Causality Among Fed Cattle Market Variables: Directed Acyclic Graphs Analysis of Captive Supply

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Abstract

In quantitative research, direction of causality among the variables is often assumed without a rigorous test. In this study, the directed acyclic graph (DAG) method was used to illuminate causal relationships among fed cattle industry variables, in particular, it was shown that captive supply causes spot market price to change.

Keyword: causality, cattle captive supply, direct acyclic graph

CAUSALITY AMONG FED CATTLE MARKET VARIABLES: A DAG ANALYSIS OF CAPTIVE SUPPLY

Introduction

In empirical research using non-experimental data, causal relationships among a set of data is an important issue. This study applies the directed acyclic graph (DAG) approach to the investigation of causality in the U.S. fed cattle industry.

Structural changes in the U.S. beef packing industry include increasing firm size, concentration, and vertical integration through production and marketing contracts. In particular, captive supply, a form of backward integration by packers, is becoming an increasingly controversial issue.

The Grain Inspection Packers and Stockyard Administration (GIPSA, p vi) definition of captive supply include cattle owned or fed by packer, the cattle procured through forward contracts and marketing agreements, and cattle that is otherwise committed to a packer more than 14 days prior to slaughter. Arguments in favor of captive supply include reduced transaction costs, reduced market risk, efficiency, quality enhancement, and global competitiveness (Feuz et al.). Opponents argue that it has adverse impact on fed cattle cash market prices, reduce competition and market access by small cattle producers, and increase market power of packers (Conner, et al.). This research focuses on the cause and effect relationship between captive supply and fed cattle cash market price.

The current literature on the relationship between use of captive supply and the fed cattle cash market price ranges from no conclusive evidence to small, but statistically significant negative relationship between the two. Parcell, Schroeder and Dhuyvetter found that a 1% increase in captive supply shipments was associated with a $0.02/cwt and $0.03/cwt reduction in basis (cash price minus futures price) in Colorado and Texas. They did not find a statistically significant impact for Kansas or Nebraska. Hayenga and O'Brien found no conclusive evidence that forward contracting decreased fed cattle prices. Elam found individual states varied from no price difference to lower prices ranging from $0.15 to $0.37/cwt.

Schroeder et al. found small ($0.15 - $0.31/cwt) but statistically significant negative relationship between captive supplies and cash prices. Ward, Koontz and Schroeder found small but a negative relationship for the total inventory of captive supplies. A 1% increase in the total inventory of captive supply cattle was associated with less than 1% decrease in spot market prices. Barkley and Schroeder found that cattle futures prices, plant utilization rates, and spot market prices are important determinants of captive supply levels.

Review of the literature indicates that more detailed information on the interdependent nature of the relevant variables can enhance the understanding of the impact of captive supplies on the fed cattle market. In particular, one of the unresolved questions is that the cause and effect relationship between the use of captive supply and fed cattle cash market price is not known. Although a negative statistical relationship between the use of captive supply and the spot market price has been identified in several studies, researchers have not concluded that an increase in captive supply "causes" a decrease in spot market prices (GIPSA p 61).

The objective of this research is to illuminate causal relationships among the relevant cattle market variables, in particular, between captive supply and spot market price using a new tool, the directed acyclic graph (DAG) method (Pearl 1995, 2000; Spirtes, Glymore, and Scheines; Bessler and Akleman; Bessler and Yang; and Bessler, Yang and Wongcharupan). By clarifying the causal structure among the variables the DAG method can aid in specification of a model without a priori assumption on the causality among the variables. The DAG method can also help identify omitted and irrelevant variables. In addition, the method helps determine the paths through which variables impact each other, thus identifying direct and indirect causes. Further, the DAG method can be used to distinguish genuine from spurious causes in a set of data.

Method

Definition of Directed Acyclic Graph

A directed graph represents causal flows among a set of variables. Causal flows are determined based on correlations and conditional correlations among a set of three or more variables. For variables X and Y, their relationship can be shown by one of the following ways: An undirected edge (X — Y) indicates that X and Y are connected by information flow, that is, there is correlation between X and Y, but it cannot be determined whether X causes Y or vice versa based on the data at hand; A directed edge (X → Y) indicates that X causes Y; A bi-directed edge (X ↔ Y) indicates X causes Y and Y causes X (Pearl, 2000)

A "directed acyclic graph" (DAG) is a directed graph that does not cycle, thus the term "acyclic." For example, a directed graph X → Y → Z → X cycles, but a directed graph X → Y ← Z or X ← Y → Z is acyclic. The fundamental concept in assigning causal directions, called "d-separation", is described next.

D-Separation Criterion

Consider three disjoint sets of variables, X, Y, and Z, in a directed acyclic graph. A path is a sequence of consecutive edges (of any directionality) in the graph. The formal definition of d-separation is in Pearl (2000, p16):

Definition of d-Separation:

For x ∈ X, y ∈ y, and z ∈ Z, a path p is said to be d-separated by Z if and only if

i) p contains a chain x → z → y or a fork x ← z → y such that the middle variable z is in Z, or

ii) p contains an inverted fork, x → z ← y such that the middle variable z is not in Z and such that no descendant of z is in Z.

A set Z is said to d-separate X from Y if and only if Z blocks every path from a variable in X to a variable in Y. Here, "blocking" is to be interpreted as stopping the flow of information between the variables that are connected by paths. Use of d-separation in assigning causal direction is illustrated in the next section.

Determination of Causal Flows

The notion of d-separation is incorporated into PC algorithm by Spirtes, Glymour, and Scheines. PC algorithm is implemented into the software TETRAD II by Scheines, et al. and is used to determine causal flows in a model.

To illustrate the process of causal determination the following example is constructed. $X_1 = \nu_1$, $X_2 = \nu_2$, $X_3 = 0.2X_1 + 0.7X_2 + \nu_3$, $X_4 = -0.8X_3 + \nu_4$, and $X_5 = 0.8X_3 + \nu_5$, where ν_i (i = 1,…,5) is randomly generated with independent, standard normal distribution. Observations of X_i's are generated such that X_1 and X_2 cause X_3, X_3 causes X_4, and X_3 causes X_5.

The process of causal determination begins with a complete, undirected graph which shows an undirected edge between every pair of variables in the system (figure 1). PC algorithm proceeds step-wise to remove edges between variables and then assign causal flows on the remaining edges. Undirected edges between variables are removed sequentially based on zero-order correlation, first-order correlation, and higher-order correlation tests. In figure 1, the zero order correlation between X_1 and X_2 is 0.007 and p-value is 0.84 which implies that correlation is statistically insignificant. Thus, the undirected edge between X_1 and X_2 is removed. Figure 2 shows remaining edges after removal of the edges based on the zero-order correlation test.

In figure 2, the undirected edge between X_2 and X_4 is removed based on first-order correlation, $\rho\,(X_2, X_4 \mid X_3) = 0.004$ with p-value of 0.90. Similarly, the edges $X_1 - X_4$, $X_1 - X_5$, $X_2 - X_5$ and $X_4 - X_5$ are removed all conditioned on X_3. Figure 3 shows the remaining edges after the removal of edges by first-order correlation test. No edges are removed by higher-order correlation.

Once undirected edges are removed based on correlation tests, the remaining edges are directed. The notion of "sepset" is useful for this purpose. The conditioning variable(s) on removed edges between two variables is called the sepset of the two variables. For example, in figure 2, X_3 is in the sepset of X_1 and X_4; X_1 and X_5; X_2 and X_4; X_2 and X_5; and X_4 and X_5.

Causal direction is assigned as follows. In figure 3, the triple $X_1 - X_3 - X_2$ is directed as $X_1 \rightarrow X_3 \leftarrow X_2$. The reasoning for this assignment is as follows. In figure 1, the edge between X_1 and X_2 is removed by zero order correlation (that is, unconditional correlation), so X_3 is not in the sepset of X_1 and X_2. By the definition of the sepset, if conditioned on X_3, correlation between X_1 and X_2 must be non-zero. For this to happen the causal direction must be assigned as $X_1 \rightarrow X_3 \leftarrow X_2$. Here, causal direction is assigned using the notion of d-separation. This is type of causal flow is called an "inverted causal fork." Here the unconditional association between X_1 and X_2 is zero, but the conditional association between X_1 and X_2 given knowledge of the common effect X_3 is not zero: common effect does not "screen off" association between its joint causes.

The triple $X_1 \rightarrow X_3 - X_4$ is directed as $X_1 \rightarrow X_3 \rightarrow X_4$. The causal direction from X_1 to X_3 is already assigned above. The causal direction between X_3 and X_4 must be assigned as $X_3 \rightarrow X_4$, because, otherwise it makes X_3 not belong to the sepset of X_1 and X_4. Similarly, $X_1 \rightarrow X_3 - X_5$ is directed as $X_1 \rightarrow X_3 \rightarrow X_5$. A causal flow such as $X_1 \rightarrow X_3 \rightarrow X_4$ is called a "causal chain." The unconditional association between X_1 and X_4 is non-zero; however, given knowledge of X_3, the association between X_1 and X_4 is zero. So the middle variable (X_3) in a causal chain screens off association between X_1 and X_4.

The causal flow $X_4 \leftarrow X_3 \rightarrow X_5$ is called a "causal fork." Here the unconditional association between X_4 and X_5 is nonzero, but the conditional association between X_4 and X_5 given knowledge of the common cause, X_3, is zero: knowledge of a common cause screens off association between its joint effects. This completes assignment of causal directions and results in the directed acyclic graph as shown in figure 4.

The "screening-off" phenomenon is the fundamental notion that assigns direction of causal flow to a set of variables (Papineau). Screening-off phenomena associated with common effects and common causes have been recognized in the literature for fifty years (Orcutt; Simon; and Reichenbach). However, it is only recently that they have been formally introduced into the literature for assigning causal flows among three or more variables (Pearl 2000).

Application of a DAG to U.S. Fed Cattle Industry

In this section, the DAG method is used to investigate the causal structure among the U.S. fed cattle market variables.

Data

The relevant geographic procurement market for fed cattle for general purpose analysis consists of the entire United States (Hayenga). The monthly data from January 1988 to December 2001 (168 observations) for the following variables were used.

Since Nebraska tended to be the center for price discovery for the major cattle feeding region including Texas, Kansas, Nebraska, and Colorado, the Nebraska steer prices (Slaughter Steer Price, Choice 2-4, Nebraska Direct, 1100-1300 lb, USDA_AMS) were used as the fed cattle spot market prices (Ward).

Captive supply data are from the USDA_GIPSA, which is the national average of the three forms of the captive supply combined: packer-fed, forward contract, and marketing agreement cattle. The GIPSA captive supply data used in this study are the percentages of the cattle owned or controlled by packers 14 days prior to slaughter of the total slaughter volume by the four largest packing firms.

The plant utilization rate was constructed as follows. The highest slaughter volume month was used as the 85% (Barkley and Schroeder) of the "capacity" for the year and the monthly utilization rate was computed by dividing the monthly slaughter volume by this peak slaughter volume.

Feeder cattle prices are Feeder Steer Price, Med. No. 1, Oklahoma City, 500-550 lb. from AMS, USDA. Feed corn prices are Corn #2 Yellow, Central Illinois.

Boxed beef prices are the Wholesale Boxed Beef Cut-Out Value, Choice 1-3, Central U.S., 600-750 lb. from AMS, USDA. Retail beef prices are the national average prices for fresh beef from the Cattle Fax. Fed cattle futures prices were obtained from the Knight-Ridder.

Cointegration Analysis and Error Correction Model

As discussed above, PC algorithm can assign causal flows among variables. However, PC algorithm does not work directly on time-dependent data (Hoover). Swanson and Granger proposed using a Vector-Autoregression (VAR) to remove the time dependence in data. PC algorithm can be applied to the estimated residuals (innovations) from the first stage VAR model (Spirtes, Glymour, and Scheines; Pearl 1995, 2000; Swanson and Granger; Bessler and Yang).

To remove time dependence, the cointegration analysis and error correction modeling (ECM) are performed. The cointegration analysis employs the procedure developed by Johansen and Juselius (1992, 1994) and Johansen (1991, 1992). Let $\mathbf{X}_t$ denote a vector of cattle market variables under consideration, $\mathbf{X}'_t = [X_{1t}, X_{2t}, X_{3t}, X_{4t}, X_{5t}, X_{6t}, X_{7t}, X_{8t}]$, where the subscript 1 represents captive supply, 2 represents fed cattle spot market price, 3 represents plant utilization rate, 4 represents retail beef price, 5 represents boxed beef price, 6 represents feed corn price, 7 represents feeder cattle price, and 8 represents cattle futures price. All data series were found to be non-stationary except for captive supply and feeder cattle price based on the Augmented Dickey-Fuller test.

The process can be modeled in the ECM as follows:

(1) $$\Delta \mathbf{X}_t = \Pi \mathbf{X}_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta \mathbf{X}_{t-i} + \mu + \mathbf{e}_t \qquad (t = 1,2,...,T)$$

where, Π is 8 x 8 cointegrating matrix, $\mathbf{e}_t$ is the 8 x 1 residual vector. First, the number of cointegrating vectors, r, is determined as

(2) $$H_1(r) : \Pi = \alpha\beta'$$

where, Π is factored as $\alpha\beta'$. α is a matrix of weights known as the speed of adjustment parameters and β is the matrix of cointegrating parameters. Given a VAR model with a selected lag length of one (selected using the Schwarz criteria), the number (r) of long-run stationary relationships present in the system of eight variables is determined. Based on the trace-test statistics on the rank of Π, four cointegrating vectors (r = 4) are found. No variable is excluded from β by the exclusion test and feed corn price is found to be weakly exogenous in

α by the weak exogeneity test. Contemporaneous residuals are obtained from estimation of the ECM with the feed corn price replaced with zero in the cointegration matrix.

The contemporaneous causal structure on innovations can now be identified through the directed graph analysis of the correlation matrix of $\hat{\mathbf{e}}_t$ (Spirtes, Glymour, and Scheines; Pearl 1995, 2000; Swanson and Granger; Bessler and Yang). As discussed above, the DAG is specified by the TETRAD II. The directed acyclic graph for the fed cattle market is shown in figure 5.

Innovation Accounting

The dynamics of variables will be studied using the error variance decomposition and impulse response functions.

Discussion

The directed acyclic graph (figure 5) shows the contemporaneous causal relationships among the innovations of the variables.

Captive supply is shown to directly cause fed cattle cash market price. In addition, plant utilization rate and boxed beef price are also direct causes of cash market price. Cash market price is also affected indirectly by plant utilization rate and retail beef price.

Feed corn price and boxed beef price directly and indirectly cause many other variables, but not affected by any other variable. This type of variable is called a “root.” Recall that feed corn price was weakly exogenous in cointegration vector which means that its residual is not affected by any other residuals. Government price support programs might partially explain this independence of feed corn price.

Feeder cattle price is affected by all variables, but it does not affect any other variable. In particular, feeder cattle price does not affect fed cattle price. This result is consistent with the imbalance in the negotiating power in fed cattle price bidding between feeders and packers. Feeder cattle price is an information "sink" in the fed cattle industry. All information flows converge to it. Every DAG has at least one root and at least one sink.

It is noted that causal relationship between cattle futures price and retail beef price is bi-directional. This implies there exists an omitted variable between the two variables. This will be pursued in further research.

Conclusions

In quantitative research, direction of causality among the variables is often assumed without a rigorous test. In this study DAG method was used to illuminate causal relationships among the variables in the fed cattle industry, in particular, it was shown that captive supply causes spot market price to change. This research demonstrates the potential of the DAG method in investigation of causality in non-experimental data and contributes to the analytical methodology in empirical research.

In light of the recent federal court ruling in favor of Tyson (2004), the Johnson Amendment (Johnson) debate in the Farm Bill 2002, and continuing controversy of the issue (U.S. House of Representative), the results of this research have implications for the policy debate on the impacts of captive supply on the beef industry.

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FIGURES

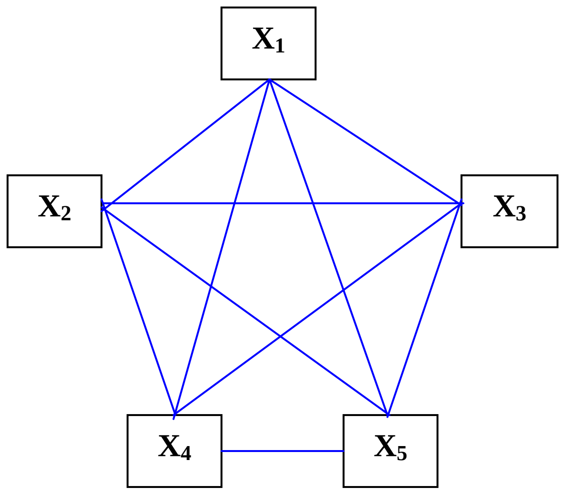

Figure 1. Complete undirected graph

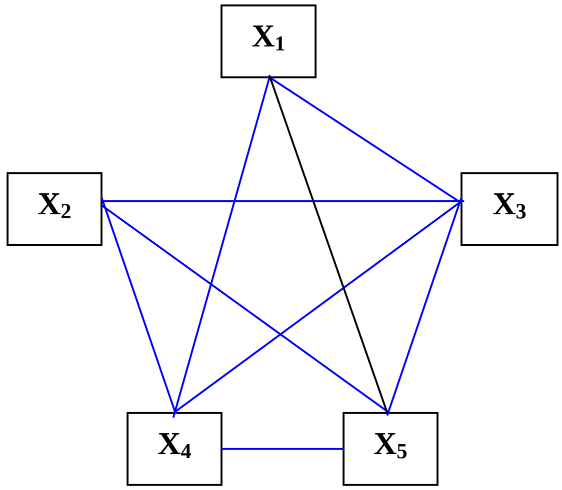

Figure 2. Remaining edges after removing based on zero order correlation

```
Significance level = 0.01

Edge                (Partial)
Removed             Correlation        Corr.     Prob.
-------             -----------        -----     -----
x1 -- x2            rho(x1, x2)        0.0065   0.8370
```

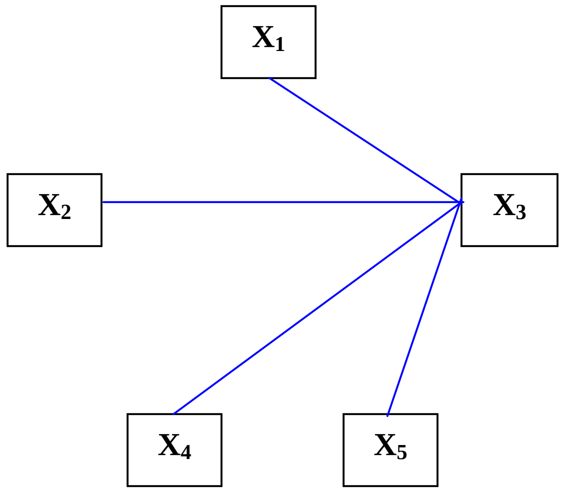

Figure 3. Remaining edges after removing based on first order correlation

```
Significance level = 0.01

                 (Partial, First Order)
Removed          Correlation                Corr.     Prob.
-------          -----------                -----     -----
x4 –- x5         rho(x4, x5 | x3)         -0.0164    0.6055
x2 -- x4         rho(x2, x4 | x3)          0.0038    0.9038
x1 -- x4         rho(x1, x4 | x3)         -0.0285    0.3684
x1 -- x5         rho(x1, x5 | x3)         -0.0638    0.0443
x2 -- x5         rho(x2, x5 | x3)         -0.0141    0.6569
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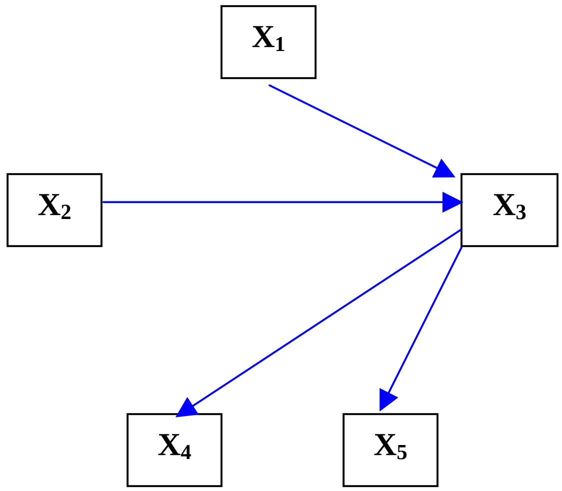

Figure 4. Final directed acyclic graph

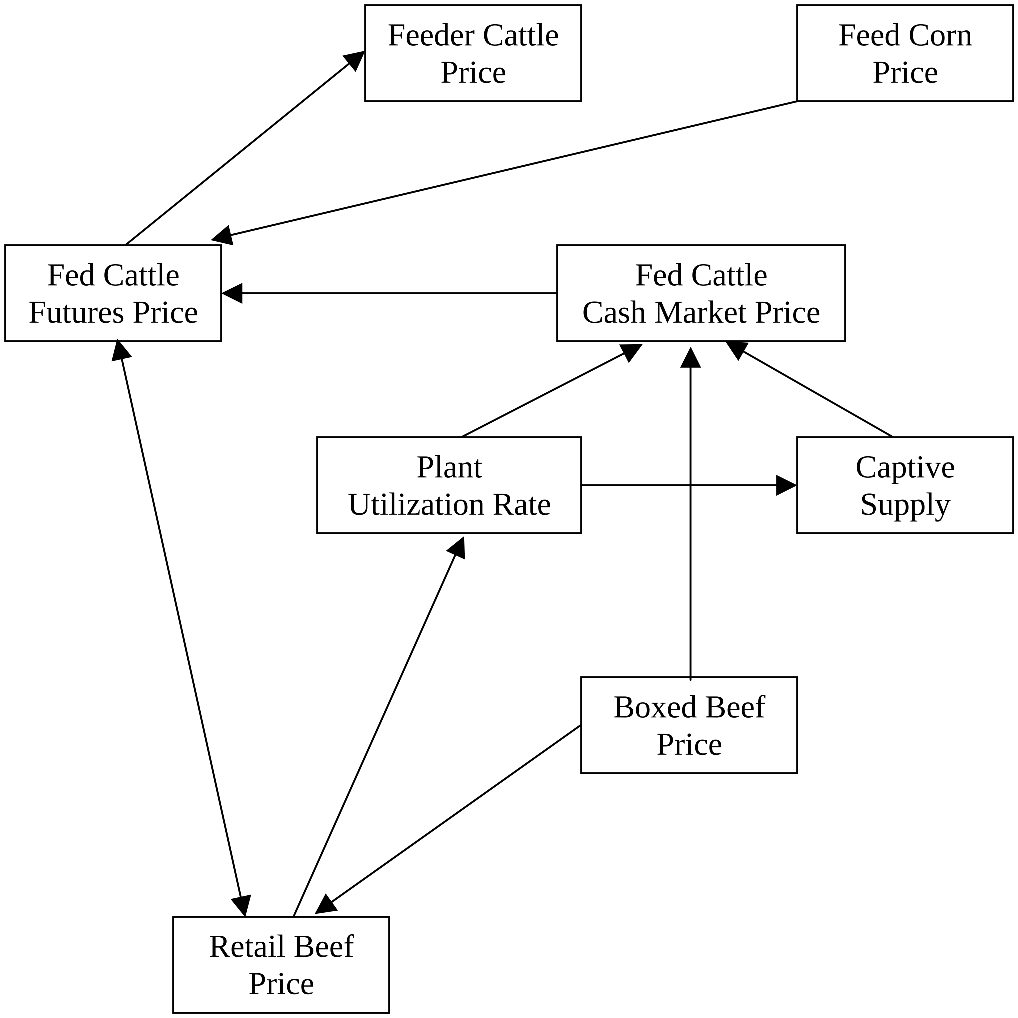

Figure 5. Directed acyclic graph for fed cattle market