Causality Between Captive Supplies and Cash Market Prices in the U.S. Cattle Procurement Market

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This study tests the causal direction between captive supply and cash market price in the U.S. cattle procurement market. Finding the correct causality should provide useful information to the decades-long debate on packers' anti-competitive behavior in the U.S. cattle procurement market. It should also help researchers find better econometric specifications for the cash price-captive supply relationship. Two causality tests—the Granger test and the Modified Wald test—were conducted. Overall test results indicate that captive supply causes cash market price, and it favors the price-dependent model.

Key Words: captive supply, cattle procurement market, causality, Modified Wald test, unit root

Several studies in the cattle procurement literature have reported a negative relationship between cash market price and captive supply (Elam 1992, Schroeder et al. 1993, Ward et al. 1996, Ward, Koontz, and Schroeder 1998, Schroeter and Azzam 2004).[1] One justification of this negative relationship is that the captive supply procurement methods could lower cattle prices in the cash market because the packers are already guaranteed a majority of cattle for slaughter (Zhang and Sexton 2000). A second justification is that sellers would choose their selling time based on their expected price. For example, captive supply sellers could control their delivery time to receive the highest expected price (Schroeter and Azzam 2004). Under these circumstances, when expected cash market price is low, captive supply would increase.

These two justifications are well reflected in the case of Pickett vs. Tyson Fresh Meats (Domina 2004, Taylor 2006). The plaintiff insisted that captive supplies caused low cash market price, while the defendant claimed that captive supply did not establish the causation. The defendant claimed producer expectations of price caused producers to deliver more captive supply in the week when prices went down for other reasons. Initially, Tyson was ordered by the U.S. District Court to return $1.28 billion to the members of all cattle producers who sold fed cattle directly to Iowa Beef Processor (IBP, now Tyson Fresh Meats) from February 1994 through April 30, 1999. However, the U.S. District Court judge entered a final judgment in Tyson's favor in 2004. Finally, the U.S. Supreme Court denied the appeal of the lower court decision in April 2006. Therefore, a crucial task in the literature of captive supply should be to investigate the causality between cash market prices and captive supplies. However, to our knowledge no study has examined the causality directly. Finding the correct causal direction should provide useful information to the decades-long debate on packers' anti-competitive behavior in the U.S. cattle procurement market. It should also help researchers find better econometric specifications for the cash market price-captive supply relationship.

The objective of this study is to investigate the causality between captive supplies and cash mar-

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[1] The definition of captive supply by USDA's Grain Inspection, Packers and Stockyards Administration (GIPSA) includes animals procured through forward contracts, formulas, and packer feeding arrangements or otherwise committed to a packer more than 14 days prior to slaughter.

ket prices in the U.S. cattle procurement market. This study particularly attempts to answer the question of whether packers use predetermined captive supply as an instrument to depress cash market price, or if feeders use the previous cash market prices as expected prices they will receive in the future to determine their cattle delivery. The Granger causality Wald test (Granger test) and the Granger causality with a modified Wald test (Modified Wald test) are used to examine the causality using weekly data of captive supply quantities and cash market prices in the U.S. cattle procurement market. We test the causal relationship between cash market price and total captive supply. We also test the relationships between cash market price and each of the captive supply methods, such as formula, forward contract, and packer-fed cattle, using both bivariate and multivariate models.

Both the Granger and the Modified Wald tests show the same results. Cash market price is affected by total captive supply and formula. The bidirectional causality is revealed between cash market price and forward contract. For packer-fed cattle and cash market price, packer-fed cattle cause cash market price in the bivariate models, but causal direction cannot be determined in the multivariate models. Although the causal relationships for cash market price-forward contract and cash market price-packer-fed cattle are unclear, overall test results indicate that captive supply causes cash market price and it favors the price-dependent model.

Literature Review

Two types of modeling approaches have been used in the literature to explain the negative relationship between captive supply and cash market price: the price-dependent model and the quantity-dependent model. Some researchers assume that packers' captive supplies negatively affect cash market prices and model the relationship using the price-dependent model (Elam 1992, Schroeder et al. 1993, Ward, Koontz, and Schroeder 1998, Zhang and Sexton 2000). Both Elam (1992) and Schroeder et al. (1993) estimate the impact of forward contract on cash price by regressing cash price on contract cattle shipments and other independent variables. Elam (1992) estimates that the average cash price of fed cattle decreases by less than \$0.01/cwt for each increase of 1,000 head of contract cattle shipments. Schroeder et al. (1993) estimate that average fed cattle cash transaction prices are lowered by \$0.15/cwt to \$0.31/cwt as a result of forward contract cattle shipments. Ward, Koontz, and Schroeder (1998) model transaction prices as a dependent variable, and they model percentage deliveries from the inventory of forward contracted and marketing agreement cattle as independent variables. They find a negative relationship between fed cattle transaction prices and captive supplies, but corresponding coefficients are relatively small. Zhang and Sexton (2000) develop a non-cooperative game approach in a spatial analysis setting to show that processors can use exclusive contracts (captive supplies) to manipulate cash market prices. The study demonstrates that captive supplies can form an effective spatial barrier between firms through high buyer concentration and shipping costs.

Others use quantity-dependent models because they believe the quantities of delivery are determined by the expected price that sellers can be paid when they deliver their cattle to packers in the future. Schroeter and Azzam (2004) and Schroeter (2007) find that cash market prices or expected cash market prices form a negative relationship with delivery of captive supplies. Schroeter and Azzam (2004) insist that delivery scheduling decisions could have led to a negative relationship between the volume of captive deliveries and an *ex ante* expectation of a future price change in the cattle procurement activities of four large packing plants in Texas in the mid-1990s. Schroeter (2007) extends Schroeter and Azzam (2004) to a dynamic rational expectations model of delivery timing. He claims that sellers of marketing agreements and cash markets have flexibility in scheduling cattle delivery while responding to changes in expected cattle price.

Ward et al. (1996) use a quantity-dependent model for the long-run analysis while the study uses a price-dependent model for the short-run analysis. In the long-run analysis, the plant-level study finds that relative prices play a major role in determining the level of captive supplies for the 16 largest plants, but do not influence captive supply levels of the 15 small plants. The study also finds that cash price variability is positively associated with the level of contract cattle for the 16 largest plants, but that it is not a determinant of packer-fed cattle or total levels of captive supplies. In the short-run analysis, Ward et al. (1996) show that the overall short-run impact of captive supply deliveries or inventories on fed cattle transaction prices is relatively small.

As discussed, previous studies in the literature use either a price-dependent model or quantity-dependent model to explain the negative relationship between captive supplies and cash market prices. However, no study in the literature has directly tested the causal direction between captive supply and cash market price.

Captive Supply Arrangements in the Cattle Procurement Market

According to the Mandatory Reporting Act, four types of methods are used to commit cattle for slaughter: negotiated purchase, formula, forward contract, and packer-owned cattle. Negotiated purchase is a cash or spot market purchase by packers. In this case, the base price is determined by seller-buyer interaction and agreement on a delivery day, and the delivery is scheduled to be made no more than 14 days after the date on which the livestock are committed to the packer.

Formula is the advance commitment of cattle for slaughter by any means other than through a negotiated purchase or a forward contract using a method for calculating price in which the final price is determined at a future date. The original base price may or may not be known at the time of slaughter—only the mechanism of arriving at the base price may be known. A feeder and a packer make a contract that contains a price formula and an approximate number of cattle scheduled for delivery per year. Generally the feeder makes a decision about two weeks before the time of delivery on the amount of cattle to deliver to the packer for each week. When the delivery volume is set by the feeder for a given week, the packer usually decides the specific day or days of the week when delivery will be made. The price of cattle delivered through formula is calculated by several formulas, which include base price, system of premia and discounts, and quality characteristics such as yield grade, quality grade, and carcass weight range. The base price is tied to the cash market price paid the week prior to delivery of the formula cattle (Schroeter and Azzam 2004).

Forward contracts are those purchases based on the Chicago Mercantile Exchange (CME) plus a very limited number based on other futures type pricing mechanisms such as the Mid-America Exchange, the Chicago Board of Trade, and other futures trading exchanges where the price is available for months in the future. A price can be locked in at any time based on those prices. Forward contracts may also include a straight cash deal for delivery in excess of 14 days (USDA 2010). Packer-fed cattle are owned by the packer prior to the time the cattle are ready for slaughter. Packers purchase feeder cattle and place them on feed in packer-owned or commercial feedlots. They are priced by a transfer pricing formula or cost accounting price (Ward et al. 1996).

What are the captive supplies? In this study, we consider formula, forward contract, and packer-owned cattle as captive supply. While forward contract and packer-owned cattle can easily be considered as captive supply, we note that the categorization seems less clear for formula pricing because not all formula-priced cattle are associated with marketing agreements. However, as many formula trades are associated with supply contracts or marketing agreements, and many of those agreements allow feeders to determine the delivery date for fed cattle one to three weeks prior to harvest (Ward 2005), we believe that most formula-priced cattle are captive supply. Therefore, we include formula pricing in the category of captive supply in this paper.

Causality Tests

To investigate the direction of the causal relationship between captive supply and cash market price in the cattle procurement market, two causality tests—the Granger test and the Modified Wald test—are used in this study.

Granger Test

In the Granger test, a variable x causes a variable y, if a variable y can be predicted with greater accuracy by using past values of a variable x than by not using such past values, while all other terms remain unchanged (Granger 1969). Three types of causality are feasible for our study. First, if $x(y)$ causes $y(x)$, but $y(x)$ does not cause $x(y)$, then a directional causality exists. Second, if x causes y, and y causes x, then a bidirectional causality (feedback) exists. Finally, the third causality type is that the direction cannot be determined.

Various ways to test for Granger causality exist. However, the most popular one is the one following a vector autoregressive (VAR) system:

$$(1)\qquad y_t = \alpha_1^G + \sum_{i=1}^{n} \beta_i^G x_{t-i} + \sum_{j=1}^{m} \gamma_j^G y_{t-j} + \varepsilon_{1t},$$

$$(2)\qquad x_t = \alpha_2^G + \sum_{i=1}^{n} \delta_i^G x_{t-i} + \sum_{j=1}^{m} \eta_j^G y_{t-j} + \varepsilon_{2t},$$

where y_t and x_t are assumed to be stationary, n and m are numbers of lags, and ε_{1t} and ε_{2t} are white noise disturbances.

The variable x_t does not cause y_t if $\beta_i^G = 0$ for $i = 1, 2, \ldots, n$, but the variable y_t causes x_t if $\eta_j^G \neq 0$. The implication of this model structure is that values of the process y_t are influenced only by its own past but not by the past of x_t, while values of x_t are influenced by the pasts of both x_t and y_t. A Wald test is used to test these hypotheses within the framework of VAR models (Konya 2004).[2] Before applying the Granger test procedure, a pre-test needs to be conducted for potential unit root and cointegration problems. Two types of VAR models—bivariate and multivariate models—are specified for this study. Bivariate models are designed to test pair-wise causal relationships such as cash market price versus total captive supply, and cash market price versus each of the captive supply methods (formula, forward contract, and packer-fed cattle) separately. The multivariate model considers all potential causal relationships simultaneously in a multi-equation system. The multivariate model drops total captive supply due to the multicollinearity problem.

Modified Wald Test

The Granger tests require time-series data pre-tested for potential unit root and cointegration problems (Konya 2004). When variables are stationary, conventional asymptotic theory is valid for hypothesis testing in the VAR models. If variables are cointegrated, then one can use Error Correction Models (ECM). Therefore, one limitation of the Granger tests may be that the direction of causality can depend on pre-tests, more specifically unit root and cointegration tests. Toda and Yamamoto (1995) propose an alternative causality test, the Modified Wald test. Unlike the Granger tests, the Modified Wald test uses the level data directly, and it is valid even under uncertainty about integration and cointegration (Konya 2004).

The Modified Wald test is conducted in VAR systems with augmented lag levels, $n + d$ and $m + d$, where n and m are the lag length for the variables, and d is the highest order of integration suspected in the system. Then, a bivariate framework for the Modified Wald test can be written as

$$(3)\qquad y_t = \alpha_1^M + \sum_{i=1}^{n} \beta_i^M x_{t-i} + \sum_{i=n+1}^{n+d} \beta_i^M x_{t-i} + \sum_{j=1}^{m} \gamma_j^M y_{t-j} + \sum_{j=m+1}^{m+d} \gamma_j^M y_{t-j} + u_{1t},$$

$$(4)\qquad x_t = \alpha_2^M + \sum_{i=1}^{n} \delta_i^M x_{t-i} + \sum_{i=n+1}^{n+d} \delta_i^M x_{t-i} + \sum_{j=1}^{m} \eta_j^M y_{t-j} + \sum_{j=m+1}^{m+d} \eta_j^M y_{t-j} + u_{2t}.$$

In this model the null hypothesis is $\beta_i^M = 0$ for $i = 1, 2, \ldots, n$ and $\eta_j^M = 0$ for $j = 1, 2, \ldots, m$, and the test statistic follows an asymptotic χ^2 distribution with the degrees of freedom, $n + d$ and $m + d$ (Toda and Yamamoto 1995).[3] If the parameters of the value of x_t are not zero, i.e., $\beta_i^M \neq 0$ for $i = 1, 2, \ldots, n$, then x_t causes y_t, and if the parameters of the value of y_t are not zero, i.e., $\eta_j^M \neq 0$ for $j = 1, 2, \ldots, m$, then y_t causes x_t. A multivariate model is also specified for the Modified Wald tests by extending the pair-wise bivariate model in equations (3) and (4).

[2] The Likelihood ratio (LR) test and Lagrange multiplier (LM) test can be used, but the Wald test is used in this study because the Wald test is usually more powerful and valid in small samples with linear hypotheses and linear models. For more detail, see Greene (2008, pp. 498–504).

[3] The last d lags are not considered explicitly in the Wald test. These extra lags, however, are necessary in the specification to ensure the asymptotically χ^2 sampling distribution of the test statistic (Konya 2004).

Data

This study uses national level weekly volume (head) data for formula, forward contract, packer-fed cattle, and total captive supply (which is the sum of formula, forward contract, and packer-fed cattle). Heads of formula and forward contract are compiled from LM CT151 (National Weekly Direct Slaughter Cattle Report—Formulated and Forward Contract) of USDA's Agricultural Marketing Service's mandatory price reports. Heads of packer-fed cattle are compiled from LM CT153 (National Weekly Direct Slaughter Cattle—Prior Week Slaughter and Contract Purchases). Cash market price is compiled from LM CT150 (5 Area Weekly Weighted Average Direct Slaughter Cattle—Negotiated Purchases) and is live steer weighted average FOB price from five areas (Texas/Oklahoma/New Mexico, Kansas, Nebraska, Colorado, and Iowa/Minnesota). The five-area weighted average price includes prices for all grades of fed cattle purchased from several major cattle-feeding states.[4] An argument could be made that the five-area weighted average price is the most comprehensive and representative of market conditions in the cash market. The data include 383 weekly observations of total captive supplies of cattle procurement from formula, forward contract, and packer-fed cattle plus cash market price from April 2004 to August 2011 (USDA 2011).[5]

Table 1 shows the descriptive statistics for the data. During the data period, the average cash market price was $91.00 per hundredweight of cattle, and the total captive supply accounted for 51.5 percent of all cattle procurement. Of the total captive supply, formula, forward contract, and packer-fed cattle accounted for 72.9 percent, 16.1 percent, and 11.0 percent, respectively (37.5 percent, 8.3 percent, and 5.7 percent of all cattle procurement).

Figure 1 shows that the total captive supply quantity has an increasing trend after 2004. The trend of formula quantity is similar to the trend of total captive supply since the majority of the total captive supply quantity is accounted for by formula. Forward contract gradually increases from the beginning of 2006, but packer-fed cattle shows fluctuations with no increasing or decreasing trend.

Econometric Procedure

Before conducting the Granger tests, unit roots are tested to determine whether economic variables are stationary or nonstationary. If variables do not have unit roots, then the Granger tests can be conducted with level data. If variables have unit roots, then one can make the data stationary by taking time-difference. If the variables are not cointegrated, then one can run the Granger tests in the VAR with the differenced data. If the variables are cointegrated, then the Error Correction Model (ECM) needs to be introduced. The Modified Wald test is conducted without pre-testing of unit root and cointegration. All variables are transformed into natural logarithms for all causality tests because the transformation tends to produce linear trends and constant variances when the variables have exponential growths and the variability of variables increases over time (Lutkepohl and Xu 2009).

Another important task in testing the causality between captive supply and cash market price is to take into account the existence of time lag between the time of decision on captive supply and actual delivery. As discussed earlier, the quantity of captive supplies is usually determined by feeders one or two weeks before they are delivered under the formula and forward contract, respectively (Schroeter and Azzam 2004). The quantity of packer-fed cattle is totally dependent on the packer's decision. Since the vast majority of captive supply comes from formula (72.9 percent), we assume a two-week time lag between captive supplies and their actual delivery (therefore cash market price).[6]

[4] We use five-area aggregated price data and national aggregated quantity data because the cattle procurement market is national in scope, and all of the U.S. geographic fed cattle price reporting regions are reasonably well linked into the national fed cattle market. For example, some cattle are shipped over 1,000 miles to slaughter (Hayenga, Koontz, and Schroeder 1996, Muth and Wohlgenant 1998).

[5] The negotiated grid was combined with formula until April 2004. The USDA started reporting negotiated grid separately after April 2004. Therefore, the causality tests are performed with the data after April 2004 for data consistency.

[6] The weekly price and quantity data used in this study are for cattle slaughtered each week. Therefore, cash price is the negotiated cash price for cattle slaughtered each week, while the captive supply quantities are formula, forward contract, and packer-fed cattle that are slaughtered in that week. Regardless of the arrangement types, we assume that all cattle slaughtered each week are delivered the same week. Consequently, we assume that a two-week time lag exists between the captive supplies and the corresponding cash price.

Table 1. Descriptive Statistics of Variables

Variable	Cash Market Price ($/cwt)	Total Procured Cattle (Head)	Total Captive Supply (Head)	Formula (Head)	Forward Contract (Head)	Packer-Fed Cattle (Head)
Mean	91.00	432,643	222,924	162,410	35,934	24,580
S.D.	8.46	47,012	43,546	31,251	18,349	6,876

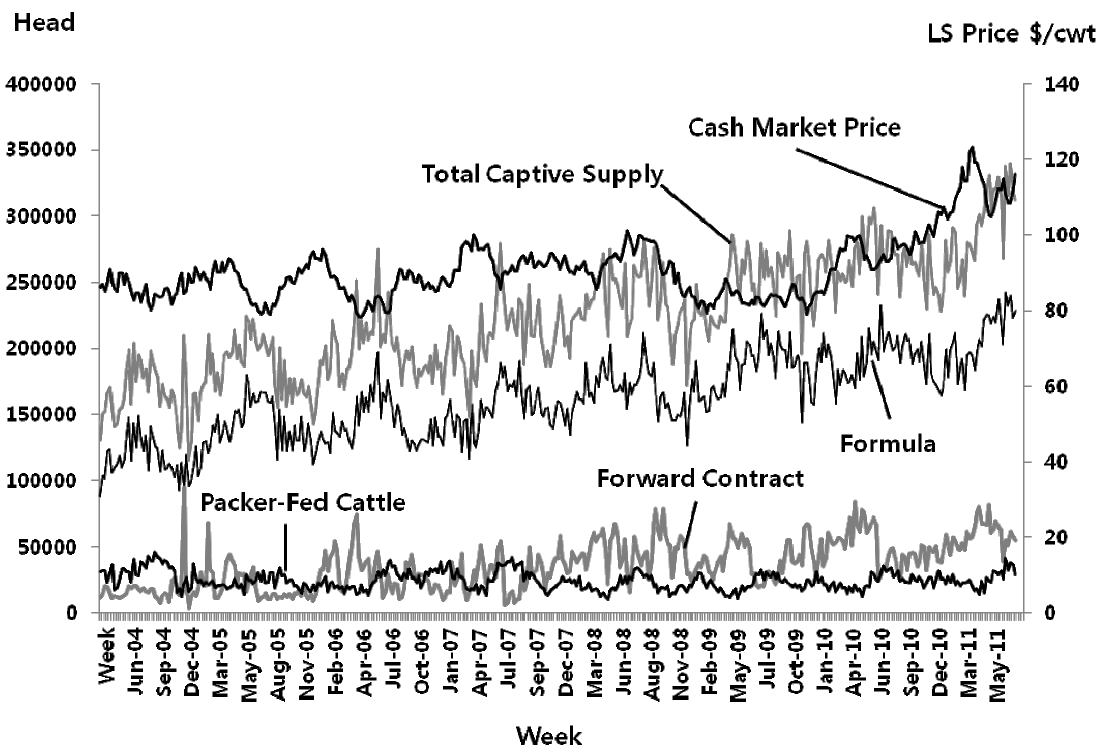

Figure 1. Weekly Captive Supplies and Cash Market Prices (April 2004 to August 2011)

Unit Root Test

The Augmented Dickey-Fuller (ADF) test, the Philip-Perron (PP) test, and the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test are carried out to check the stationarity. The ADF test and the PP test are commonly used to test the unit root hypothesis. However, the null hypotheses for these tests are of a unit root (nonstationary), which can be accepted unless there is strong evidence against it. These types of unit root tests tend to have low power against the alternative hypothesis (Diebold and Rudebusch 1991, DeJong et al. 1992, Park, Jin, and Love 2011). Kwiatkowski et al. (1992) developed the KPSS test of the null hypothesis that is stationarity. Therefore, the KPSS test could be the complement to the ADF and PP tests to prevent mistakes in checking the stationarity for the data series. The autoregressive model with constant and time trend terms is used for unit root tests to account for a time trend of each variable.

Test results for unit root versus stationarity with level data are reported in Table 2. The null hypotheses of unit root for formula, forward contract, packer-fed cattle, and total captive supply

Table 2. Results of Unit Root Tests with Level Data

Variables	ADF (tau)	PP (tau)	KPSS (eta)	Unit Root
Formula	-4.2040**	-10.2092**	0.0583	No
Forward contract	-5.9291**	-9.0955**	0.0745	No
Packer-fed cattle	-4.4105**	-7.9143**	0.1534**	No
Total captive supply	-5.2290**	-10.6824**	0.0390	No
Cash market price	-2.2537	-2.3022	0.4481**	Yes

Note: The lag lengths of ADF tests and PP tests are 3, those of KPSS are 5. ** indicates significance at the 5 percent level.

are rejected at the 5 percent significance level, while the null hypotheses of unit root for cash market price are not rejected at the 5 percent significance level in both the ADF and the PP tests. In the KPSS test, the null hypotheses of stationarity for formula, forward contract, and total captive supply are not rejected at the 5 percent significance level, while the null hypotheses of stationarity for packer-fed cattle and cash market price are rejected at the 5 percent significance level. Test results indicate that formula, forward contract, packer-fed cattle, and total captive supply are stationary, while cash market price is not stationary. All variables are also tested with first-differenced data in Table 3, and test results show they are all stationary at the first differences. Consequently, we conclude that formula, forward contract, packer-fed cattle, and total captive supply are stationary I(0), while cash market price is integrated order 1, I(1). Since formula, forward contract, packer-fed cattle, total captive supply, and cash market price are integrated of different orders, cointegration tests are not conducted. Therefore, we set two VAR models for the Granger tests. First, we set a VAR model that uses level data for captive supplies and first-differenced data for cash market price. The second model uses first-differenced data for both captive supplies and cash market price.

Empirical Results

For both Granger and Modified Wald tests, we estimate bivariate and multivariate models. From the bivariate models, pair-wise causal relationships are tested between cash market price and formula, between cash market price and forward contract, between cash market price and packer-fed cattle, and between cash market price and total captive supply. For the multivariate model, a VAR model is constructed for formula, forward contract, packer-fed cattle, and cash market price in a multi-equation system. In the model, we do not include total captive supply for the multivariate model to avoid the collinearity problem.

For the Granger test, time lags [i.e., n and m in equations (1) and (2)] are chosen based on Akaike Information Criteria (AIC) for all sets of series. The results with level data for captive supplies and first-differenced data for cash market price are reported in Table 4. In Table 4, the null hypothesis that cash market price does not cause formula is not rejected, while the null hypothesis that formula does not cause cash market price is rejected at the 5 percent significance level in both bivariate and multivariate models. Therefore, we can conclude that formula causes cash market price, but cash market price does not cause formula. For the relationship between cash market price and forward contract, both null hypotheses are rejected in bivariate as well as multivariate models. Therefore, forward contract and cash market price show the bidirectional causal relationship. The test results for the relationship between cash market price and packer-fed cattle show that packer-fed cattle causes cash market price in the bivariate model, but no causation occurs in the multivariate model. For the relationship between total captive supply and cash market price, the null hypothesis that cash market price does not cause total captive supply is not rejected, while the null hypothesis that total captive supply does not cause cash market price is rejected at the 5 percent significance level in the bivariate

Table 3. Results of Unit Root Tests with First-Differenced Data

Variables	ADF (tau)	PP (tau)	KPSS (eta)	Unit Root
Formula	-13.7623**	-39.4793**	0.0268	Yes
Forward contract	-12.6850**	-23.4955**	0.0086	Yes
Packer-fed cattle	-11.3834**	-32.9556**	0.0113	Yes
Total captive supply	-14.6301**	-31.6971**	0.0175	Yes
Cash market price	-10.2248**	-17.8172**	0.0423	Yes

Note: The lag lengths of ADF tests and PP tests are 3, those of KPSS are 5. ** indicates significance at the 5 percent level.

Table 4. Results of the Granger Tests with Mixed-Level Data

	Bivariate Model			Multivariate Model		
Null hypothesis (H_0)	DF	Chi-Square	Pr > Chi-Square	DF	Chi-Square	Pr > Chi-Square
CP does not cause FO	4	2.22	0.6952	4	3.20	0.5250
FO does not cause DCP	4	10.94	0.0272	4	10.79	0.0290
DCP does not cause FW	5	28.70	<.0001	4	12.10	0.0166
FW does not cause DCP	5	20.49	0.0010	4	17.78	0.0014
DCP does not cause PK	5	4.19	0.5221	4	2.98	0.5604
PK does not cause DCP	5	14.32	0.0137	4	7.12	0.1296
DCP does not cause CS	4	6.19	0.1857			
CS does not cause DCP	4	23.48	0.0001			

Note: DCP is first differenced cash market price, FO is formula, FW is forward contract, PK is packer-fed cattle, and CS is total captive supply.

model. The test results suggest that total captive supply causes cash market price, but cash market price does not cause total captive supply in the bivariate model. Table 5 reports results from the Granger test with first-differenced data for all variables. The results are consistent with the case where level data is used for captive supplies.

Because the Modified Wald test does not require unit root and cointegration tests, five VAR models are tested with level data: one multivariate and four bivariate VAR models (for formula-cash market price, forward contract-cash market price, packer-fed cattle-cash market price, and total captive supply-cash market price). We assume that the maximal order of integration is one, i.e., $d = 1$, and experiment with $n + d = m + d = 2,3,4,5$ for all models. Time lags for each bivariate model are determined using AIC, which are 4, 5, 5, and 4 [i.e., n and m are 3, 4, 4, and 3 in equations (3) and (4)] for the Modified Wald tests between formula and cash market price, between forward contract and cash market price, between packer-fed cattle and cash market price, and between total captive supply and cash market price, respectively. Time lag for the multivariate model is 4, i.e., $n + d = m + d = 4$, based on AIC.

Table 6 reports results of the Modified Wald tests. From the bivariate models, formula causes cash market price, but cash market price does not cause formula. Forward contract shows bidirectional causal relationship with cash market price. However, packer-fed cattle and cash market price show no causal relationship. The test results show that total captive supply causes cash market price.

Table 5. Results of the Granger Tests with First-Differenced Data

	Bivariate Model			Multivariate Model		
Null hypothesis (H_0)	DF	Chi-Square	Pr > Chi-Square	DF	Chi-Square	Pr > Chi-Square
DCP does not cause DFO	5	2.30	0.8060	5	1.44	0.9203
DFO does not cause DCP	5	15.21	0.0095	5	11.08	0.0498
DCP does not cause DFW	5	33.30	<.0001	5	24.42	0.0002
DFW does not cause DCP	5	17.86	0.0031	5	15.67	0.0078
DCP does not cause DPK	5	3.63	0.6035	5	2.80	0.7301
DPK does not cause DCP	5	13.99	0.0157	5	10.82	0.0551
DCP does not cause DCS	5	7.06	0.2162			
DCS does not cause DCP	5	35.86	<.0001			

Note: DCP is first differenced cash market price, DFO is first differenced formula, DFW is first differenced forward contract, DPK is first differenced packer-fed cattle, and DCS is first differenced total captive supply.

Table 6. Results of the Modified Wald Tests

	Bivariate Model			Multivariate Model		
Null hypothesis (H_0)	DF	Chi-Square	Pr > Chi-Square	DF	Chi-Square	Pr > Chi-Square
CP does not cause FO	4	2.44	0.4858	4	3.09	0.3773
FO does not cause CP	4	8.98	0.0296	4	8.60	0.0235
CP does not cause FW	5	19.66	0.0006	4	11.73	0.0084
FW does not cause CP	5	15.68	0.0035	4	15.08	0.0017
CP does not cause PK	5	0.90	0.9245	4	2.52	0.4719
PK does not cause CP	5	8.49	0.0751	4	5.66	0.1296
CP does not cause CS	4	5.79	0.1221			
CS does not cause CP	4	21.18	<.0001			

Note: CP is cash market price, FO is formula, FW is forward contract, PK is packer-fed cattle, and CS is total captive supply.

Results from the multivariate model are consistent with those from the bivariate models. Therefore, overall results of the Modified Wald test are consistent with those of the Granger tests.

Causality test results reported in Tables 4 to 6 are summarized in Table 7. Both tests indicate that formula and total captive supply cause cash market price, while forward contract and cash market price show bidirectional causal relationship. Both tests show packer-fed cattle causes cash market price in the bivariate models, but no causal relationship is detected between packer-fed cattle and cash market price in the multivariate model.

Conclusions

One of the controversial debates in the cattle procurement market is about the causal relationship between cash market price and captive supply. Some researchers claim that the captive supply procurement methods could lower cattle prices in

Table 7. Summary of Two Causality Tests

Variables vs. Cash Market Price	Granger Test		Modified Wald Test	
	Bivariate	Multivariate	Bivariate	Multivariate
Formula	FO → CP	FO → CP	FO → CP	FO → CP
Forward contract	FW ↔ CP	FW ↔ CP	FW ↔ CP	FW ↔ CP
Packer-fed cattle	PK → CP	PK ? CP	PK → CP	PK ? CP
Total captive supply	CS → CP		CS → CP	

Note: CP is cash market price, FO is formula, FW is forward contract, PK is packer-fed cattle, and CS is total captive supply. FO → CP means formula cause cash market price, FW ↔ CP means bidirectional causal relationship, and PK ? CP means the causal relationship cannot be found.

the cash market because the packers are already guaranteed a majority of cattle for slaughter. However, others argue that cash market price influences feeders' decisions of cattle delivery time. That is, when expected cash market price is low, captive supply would increase for the higher expected price in the future. The two arguments imply two opposite directions of the causal relationships between captive supply and cash market price, which were effectively used in the case of Pickett vs. Tyson Fresh Meats for plaintiff and defendant, respectively, and also led to two alternative specifications: price- and quantity-dependent models in the literature.

This study tests the causal direction between captive supply and cash market price in the U.S. cattle procurement market. Finding the correct causality should provide useful information for the decades-long debate on packers' anti-competitive behavior in the U.S. cattle procurement market and should also help researchers find better econometric specifications for the cash price-captive supply relationship.

Two causality tests—the Granger test and the Modified Wald test—are conducted for four relationships: cash price-total captive supply, cash price-formula, cash price-forward contract, and cash price-packer fed cattle. Both tests indicate that cash market price is caused by total captive supply and formula. Cash market price and forward contract show the bidirectional causality. The bivariate models find that packer-fed cattle causes cash market price while the multivariate models reveal no causal relationship between cash market price and packer-fed cattle. Although the causal relationships for cash market price-forward contract and cash market price-packer-fed cattle are unclear, overall test results indicate that captive supply causes cash market price and favor the price-dependent model.

While this study was the first in directly testing the causal relationship between captive supply and cash market price and provides useful information about the relationship, we note that our findings should be interpreted strictly based on econometric specifications and the data period used in this study. In our model specifications, we focus on the relationship between captive supply quantities and cash market price. However, the price effect may also be influenced by other factors such as decreasing trend of beef consumption, increasing chicken consumption, and the change in overall cattle inventory. Our findings may be sensitive to the use of alternative data periods, geographical data, and time lags between captive supplies and their actual delivery. Therefore, to verify our findings, further study is needed using different data sets while accounting for many factors that can affect the complex relationship between cash market price and captive supply.

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