except for those in Heien (1980), Freebairn (1984) and Weersink and Tauer (1991), all causality results reported in table 1 are derived from bivariate models. In most cases the lag-lengths are determined arbitrarily. While a wide variety of prefiltering, ranging from simple first differencing to complex ARIMA procedures, has been used to create white noise series, only in a few cases it has been empirically verified that such prefiltering did adequately remove serial correlation from the data.

Given the variations in lag lengths, model specifications and data used, it is difficult to compare causality results from various studies reported in table 1. Clearly, the price transmission and price discovery studies dominate traditional causality analysis in agricultural economics. The results are, however, mixed. For example, both Heien (1980) and Ward (1982) investigated Granger causality between prices at different levels in the food marketing chain with US data. Both found unidirectional causality running up the marketing chain from wholesale to retail prices. However, these findings are disputed by Freebairn (1984).

Causality results from international price transmission and price leadership studies are also mixed. For example, while Spriggs *et al.* (1982) found US wheat prices to lead Canadian wheat prices only during the commodity boom period of the mid 1970s (*i.e.*, during the 1974-76 period), Lee and Cramer (1985) found US wheat prices to lead all other wheat prices including the Canadian prices since 1972. In a bivariate study of land rents and land prices Phipps (1984) discovered unidirectional Granger causality from rents to land prices which is consistent with the present value model of land price determination. However, in a bivariate study of research expenditures and output growth in agriculture Pardey and Craig (1989) found feedback relationship between research expenditure and agricultural productivity which is not quite consistent with the expected theoretical relationship. In their study of the effects of advertising, Reynolds *et al.* (1991) found advertising to Granger cause the sale of both butter and cheese in Canada. Finally, in a multivariate model Weersink and Tauer (1991) found dairy herd size to Granger cause productivity. They also found unidirectional causality from input and output prices to both herd size and dairy productivity in the United States.

Table 1. **Summary of Selected Traditional Causality Studies in Agricultural Economics**

Author(s)	Problem investigated	Nature of data used	Type of filter used	Lag selection criterion	Causality test used	Conclusion(s)
Bessler and Shrader (1980)	Causality between EMEC and UB price quotes for eggs in the US	Twice weekly price quote data of UB and EMEC for 1977-78	Box-Jenkins ARIMA filters	Ad hoc : 0,9 ; 10,10 (3,3) and (9,9) lags	Haugh-Pierce test and Sims test	Egg marketing evaluation Committee price quotes causes Urner Barry's price quotes
Heien (1980)	Causality between retail and wholesale prices in the US	Monthly data for 23 food items : 1960-1 to 1976-12	Quadratic : $(1\text{-kL})^2$ with k=0.75	Ad hoc : 4 leads and 8 lags	Sims test	Unidirectional causality runs from wholesale to retail levels
Spreen and Shonkwiler (1981)	Causality between feed costs and feeder and slaughter cattle prices in the US	Monthly data from Jan. 1966 to Dec. 1979	First differencing	Ad hoc : use a priori notion of the cattle production process	Granger test, Sims test and Haugh-Pierce test	Feed costs lead both slaughter steer and feeder prices
Spriggs, Kaylen and Bessler (1982)	Price leadership between US and Canadian wheat prices	Daily Canadian and US prices of spring wheat for 1963/64-1978/79 period	Box-Jenkins ARIM filters	Ad hoc : 0 to 3 lags	Haugh-Pierce test	US wheat prices lead Canadian wheat prices only during the 1974-76 period
Ward (1982)	Causality between retail, wholesale and shipping point prices in the US	Monthly average prices of 8 perishable commodities for four major cities	Empirically determined filters	Ad hoc : 4 leads and 8 lags	Sims test	Wholesale prices lead both retail and shipping point prices
Grant *et al.* (1983)	Causality between wheat, rice, sorghum, corn, oats and barley prices in the US	Weekly prices at Kansas City, Minneapolis and Houston (1974-1980)	Autoregressive filters after first differencing	Ad hoc : 30 lags for rice and 20 for all other grains	Haugh-Pierce test	Instantaneous causality between feed grain prices, and the price of rice causes wheat price

Author(s)	Problem investigated	Nature of data used	Type of filter used	Lag selection criterion	Causality test used	Conclusion(s)
Blank (1985)	Price discovery process in the international tobacco market	Annual prices of flue-cured tobacco in Australia and in the US (1960-82)	No prefiltering	Ad hoc : 1 lag only	Granger test	Causality runs from US to Australian tobacco prices
Lee and Cramer (1985)	Examines the price leadership in the international wheat market	Ten monthly and four weekly price series	First differencing and ARIMA filters for weekly and monthly series respectively	Ad hoc : 0 lag	Haugh-Pierce test	US wheat prices led all other wheat prices during the 1972- 1981 period
Pardey and Craig (1989)	Causality between research expenditures and output growth in agriculture	Yearly data from 1910 to 1984	No prefiltering but detrended	FPE criterion and Bayesian criterion	Granger test	Feedback relationship between research expenditures and output in the US agriculture
Reynolds *et al.* (1991)	Effects of advertising on the sales of cheese and butter in Canada	Quarterly data : 1978-87 for butter and 1977-84 for cheese	Seasonal differencing	Akaike's FPE criterion	Granger test	Advertising causes the sale of both butter and cheese in Canada
Phipps (1984)	Relationship between farmland prices and farm-based residual returns	Annual data on land price and returns per acre from 1940 to 1979 for the US	Univariate ARIMA with first and second order differencing	Ad hoc : 7 leads and 7 lags	Haugh-Pierce test	Farm-based residual returns cause farmland prices in the United States
Freebairn (1984)	The direction of causality between farm and retail prices in Sydney, (Australia)	Monthly farm and retail prices for 3 meats, 7 fresh vegetables, 5 fruits, eggs and cereals from 1971-01 to 1982-05	An ad hoc Quadratic filter : $(1\text{-}k)^2$ with $k=0.75$	Ad hoc : 4 leads and 8 lags	Sims test	Farm prices caused retail prices for only 6 of 17 commodities. No causal relationship was found between the two prices for 10 commodities
Brorsen *et al.* (1984)	The dynamic relationships of imported rice prices in Europe	Weekly price of rice at Rotterdam imported from the US, Thailand and Argentina during Oct. 1976 and Sept. 1981	First differencing and a quarterly spline filter	AIC criterion : 1, 3 and 4 lags respectively for Thai, the US and Argentinean rice prices	Haugh-Pierce test and the modified Sims test	Both the US and Argentinean prices are influenced by Thai prices. There is also a feedback relationship between the US and Argentinean prices

Author(s)	Problem investigated	Nature of data	Type of filter	Lag selection	Causality test	Conclusion(s)
Boyd and Brorsen (1986)	The dynamic price relationships for the US and the EC corn gluten feed and related feed markets	Weekly Rotterdam (cif) and Chicago prices for soybean meal and corn gluten feed and weekly German prices of barley and the US prices of corn. The data span from Jan. 1978 to April 1984	First differencing	Akaike's information criterion (AIC)	Granger test	Chicago corn gluten feed price is unidirectionally caused by all other prices. Rotterdam corn gluten feed and soybean meal are close substitute while they are only weak substitute for German barley
Dries and Unnevehr (1990)	Impact of domestic trade policies on price integration in the world beef market	Quarterly international beef prices from early 1960s to 1986 for the US, Australia, Argentina, Germany, France and Ireland	First differencing	Schwarz's Bayesian information criterion	Granger test	The US is the price leader in the world beef market. Domestic trade policies have strongly influenced price integration in the international beef market
Weersink and Tauer (1991)	Causality between dairy farm size and productivity in the US	Yearly state level data from 1964 to 1987	First and second order differencing	Akaike's FPE criterion	Granger test	Herd size caused productivity, and they are both caused by input and output price changes

Although there has been many applications of Granger causality tests in agricultural economics, it has become clear in recent years that a number of serious problems are associated with the method (Conway *et al.*, 1984). Causality results are not robust to model specifications. Unidirectional causality between two variables obtained from a bivariate model can be reversed with the inclusion of a third relevant variable into the model. For example, the one-way causality from rents to land prices in a bivariate model obtained by Phipps (1984) may change if the model is expanded to include direct government subsidies to farmers and the rate of inflation, both of which are expected to influence land prices. All causality results from bivariate models reported in table 1 are subject to this criticism.

Data transformation or prefiltering, such as simple first differencing, quadratic filtering etc. are essential component of traditional causality analysis. However, they are not causality preserving (Schwert, 1979). Since most of the commodity price series are characterized by stochastic rather than deterministic trends, this aspect of traditional causality test is especially troublesome. While differencing reduces the effects of stochastic trends it also removes the long-run information from the data. When long-run information are removed from the data, there is no valid ground for mounting Granger causality tests in models containing one or more nonstationary variables (Toda and Phillips, 1993). To the extent data nonstationarity is present, causality results summarized in table 1 may also suffer from spurious regression problem identified by Granger and Newbold (1974).

The choice of appropriate lag-lengths are important for introducing adequate dynamics in the model. The results of traditional causality tests critically depend on the parameters of the lagged variables in the model. Consequently, arbitrary choice of lag-lengths may produce misleading causal results (Thornton and Batten, 1985; Gupta, 1988). Such lag selection bias is present in 10 out of 16 studies reported in table 1.

The majority of the traditional causality models in agricultural economics involves only two variables. Some relevant variables have not been included in the analysis. The estimated models are, therefore, missspecified. Since there is a tendency for some commodity prices to be correlated, the estimated parameters of bivariate models can be biased. Such specification errors may generate misleading causality results. For example, Pardey and Craig (1989) investigated causality between research expenditures and output growth in US agriculture with annual data from 1910 to 1984. During this period two additional factors, such as the weather and farm programs, must have contributed to the growth of agricultural output in the US. The farm program spending may also be correlated with research expenditures. Exclusions of these two important variables from the model may have generated the somewhat troubling results reported in Pardey and Craig (1989).

By construction, the Haugh-Pierce test has an inherent bias in favour of the null hypothesis, except in a special case when the omitted variables are uncorrelated with the included ones (Sims, 1977). Moreover, once the innovations of y_t and z_t are significantly correlated, there is no way for the data to shed light on the truth or falsehood of the causal assumption (Ling, 1982). So, the cross-correlation approach may not be appropriate for determining causal relationships. Consequently, the causality results generated from the Haugh-Pierce test, such as those in Spriggs *et al.*, Grant *et al.*, Lee and Cramer and Phipps are suspect.

The most important criticism of the traditional causality tests is that they lack any explicit theoretical structure. Consequently, the traditional causal models may be only summarizing correlations rather than determining causal relationships (Cooley and LeRoy, 1985). The lack of an explicit theoretical structure also makes it difficult to give proper interpretation to causality results. For example, Heien (1980) discovered unidirectional causality from the wholesale to retail level for the majority of 23 food items tested. The results suggest lags up to four months between wholesale and retail price changes. How can we interpret these results? In particular, do the lags reflect imperfections in food manufacturing industries or do they reflect dynamic adjustments to food price and wage rate changes? Without an explicit theoretical framework, it is problematic to give proper interpretation to these causality results.

The above analysis suggests that a number of critical problems are associated with the traditional causality tests and that Granger causality results should be judged with a healthy dose of skepticism. Despite all these problems associated with the traditional causality tests, application of causality analysis in agricultural economics continued. Many economists including David Hendry (see Gilbert, 1986) and P.C.B. Phillips (see Toda and Phillips, 1993, 1994), believe that causality testing will remain as a useful tool for model identification in empirical economic analysis.

A number of attempts have been made since the mid 1980s to improve causality testing in agricultural economics. Holmes and Hutton (1988) developed a nonparametric Granger causality test and applied it to investigate prima facie causal relationships in the livestock market (Holmes and Hutton, 1991). They employed a multiple-rank F-test to determine causal ordering. Larue and Ker (1993) have also applied this test to investigate if there is any prima facie causal relationship between world price variability and protectionism in meats, cereals and oilseeds. The results are mixed. While the nonparametric test represents an interesting functional-form and distribution free alternative to the traditional Granger causality test, it has two basic limitations. This test can be used only for inference and not for forecasting or policy analysis. Also, it has low power in finite samples when the errors are approximately normally distributed (Holmes and Hutton, 1990).

A second attempt was made by Uri and Lin (1992) to develop a parametric test for instantaneous causation. In a bivariate context, they used ARIMA filters to obtain white noise series. Instead of cross-correlating the filtered series as in Haugh-Pierce test, they regress one series on the current and lagged values of the other series and on the lagged values of the same series. The instantaneous causality from one variable to another is determined by the significance of the coefficient of the current value in the regression. Uri and Lin used this test to examine substitutability between domestically produced beef and beef imported from the United States in Japan while Uri *et al.* (1993) applied this test to determine the nature and extent of spatial market integration for soybeans and soybean products. In addition to the problems associated with the traditional causality tests in bivariate models, the parametric and nonparametric tests developed for testing prima facie or instantaneous causality have a fundamental structural problem.

Since a lagged time sequence is essential for Granger causality test, the prima facie or instantaneous causality tests are not consistent with Granger's concept of causality (Granger, 1988). Due to these inadequacies, the prima facie causality test developed by Holmes and Hutton and the instantaneous causality test developed by Uri and Lin did not receive wide applications in agricultural economics. Causality analysis in agricultural economics, however, continues to flourish in VAR and cointegrated VAR models. The following sections focus on this literature.

CAUSALITY ANALYSIS IN UNRESTRICTED VAR MODELS

In view of the weaknesses of traditional Granger causality tests, a number of recent studies in agricultural economics used impulse responses from unrestricted VAR models to test for causality. This section provides a brief review of the methodology and a critical assessment of its application in agricultural economics.

Vector autoregression (VAR) is a time-series econometric method introduced by Sims (1980) and subsequently developed by Sims (1982), Doan *et al.* (1984) and Sims (1986). It is essentially a dynamic simultaneous equation system with all dependent variables as endogenous and all independent variables as lagged observations of the endogenous variables in the system. Thus, all variables in a VAR model affect each other through the system of lags. Unlike traditional structural models, a VAR model emphasizes more on empirical regularities and less so on the theoretical restrictions.

A traditional VAR model with a set of k variables can be written as:

$$A_0 Y_t = \sum_{i=1}^{m} A_i Y_{t-i} + u_t \tag{5}$$

Where Y_t is a (k x 1) vector of observed variables, u_t is a (k x 1) vector of error terms. The error terms are assumed to have a zero mean and a diagonal variance-covariance matrix, Ω. Finally, A_0 and A_i's are (k x k) matrices of parameters defining dynamic interactions among the variables in the model. All these parameters need to be estimated from the VAR model.

Premultiplication of equation (5) by the inverse of A_0 yields:

$$Y_t = \sum_{i=1}^{m} B_i Y_{t-i} + v_t \tag{6}$$

where $B_i = A_0^{-1} A_i$ for i = 1, 2, ..., m, and $v_t = A_0^{-1} u_t$. The residual vector v_t represents the one-step ahead prediction error in Y. The variance-covariance matrix of these residuals is Σ (since var(u_t) = Ω, var(v_t) = $A_0^{-1} \Omega A_0^{-1'}$). This covariance matrix plays a key role in identification and estimation of the VAR model. Note, however, the residuals v_t are contemporaneously correlated and their variance-covariance matrix is not diagonal. The model, therefore, needs to be transformed so that the error terms are no longer contemporaneously correlated.

Equation (6) can be estimated using ordinary least squares or SUR and the estimates of B_i and Σ can be obtained. Notice, however, the crucial element of the VAR analysis is to determine the effects of the shocks u_t on the observed variables, Y_t. Since all variables in the system are interrelated through lags, it is not possible to disentangle the effects of shocking one variable on another using the autoregressive (AR) representation in equation (6). This can be accomplished by inverting the AR process in equation (6) into a moving average (MA) process. Inversion of equation (6) yields:

$$Y_t = \sum_{i=0}^{\infty} H_i v_{t-i} = \sum_{i=0}^{\infty} H_i u_t A_0^{-1} \tag{7}$$

where Hi is a (k x k) matrix of MA coefficients derived from the AR model. The only missing element in equation (7) is an estimate of A_0^{-1}. This can be derived from S through Cholesky decomposition. The estimate of A_0^{-1} is obtained as a triangular matrix which transforms error terms v_t into orthogonal innovations and their variance-covariance matrix into a diagonal one. Consequently, the impact of the behavioral shocks in each equation on all endogenous variables can now be identified from equation (7). It is for this reason, equation (7) is called the impulse response function (IRF). The IRF summarizes the dynamic multipliers by providing the response of all variables in the system to a one-time unit shock in one variable. Note that impulse responses generated from the IRF might be sensitive to the ordering of the variables in the VAR model. The estimates of A_0^{-1} can also be used to decompose the forecast-error variance (FEV) for each element of Y_t into components attributable to innovations in each of the endogenous variables in the system.

It is often argued in the context of VAR models that non-zero impulse responses indicate the presence of Granger causality, while variance decompositions yield measures of Granger causal priority. Sims (1982) states:

> "*A natural measure of the degree to which Granger causal priority holds is the percentage of forecast error variance accounted for by a variable's own future disturbances in a multivariate linear autoregressive model...A variable that is optimally forecast from its own lagged values will have all its forecast error variance accounted for by its own disturbances*" (pp. 131-132).

Thus, it has become a standard practice in multivariate VAR models to infer Granger causality from impulse responses and variance decompositions.

Table 2 provides a summary of 10 selected agricultural economics studies which derived causal inferences from unrestricted VAR models. Here also commodity price analysis dominates the scene; six out of ten studies deal with dynamic relationships among various commodity or input prices. Most of the price series used are monthly and the dimension of the VAR varies from three to eleven. Compared to traditional Granger causality tests, all but one study in table 2 used either Sims' modified likelihood ratio test or other empirical methods to determine the level of lag truncation. While causal inferences are mostly generated from impulse responses and decomposition of forecast error variances, a few studies have also used Granger type F-test to determine causal ordering.

Impact of macroeconomic changes, such as changes in money supply, interest rates and taxes on agriculture has been a fertile area of research since the mid 1980s. Three studies summarized in table 2 attempt to investigate the causal effects of money supply on agricultural and industrial prices. The results are, however, mixed. Using monthly data from 1964-01 to 1981-12 Bessler (1984) found money supply to cause agricultural prices in Brazil. Using quarterly data from 1975-1 to 1988-1, Orden and Fackler (1989) found that money supply is not the major cause of price instability in US agriculture. Using monthly data from 1970-01 to 1979-12, Sanni (1986) found little evidence of money supply causing agricultural exports, imports or price level in Nigeria. Higginson *et al.* (1988) found in a nine-variable VAR system that Canadian swine exports to the US did not cause the US hog prices.

Table 2. **Causality Analysis in VAR Models : A Summary of Selected Agricultural Economics Studies**

Author(s)	Problem investigated	Nature of data used	Dimension of the VAR	Lag selection	Causal inference	Conclusion(s)
Bessler (1984)	Dynamic relationships between money supply, agricultural prices and industrial prices in Brazil	Monthly data from 1964-01 to 1981-12	A three-variable system	Ad hoc : 22 months	Based on Granger-type F-tests and impulse responses	Money supply causes agricultural prices but it has a feedback relationship with industrial prices
Sanni (1986)	Dynamic effects of money supply on the Nigerian agricultural sector	Monthly data on money supply, agricultural exports and imports and CPI from 1971-01 to 1979-12	A four-variable system	Sims' modified likelihood ratio test : 4 lags	Impulse responses and FEV decompositions	Money supply has little impact on agricultural exports and imports in the short-run. Only at lags 12 or higher M2 impact on other variables
Featherstone and Baker (1987)	The dynamic response of farm asset values to changes in net residual farm returns and interest rates in the US	Annual data from 1910 to 1985	A three-variable system	Sims' modified likelihood ratio test : 5 lags	Based on Granger-type F-tests and impulse responses	Residual returns from farming cause farm asset values. The results also suggest a farmland market with a propensity for bubbles
Higginson *et al.* (1988)	Determine the effect of Canadian swine export on US prices and the impact of the countervailing duty on the Canadian hog sector	Weekly data from 1982 to 1986	A nine-variable system	Sims' modified likelihood ratio test : 3 weeks	Based on Granger-type F-test and FEV decompositions	Canadian swine exports did not cause the US prices and that the countervailing duty had a negative impact on pricing efficiency in the Canadian hog markets
Orden and Fackler (1989)	Examine monetary impacts on agricultural prices in the US	Quarterly data from 1975-1 to 1988-1 for seven variables	A seven-variable system	Sims' modified likelihood ratio test : 2 lags for each variable	Based on impulse responses	Increased money supply raise agricultural prices more relative to general price level, but it is not the major cause of price instability in agriculture

Author(s)	Problem investigated	Nature of data used	Dimension of the VAR	Lag selection	Causal inference	Conclusion(s)
Babula and Bessler (1990)	Dynamic relationships between farm corn price and farm and retail egg prices in the US	Monthly data from 1957-1 to 1989-12	A three-variable system	The Tiao-Box likelihood ratio test : 21 lags	Based on impulse responses and FEV decompositions	The farm corn price causes farm and retail egg prices. Retail egg price is also caused by farm egg price
Dronne and Tavera (1990)	Examine causal relationships between the prices of major animal feed ingredients at Rotterdam	Weekly cif import prices of soybean meal, cassava, corn gluten feed and sunflower cake and fob price for rapeseed meal at Rotterdam from January 1, 1981 to July 16, 1987	A five-variable system	Empirically determined lags based on Akaike's FPE criterion	Based on Granger-type F-test and impulse responses	The price of soybean meal unidirectionally causes the sunflower and rapeseed meals and those of the CGF. Cassava prices also cause the CGF prices. The CGF is a substitute both for soybean meal and cassava
Goodwin and Schroeder (1991a)	Dynamic relationships among six international wheat prices	Monthly price data for Australian, Argentinean, Canadian and the US wheat exports and Japanese and European import from 1975-7 to 1986-12	An eight-variable system	Sims' modified likelihood ratio test : 4 lags	Based on impulse responses and FEV decompositions	The US and Canadian prices have significant influence on wheat prices in other markets. The US wheat price also leads the Canadian price. Freight and exchange rates also influence spatial price linkages
Van Tassell and Bessler (1988)	The dynamic relationships between the prices of purebred bulls, slaughter steers, utility cows, feeder calves and cow-calf	Monthly prices from 1972-01 to 1985-12	A five-variable system	The Tiao and Box U-statistic : 9 lags	Based on impulse responses and FEV decompositions	The purebred bull prices are caused by all other prices in the model at lags over 12 months. The prices of cull bull act as a price floor for purebred bulls in the US
Schroeder and Goodwin (1990)	Dynamic price relationships among regional slaughter cattle markets in the US	Weekly average price for 900-1100 lb slaughter steers for 11 regional markets from 1976 to 1987	An eleven-variable system	Sims' modified likelihood ratio test : 3, 3 and 2 lags respectively for periods I, II and III	Based on Granger-type F-test and impulse responses	Three regional markets : Iowa-S. Minnesota direct, E. Nebraska direct and the Omaha terminal lead other markets in the price discovery process. Regional price adjustments take 1-3 weeks to complete

Causality analysis in unconstrained VAR models represents a significant departure from the traditional causality tests in bivariate models. In multivariate VAR models one can include past information of many related variables. This freedom, however, comes at a cost. Firstly, unconstrained VAR models usually have many parameters relative to the number of data points and one may question the reliability of the estimates. While economic theory can be used to impose restrictions on the model, in recent empirical studies such restrictions were found to be controversial. The controversy arises from the fact that the nature of identification restrictions imposed on VARs is different than those typically used to identify structural models. Secondly, Dufour and Tessier (1993) have shown that while there is a duality between the AR and MA characterizations of Granger noncausality in bivariate models, such duality does not extend to multivariate systems. Consequently, a different set of restrictions are required to test Granger noncausality from moving average coefficients. Without these restrictions inference on Granger noncausality based on MA coefficients (*i.e.*, based on impulse responses and variance decompositions) can be misleading. All causality results reported in table 2 are subject to this criticism. Thirdly, Wald tests used for testing Granger causality between subsets of variables may not have asymptotic chi-squared distribution. This is particularly true if the VAR system contains nonstationary variables (Park and Phillips, 1989; Sims *et al.* 1990). Moreover, the limit theory of Wald tests involve nuisance parameters and nonstandard distributions both of which complicate causal inference procedures in unrestricted VAR models. Toda and Phillips (1993) have also shown that without explicit information on the number of cointegrating vectors in the system and the rank of certain submatrices in the cointegration space, it is impossible to determine the appropriate limit theory for Granger causality tests. Consequently, they recommend against the empirical use of Granger causality tests in levels VAR models when there are nonstationarity in the data and the possibility of cointegration. In view of these findings, all causality results in table 2 should be taken with caution.

NONSTATIONARITY, COINTEGRATION AND CAUSALITY ANALYSIS

It is now well known that most economic time series are characterized by a unit root nonstationarity in their univariate representation and that data nonstationarity complicates Granger causality analysis both in traditional bivariate models and in unrestricted VAR models. When the system under investigation involves nonstationary variables and there is a possibility of comovement of some of the variables, cointegration is the appropriate methodology to investigate Granger causality. Since cointegration analysis allows researchers to investigate economic hypotheses in a theoretically consistent and econometrically efficient manner, this approach has gained enormous popularity in agricultural economics in recent years. The determination of long-run or stable economic relationships and subsequent re-examination of some well known hypotheses by agricultural economists have already generated a healthy debate in the profession. Even the results from some established theories have been thrown in doubt. For example, the findings by Phipps (1984) and Featherstone and Baker (1987) of unidirectional causality from returns to land prices lend empirical support to the present value model (PVM) of land price determination. But three most recent studies have shown, using cointegration analysis, that other stronger implications of the PVM are soundly rejected by the data (Falk, 1991; Clark *et al.*, 1993a,b). Similarly, the assumption of perfect commodity price arbitrage (popularly known as the law of one price (LOP)), so crucial in exchange rate and international trade models, have been brought to question (Ardeni, 1989; Baffes, 1991 and Goodwin, 1992). Also, the traditional measurement of the effects of technological change on agricultural production has been thrown in doubt (see Clark and Youngblood 1992) and significant changes in econometric modelling of popular relationships in agricultural economics, such as supply response to policy changes, output supply and input demands etc. are being sought (see Clark and Spriggs, 1992, Clark and Coyle, 1994, and Rayner and Cooper, 1994). These are very positive developments essential for the future development of agricultural economics research. However, not all of these developments are directly related to causality analysis. Consequently, only a subset of the cointegration studies is reviewed in this section. These studies have generated causal inferences but not always through a formal causality test.

To provide a better understanding of the literature, a brief overview of nonstationarity, cointegration and causality analysis in cointegrated systems is presented first. This is followed by a review of sixteen agricultural economics studies which derived causal inferences from cointegrated systems. The limits of causality analysis in cointegrated system and possible future directions of causality analysis are presented in the final paragraph of this section.

A set of variables is said to be cointegrated if each variable in the set has a unit root in its univariate representation, but some linear combination of these variables is stationary (Engle and Granger, 1987). A variable X_t is said to have a unit root in its autoregressive process if it has the following autoregressive representation:

$$(1 - L)X_t = \phi_1(1 - L)X_{t-1} + \ldots\ldots + \phi_p\,(1 - L)X_{t-p} + \varepsilon_t \qquad (8)$$

Where ε is a stationary stochastic process, $\Sigma\,\phi_i < 1$, and L is the lag operator. In general, X_t is said to be integrated of order d [or $X_t \sim I(d)$] if it has a stationary representation after differencing d times. Thus, an $I(1)$ variable becomes stationary after first differencing. The variance of an $I(1)$ variable is time dependent; it goes to infinity as time approaches infinity. The underlying data generation process (DGP) of an $I(1)$ variable also has an infinitely long memory. Therefore, a disturbance will have a permanent effect on the process.

Since there is a close correspondence between tests for unit roots and tests for cointegration and since cointegration is most interesting among $I(1)$ variables, it is useful to begin the analysis by considering whether or not the univariate time series have unit roots. In particular, it is necessary to show that unit root nonstationarity characterizes the univariate representation of each variable under consideration if cointegration analysis is to take place. A number of tests have been proposed in the literature to test for the presence of unit root nonstationarity. Notable among these tests are the Dickey-Fuller test or augmented Dickey-Fuller test, Phillips-Perron test and Kwiatkowski *et al.* test. The first three of these tests investigate the null hypothesis that the series has a unit root against a stationary around a time trend alternative while the last one tests the null hypothesis that the series is stationary around a linear trend against the unit root alternative. Thus, for a given series, if the first three tests are accepted and the last one is rejected, it would imply that the series is characterized by a unit root nonstationarity(3).

The unit root tests discussed above implicitly assume that the root corresponds to a zero frequency peak in the spectrum and that there are no other unit roots in the system. Since many economic time series exhibit considerable seasonality, there is a possibility that there may be unit roots at seasonal frequencies as well. If a series is characterized by seasonal unit roots in addition to a unit root at zero frequency, then seasonal differencing is also required to make the series $I(0)$. The consequence of not recognizing seasonal unit roots in the analysis is that one may not detect cointegration among a group of variables. It is, therefore, important to test the null hypothesis of seasonal unit root along with the null of unit root at zero frequency. The tests developed for this purpose by Osborn *et al.* (1988) are based on the following equation:

$$\Delta_1\Delta_4X_t = \alpha_1D_{1t} + \alpha_2D_{2t} + \alpha_3D_{3t} + \alpha_4D_{4t} + \beta_1\Delta_4X_{t-1} + \beta_2\Delta_1X_{t-4} + \sum_{i=1}^{p} \phi_i\Delta_1\Delta_4X_{t-i} + u_t \qquad (9)$$

Where D_i is the dummy variable corresponding to the ith quarter. The t-ratios on β_1 and β_2 are used to test seasonal and non-seasonal unit root hypotheses. In particular, $H_{0:}$ X_t is $I(0,1)$ [*i.e.*, there is seasonal unit

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(3) These unit root tests have become standard procedures in time series literature. So, it is not essential to provide detailed description of each of these tests in this paper. Interested readers are referred to Phillips and Perron (1988), Dolado *et al.* (1990), Kwiatkowski *et al.* (1992), and Clark *et al.* (1993b) for details on these tests.

root in X_t] implies that $\beta_2 = 0$ with $\beta_1 < 0$. Similarly, $H_{0:}$ X_t is $I(1,0)$ [*i.e.*, there is non-seasonal unit root in X_t] implies $\beta_1 = 0$ with $\beta_2 < 0$. The alternative hypothesis in either case is: $H_{a:}$ X_t is $I(0,0)$. Hylleberg *et al.* (1990) proposed a set of alternative tests based on the decomposition of seasonal differences to test seasonal and non-seasonal unit roots. These tests are complicated but more robust than those developed by Osborn *et al.* (1988). The critical values for these tests can be obtained from Dickey and Fuller (1979) and from Dickey, Hasza and Fuller (1984)(4).

If the results form above seasonal and non-seasonal unit root tests reveal that all variables under investigation have a unit root at zero frequency, then the next step is to find out if the variables are cointegrated and how many stable or long-run cointegrating relationships are there. Six major procedures have been proposed in the literature for testing cointegration. These are: (i) the Dickey-Fuller test on cointegration regression residuals (Engle and Granger, 1987); (ii) the cointegration regression Durbin-Watson (CRDW) test (Engle and Granger, 1987); (iii) the Park J_1 superfluous variable addition test using the canonical cointegration regression (Park, 1990, 1992); (iv) the Hansen fully modified regression estimator L_c test (Hansen, 1992); (v) the dynamic ordinary least squares procedure developed for testing common trends (Stock and Watson, 1988); and, (vi) the maximum likelihood cointegration approach (Johansen, 1988, 1991). The first five tests are based on some variations of regression analysis (conventional and modified), while the last one is based on a VAR model. Also note that the first four tests involve single-equation method while the last two involve multiple-equation method of identifying long-run cointegration relationships. Multiple-equation methods are particularly useful for systems involving more that one long-run cointegration relationships. One can also impose and test various cross-equation restrictions in such a method. The Engle-Granger procedure has been used extensively in early applications of cointegration analysis in agricultural economics. While the Engle-Granger procedure offers a simple and attractive test for bivariate models, it does not perform well in a multivariate situation (Dickey *et al.*, 1991). In light of this result, the most recent studies in agricultural economics use Johansen's maximum likelihood cointegration approach to identify long-run steady state economic relationships(5).

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(4) Note that given the large volume of theoretical and empirical studies on unit roots and cointegration, the issue of stochastic seasonality attracted little research attention. Only a few studies explored seasonal integration in various macroeconomic time series. In studies involving cointegration analysis in agricultural economics, the issue of stochastic seasonality has been overwhelmingly ignored. Since the production, consumption, prices and trade of most of the farm commodities exhibit substantial seasonality, researchers in agricultural economics should look into the issue of stochastic seasonality more seriously in the future.

(5) Since the approaches developed by Park, Hansen and Stock and Watson did not yet receive wide acceptance among agricultural economists, no additional space is allocated for these tests in this paper. Details on these tests can be found in the references cited in this section as well as in Muscatelli and Hurn (1992).

The full-system approach developed by Johansen is by far the most interesting approach for testing cointegration. It is based on the estimation of a VAR system by maximum likelihood method. Johansen's approach essentially extends the Engle-Granger procedure to a multivariate context where there may exist more than one cointegration relationship among a set of n variables. The maximum likelihood procedure gives estimates of the system's cointegrating vectors and their weights and these estimates can be used to test relevant hypotheses about the structure of cointegrating vectors and their weights. Unlike the estimates obtained from levels VAR estimation, the maximum likelihood estimates are symmetrically distributed, median unbiased and have mixed normal distributions. Consequently, they are better suited for testing Granger causality among economic variables (Johansen, 1992 ; Toda and Phillips, 1993) than those from levels VARs.

Following Johansen (1988, 1991) and Johansen and Juselius (1990, 1992), the full-system approach is based on a kth order unrestricted VAR representation of X_t such that:

$$X_t = \pi_1 X_{t-1} + \pi_2 X_{t-2} + ... + \pi_k X_{t-k} + \mu + \Phi D_t + \varepsilon_t \tag{10}$$

where X_t is a vector of p variables including y_t and z_t and each of these variables is integrated of order one or $I(1)$, D_t are seasonal dummies, π_i are p x p matrices of parameters, μ is a p x 1 vector of constant terms and ε_t are normally identically distributed error terms. Using lag operators the model in eq. 9 can be reparameterized as:

$$\nabla X_t = \mu + \Gamma_1 \nabla X_{t-1} + \Gamma_2 \nabla X_{t-2} + ... + \Gamma_{k-1} \nabla X_{t-k+1} - \Pi X_{t-k} + \Phi D_t + \varepsilon_t \tag{11}$$

Where, $\Gamma_i = - I + \pi_1 + ... + \pi_i$, and $- \Pi = I - \pi_1 - \pi_2 - ...... - \pi_k$; for all $i = 1,2,....., k - 1$. Notice that the reparameterized model in eq. (10) is a traditional first-difference VAR model except for the term ΠX_{t-k}. The matrix Π, which is sometimes called the impact matrix, contains information about the cointegrating relationships among the variables in the system. If Π has a full rank, then X_t is a stationary process. If Π has a zero rank, then the impact matrix is a null matrix and X_t is an integrated process. Only in this case, a traditional first-difference VAR model is appropriate for testing causal hypothesis. If, however, $0 < (\text{rank}\ (\Pi) = r) < p$, cointegration holds and Π can be represented as the product of two pxr matrices, α and β, such that $\Pi = \alpha\beta'$. The β's are the cointegrating vectors and the α's are the weights or loading vectors. When cointegration holds, $\beta' X_t$ is stationary. Once the model is estimated, the null hypothesis that there are r cointegrating vectors in the system can be tested using two likelihood ratio tests called the trace test and the maximum eigenvalue test (see Johansen and Juselius, 1990 for details). If H_1: is a special case of H_2: for $r = p$, then the trace statistic is defined as:

$$-2\ln(Q;H_2|H_1) = -T\sum_{i=r+1}^{p}\ln(1-\lambda_i) \tag{12}$$

Similarly, the maximum eigenvalue statistic for testing $H_2(r)$ in $H_2(r + 1)$ can be defined as:

$$-2\ln(Q;r|r+1) = -T\ln(1-\lambda_{r+1}) \tag{13}$$

Notice that the asymptotic distributions of these likelihood ratio tests do not follow the standard *chi*-squared distribution. They are distributed as standard Brownian motion which may be considered as a multivariate version of the Dickey-Fuller distribution. The critical values for these tests are generated through simulations and are reported in Johansen and Juselius (1990) and in Osterwald-Lenum (1992).

There is a close correspondence between cointegration and error-correction models. If a group of economic variables are cointegrated then, by the **Granger's representation theorem**, there must exist an error-correction representation of the relevant variables (Engle and Granger, 1987). The long-run relationship is a stable steady state relationship and the short-run relationships represent deviations around this equilibrium relationships. Through correcting these short-run errors, the relevant economic system approaches its long-run path. Hence, the term error-correction models. Thus, if all variables in a vector stochastic process X_t are $I(1)$ and they are cointegrated, then there exists an error-correction representation such as:

$$A(L)\,(1-L)X_t = -\gamma e_{t-1} + \varepsilon_t \tag{14}$$

Where L is the lag operator, $A(L)$ is a polynomial in L of the form $[\beta_0 + \beta_1 L + \beta_2 L^2 + \ldots.]$ and ε_t is a stationary multivariate disturbance. This formulation assumes that $A(0) = I$, all elements in $A(1)$ are finite and $\gamma \neq 0$. The cointegrating vector is β, where $e_t = \beta' X_t$ is $I(0)$. Because the series are cointegrated, the error-correction term is stationary and the standard errors of the error-correction models will be consistent estimates of the true standard errors. Therefore, the standard asymptotic results for parameter estimation and hypothesis testing apply (Engle and Granger, 1987). A properly formulated error-correction model can be used to test Granger causality among the relevant variables in a system.

Table 3 provides a summary of sixteen selected agricultural economics studies which derived some causal inferences from cointegration analysis. Once again, commodity price movements received the highest research attention. This is perhaps due to the fact that owing to spill over effects of supply and demand shocks and macroeconomic shocks, commodity prices exhibit a tendency of moving together and that the theory of cointegration offers a theory and data consistent approach to formalize the idea of comovements in commodity prices. Eleven out of sixteen studies reported in table 3 involve identification of some causal relationships among commodity prices.

Table 3. **Causality Analysis in Cointegrated Systems : A Summary of Selected Agricultural Economics Studies**

Author(s)	Problem investigated	Data & nonstationarity test	Lag selection	Cointegration analysis	Causal inference	Conclusion(s)
Ardeni (1989)	Examines the law of one price as a long-run relationship for seven internationally traded primary commodities	Monthly prices of wheat, wool, beef, sugar, tin, tea and zinc for Australia, Britain, Canada and the US from mid 60s to mid 80s. augmented Dickey-Fuller Test	Ad hoc : 1 and 4 lags	Engle-Granger approach	Based on bivariate cointegration analysis	The LOP does not hold for internationally traded primary commodities even in the long-run
Robertson and Orden (1990)	Monetary impacts on agricultural and non-agricultural prices in New Zealand	Quarterly data on money supply, farm-gate level agricultural and factory level manufacturing prices from 1963-1 to 1987-1 ; ADF test.	Sims' modified likelihood ratio test : 3 and 5 lags	Engle-Granger approach	Based on impulse responses from the vector error-correction model	Money supply has significant long-run and short-run impact on farm and manufacturing prices. Money supply also responds to shocks in manufacturing prices but not in farm prices
Goodwin and Schroeder (1991b)	Determine long-run spatial price linkages for regional slaughter cattle market in the US	Weekly prices for Choice grade 2-4, 900-1,100 lb slaughter steers for 11 regional markets from Jan. 1980 to Sept. 1987, ADF Test	Akaike's FPE criterion	Engle-Granger approach	Based on bivariate co-ontegrated relationships	Regional markets are segmented by lack of arbitrage opportunities. Pricing performance are influenced by increased industry concentration, distance between markets and slaughter volumes

Author(s)	Problem investigated	Data & nonstationarity test	Lag selection	Cointegration analysis	Causal inference	Conclusion(s)
Baffes (1991)	To test whether the LOP holds in the long-run	Quarterly average prices of wheat, tea, beef, sugar, wool, zinc and tin for Australia, Britain, Canada and the US (N=71 to 118). DF, ADF and DW tests	Akaike's information criterion	Engle-Granger approach	Based on bivariate co-integrated relationships	In general, the LOP holds in the long-run. The LOP fails due to transportation costs and are mostly price and time-period specific
Falk (1991)	Empirically testing the simple present value model of Iowa farmland prices	Annual data on Iowa farmland prices and rental rates per acre from 1921 to 1986, ADF test.	Sims' modified likelihood ratio test : 3 lags	Engle-Granger approach	Based on a bivariate VAR model	Spread Granger-causes changes in rents. The cross-equation restrictions implied by the SPVM are rejected
Larue (1991)	The dynamic interrelationships among farm input, farm output and food retail prices in Canada	Quarterly data from 1961-1 to 1988-4 ; DF, ADF, EGHO and OCSB tests	Ad hoc : 4 lags	Engle-Granger approach and Johansen's Maximum likelihood procedure	Based on multivariate error-correction model	Farm output and food retail prices Granger-cause farm input price. Also, farm output and input prices cause food retail prices in Canada
Goodwin (1992)	Evaluation of the LOP as a long-run equilibrium condition in international wheat markets	Monthly wheat export (Australia, Canada and the U.S.) and import (Rotterdam and Japan) prices from 1978-01 to 1989-12. DF and ADF tests	Sims' modified likelihood ratio test : 2 lags	Johansen's maximum likelihood procedure	Based on multivariate co-integration analysis	When transportation costs are taken into account wheat prices become efficiently linked to each other
Hallam *et al.* (1992)	Examination of the determinants of land prices in England and Wales	Annual data from 1948 to 1987 for England and Wales, ADF test.	Ad hoc	Engle-Granger approach	Based on bivariate cointegration	In a bivariate context, real land prices are not caused by real rent, farm income, gross product, interest and inflation rates and area traded

Author(s)	Problem investigated	Data & nonstationarity test	Lag selection	Cointegration analysis	Causal inference	Conclusion(s)
Clark *et al.* (1993b)	The determination of short-term and long-term effects of farm subsidies and income on land values in Saskatchewan	Annual data from 1950 to 1987. DF, ADF and Kwiatkowski *et al.* tests	Schwarz Bayesian criterion	Engle-Granger, Park's, Hansen's and Johansen's cointegration procedures	Based on multivariate cointegration	Farm-generated income plus direct government subsidies cause land values in Saskatchewan
Choe and Koo (1993)	An examination of the long-run and short-run behaviour of US money, farm prices, and nonfarm prices	Quarterly data from 1948-3 to 1991-3. DF, ADF and Phillips-Perron tests	Sims' modified likelihood ratio test : 2 lags	Johansen's maximum likelihood procedure	Based on multivariate cointegration and error-correction model.	Money is not neutral in the long-run. Monetary policy impact equally on farm and nonfarm prices in the long-run
Liu *et al.* (1993)	Evaluation of the impact of domestic and foreign macroeconomic variables on US meat exports	Quarterly data on nine macroeconomic and eight meat variables from 1971-1 to 1988-4, ADF test	Sims' modified likelihood ratio test : 4 lags	Johansen's maximum likelihood procedure	Based on multivariate cointegration and forecast error variance (FEV) decompositions	Foreign macroeconomic variables exert more significant effects on US meat exports than domestic macro variables both in the short-run and long-run
Sarker (1993)	Examination of the nature of causal relationships among Canadian lumber exports to the US, US lumber price and housing starts and the Canada-US exchange rate	Quarterly data from 1968-1 to 1991-1. ADF test.	Sims' modified likelihood ratio test : 4 lags	Johansen's maximum likelihood procedure	Based on multivariate cointegration, impulse responses and FEV decompositions	The bilateral exchange rate has a significant positive effect on Canadian lumber exports to the US in the long-run
Zanias (1993)	An evaluation of the degree of spatial market integration in the EC agricultural product markets	Monthly price per unit of soft wheat, cows' milk, potatoes and pig carcases for Belgium, Denmark, France, Germany, Italy and UK from 1980-01 to 1990-12. ADF test.	Unknown	Engle-Granger approach	Based on bivariate cointegration analysis	Some EC agricultural product markets are not spatially integrated. Milk market is the least integrated one. Varying transportation and transaction costs may explain non-integration

Author(s)	Problem investigated	Data & nonstationarity test	Lag selection	Cointegration analysis	Causal inference	Conclusion(s)
Rayner and Cooper (1994)	The demand for nitrogen fertilizer in the United Kingdom	Annual data on total quantity of nitrogen purchased and price per unit and output price index from 1956 to 1988. ADF test	Akaike's FPE criterion : 2 lags	Engle-Granger approach	Based on bivariate cointegration and error-correction models	The demand for nitrogen fertilizer is price inelastic both in the short-run and long-run. A nitrogen tax may not reduce nitrate pollution in agriculture
Silvapulle and Jayasuriya (1994)	Evaluation of the degree of market integration among regional rice markets in Philippines	Monthly average prices for Manila, Ilocos Norte, Central Luzon, Central Visayas and Central Mindanao from 1975-01 to 1989-12. ADF and Kwiatkowski *et al.* tests	A sequence of t-tests : 4 lags	Johansen's maximum likelihood cointegration procedure	Based on cointegration and error-correction models	The regional rice markets in Philippines are well integrated in the long-run with Manila as the dominant market
Diakosavvas (1995)	An examination of the degree of market integration between Australian and US beef prices at the farmgate level	Monthly prices of Australian steers and cowbeef, American choice steer, utility cow, cutter cow, commercial cow and canner cow from 1972-01 to 1993-03. Phillips-Perron, DF and ADF tests	Schwarz Bayesian criterion	Engle-Granger approach	Bivariate cointegration and error-correction models	Despite cointegration Australian and US beef prices are not fully integrated. No significant change in the degree of integration over time

At least one test (the ADF test) has been employed in each of these studies to investigate data nonstationarity. In most cases, Sims' modified likelihood ratio test has been used to determine the appropriate lag-length. Nine studies used the Engle-Granger approach to determine cointegrated relationships while the others used the maximum likelihood approach itself or in conjunction with other approaches. Three studies investigated the long-run validity of the law of one price and produced mixed results. Ardeni (1989) found that the LOP does not hold for internationally traded primary commodities. However, findings from two more recent studies, Baffes (1991) and Goodwin (1992), contradict Ardeni's results. The transportation costs seem to be responsible for this contradiction. Investigating the formation of land prices in cointegrated systems, both Falk (1991) and Clark *et al.* (1993b) found that the restrictions implied by the simple present value model of land prices are not data consistent. Clark *et al.* also found weak empirical support for capitalization of government subsidies into land values in Saskatchewan. 'Money is not veil in the long-run' is the message from studies by Robertson and Orden (1990) and Choe and Koo (1993). Similarly, Sarker (1993) found that the bilateral exchange rate has a significant positive effect on Canadian lumber exports to the US in the long-run. Four studies investigated the nature and degree of market integration producing mixed results. Regional livestock markets in the US are found not to be spatially integrated by Goodwin and Schroeder (1991b) while Zanias (1993) found lack of integration in the EC agricultural product markets. Diakosavvas (1995) also report less than full integration between Australian and US beef prices. In contrast, Silvapulle and Jayasuriya (1994) found the regional rice markets in the Philippines to be well integrated in the long-run with Manila as the dominant market.

As indicated earlier, only a few studies summarized in table 3 derived causal inferences from properly formulated error-correction models. This is a major limitation for most causality results currently available from cointegrated systems. Moreover, not all error-correction models can generate meaningful Wald tests with sound statistical basis for testing Granger causality. Toda and Phillips (1993) demonstrate this by using the limit theory for Wald tests of Granger causality in levels VAR's and Johansen-type error-correction models for systems that involve variables with stochastic trends and cointegration. In case of Johansen-type error-correction models, Toda and Phillips (1993) suggest testing rank conditions for the estimated cointegrating matrix and the associated loading matrix empirically before formulating the error-correction model. This amounts to a sequential testing procedure. Notice that some size distortion and loss of power are inevitable in the causality test in error-correction models suggested by Toda and Phillips because of its sequential nature (determine cointegrating vectors, verify rank conditions, formulate the error-correction model and then test causality). Even with size distortion and loss of power, however, the sequential causality tests based on Johansen-type error-correction model were found to outperform the conventional tests in simulations (Toda and Phillips, 1994). It is to be emphasized here that none of the studies reported in table 3 followed such a sequential approach to test Granger causality.

Based on the preceding discussion the following suggestions can be offered concerning the future direction of causality analysis in agricultural economics. First, use economic theory to determine relevant variables to be included in the model. Second, test for the presence of seasonal and non-seasonal stochastic trends in the univariate process of each variable in the system under investigation. Third, if the variables are found to have unit root nonstationarity, test for the existence of cointegration in the system using the full-system cointegration approach developed by Johansen. Fourth, if there is no long-run relationship among the variables then reparameterize the model as a first difference-VAR and perform causality tests based on the autoregressive parameters estimated from the reparameterized model. In this case, the Wald test has an asymptotic *chi*-squared distribution and hence, the critical values of *chi*-squared can be employed. Fifth, if cointegration is detected, then determine the number of cointegrating vectors, verify the rank conditions and formulate a Johansen-type error-correction model (ECM). Finally, test Granger noncausality hypotheses based on the estimated parameters of this error-correction model. It is to be emphasized here that the sequential inference procedures for testing causality involve some unknown dynamics at each stage. One has to select lag-length for testing unit roots and cointegration. Very recently, Gonzalo (1994) has shown that Johansen's method performs better when the model is overparameterized than when it is underparameterized. Based on this result, one should use Akaike's FPE criterion to select optimal lag-lengths. This criterion is known for its tendency to overparameterize a model.

CONCLUDING REMARKS

Testing causal hypotheses is central to empirical research in agricultural economics. The four alternative causality tests, the Granger test, the Sims test, the modified Sims test and the Haugh-Pierce test, have been developed based on the statistically testable notion of causality introduced by Granger (1969). While these tests received wide applications in agricultural economics, they have also generated conflicting causal results in bivariate models and led to a number of controversies. An attempt to improve causality analysis by developing a nonparametric causality test did not fare well. However, the use of Granger causality test in agricultural economics continued to flourish in unrestricted VAR models and in cointegrated systems. This paper provides an overview of the literature on Granger causality testing in agricultural economics. It outlines the methodology of testing causal hypothesis in traditional bivariate models, unrestricted VAR models and in cointegrated systems. Selected applications of each of these methodologies in agricultural economics are reviewed and their limitations are critically assessed. Potential avenues for improvement in causality analysis are also discussed.

Irrespective of the methodology, most applications of Granger causality tests in agricultural economics concentrate on commodity price analysis. The apparent comovement of various commodity prices may partly explain such concentration of research efforts. Effects of the macroeconomy on agriculture have also been investigated by an increasing number of researchers using levels VARs and cointegrated models. A number of established paradigms in agricultural economics, such as the LOP, land price formation, measurement of technological change etc., are being reexamined using causality analysis in cointegrated systems.

A number of crucial problems are associated with the traditional Granger causality tests. The results from traditional bivariate causality models are particularly sensitive to prefiltering, omitted variables and the choice of lag-lengths. The most important limitation of the traditional bivariate models is that they lack an explicit theoretical structure. This makes it difficult to give proper interpretation to the causality results. While causality analysis in unconstrained VARs represents a significant departure from the traditional causality tests, causal results from unconstrained levels VARs can also be controversial. The controversy can arise from the identification restrictions imposed on a VAR model during estimation or from data nonstationarity. If a VAR model includes variables with stochastic trends and there is a possibility of cointegration, the Wald test used to test for Granger causality in VAR models may not have a limiting distribution and so, there is no valid basis for mounting Granger causality tests. Consequently, the causality test breaks down. To the extent data nonstationarity is present in existing VAR models, the causality results can be dubious.

When the system under investigation involves nonstationary variables and there is a possibility of long-run relationships among them, cointegration is the appropriate methodology to investigate Granger causality. Most recent studies in agricultural economics seem to have acknowledged this and derive causal inference from cointegrated systems. However, not in all cases causal inferences are generated from a properly specified error-correction model. In view of this finding, a sequential approach to test for causality in cointegrated system is suggested in this paper. It involves testing nonstationarity, the use of Johansen's cointegration analysis to determine the number of cointegrating vectors, testing the rank condition of the loading matrix and then formulating the ECM to test Granger causality. It is hoped that such a sequential approach will provide a useful guidance to future causality analysis in agricultural economics.

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