Impacts of retail and export demand on United States cattle producers*

Authors: Melissa G.S. McKendree, Glynn T. Tonsor, Ted C. Schroeder, Nathan P. Hendricks

Abstract: Despite its importance in many decisions throughout agriculture, limited empirical work has quantified how changes in primary demand impact producers operating at different levels of vertically-connected industries. A structural system of equations was estimated to quantify the impacts of U.S. retail and export beef demand on fed and feeder cattle demand and supply. Increases in retail and export demand positively impact both feeder and fed cattle producers. The estimated transmission elasticities suggest shifts in retail and export demand, whether positive or negative, accrue proportionally more to feeder cattle producers than fed cattle producers. Using estimates from previous literature of the effect of generic advertising on beef demand, simulation results suggest feeder and fed cattle producers would benefit from increasing beef checkoff assessments from $1 to $2. Furthermore, an increase in export demand of more than 3.5% from observed values would cover aggregate costs of implementing source and age verification. While primary suppliers are often not directly involved in primary demand activities in vertically-connected industries, this study highlights the key economic value for primary suppliers to support demand enhancing activities.

Keywords: beef, demand, fed cattle, feeder cattle, price transmission, producer surplus, supply

JEL classifications: C32, C50, Q11, Q13, Q17, Q18

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Melissa G.S. McKendree is an Assistant Professor in the Department of Agricultural, Food, and Resource Economics at Michigan State University. Glynn T. Tonsor is a Professor at Kansas State University in the Department of Agricultural Economics. Ted C. Schroeder is a University Distinguished Professor at Kansas State University in the Department of Agricultural Economics. Nathan P. Hendricks is an Associate Professor at Kansas State University in the Department of Agricultural Economics. This project is supported by Michigan State University AgBioResearch and the USDA National Institute of Food and Agriculture through Hatch project MICL02558 and Hatch-Multistate project MICL04171. Correspondence should be sent to Melissa G.S. McKendree at mckend14@msu.edu

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Debates on the merits of producer-funded efforts to enhance demand are contentious (Crespi and Marette 2009; Kaiser 2016; Ward 1999). Quantifying how these demand shocks are transmitted to multiple segments of a vertically connected supply chain — such as the U.S. beef industry — is critical for understanding distributional impacts (Kinnucan, Xiao, Hsia, and Jackson 1997; Wohlgenant 1993). In general, understanding how shocks are transmitted through the supply chain is critical for policy analysis (Balagtas and Kim 2007; Okrent and Alston 2012) and estimating the impact of new technologies (Pendell, et al. 2010; Weaber and Lusk 2010). The objective of this paper is to estimate the transmission of domestic retail and export demand changes through the U.S. beef industry to cattle producers. Quantifying how changing primary beef demand is shared among production and marketing channel members is essential for an economic assessment of demand enhancing investments.

One such demand enhancing effort that has been especially polarizing is the U.S. beef checkoff.1 Under the U.S. beef checkoff program, cattle producers are required to pay $1 every time an animal is sold. These funds are then used for projects intended to benefit beef producers. One of the most controversial uses of the checkoff funds is for generic advertising intended to increase primary beef demand (Crespi and McEowen 2006; Crespi 2005). Between 2015 and 2016, the beef check collected $81.56 million in producer assessments, of which $49.30 million was spent on generic advertising (domestic and foreign) and consumer information. Whether or not producers benefit from these efforts depends primarily on two factors. First, what is the impact of advertising expenditures on primary demand (e.g., Kaiser 2016)? Second, what is the impact of changes in demand on different sectors of the vertically connected industry? For example, even if the beef industry as a whole benefits from generic advertising, some sectors in
the supply chain may benefit relatively more or some sectors could even lose. Our paper
provides new insights related to the second of these two factors.

The effect of export demand on different vertical sectors of the beef industry is also
increasingly important to understand. From the early 1980s to 2013, beef export volume grew
ten-fold from around 1% to about 10% of production (Livestock Marketing Information Center
[LMIC] 2018). The heightened importance of exports in the beef market was especially evident
in late 2003 and 2004 when foreign markets halted imports of U.S. beef due to discovery of
bovine spongiform encephalopathy (BSE) in the U.S. beef herd. Marsh, Brester, and Smith
(2008) concluded “the demand for U.S. beef was affected to a much greater degree by the
reactions of foreign governments to the BSE announcements than by the reactions of U.S.
households” (p. 136). The future role of beef exports is expected to increase, reflecting global
economic growth and expanding meat protein demand. The Economic Research Service projects
that U.S. beef exports will grow over 10% by 2026 with a large increase in beef demand coming
from China and Hong Kong (USDA 2017). However, the actual growth can vary from these
projections due to realized export market access which may depend on non-tariff trade barriers
such as product traceability. One specific program is age and source verification (SAV) which
has a history of being involved in international trade discussions and, at times, is required for a
country to obtain market access (Pendell et al., 2010; 2013). For example, in 2018, Japan, Korea,
Taiwan and China required U.S. beef to meet various SAV requirements to be eligible for import
(USDA AMS 2018a, b). However, specific market access requirements to particular countries
are dynamic, complicated and fluid. Together these factors highlight the growing critical need
for empirical assessment of how export demand shifts impact U.S. cattle producers.
Our work is most closely related to Marsh (2003) who estimated a system of equations of supply and demand for different vertical sectors of the beef industry. However, Marsh’s work is now nearly two decades old in an industry that has experienced massive changes. Among these notable changes in the U.S. beef industry is the increased role of exports; Marsh (2003) includes a retail demand index in his estimation but does not estimate the effect of shifts in export demand. Another important distinction in our work is that we account for the endogeneity of the retail demand index by using a quantity-based demand index that isolates demand shifts and incorporate an instrumental variables strategy.

**Model development and data**

Our conceptual model uses the Marsh (2003) model as a foundation, however it is changed and expanded in multiple ways to reflect the evolving structure of the beef industry and account for the endogeneity of retail and export demand.

**Demand indices**

A key component in Marsh (2003) is the integration of a price-based beef demand index (1970=100) into the econometric system to represent shifts in U.S. retail domestic beef demand. Demand indices are preferred to using beef prices to measure changes in primary demand because prices reflect both shifts in supply and demand (Marsh 2003; Brester and Marsh 1983; Wohlgenant 1989). The demand index enables us to isolate just the demand shifts.

Bekkerman, Brester, and Tonsor (2019) compare quantity- and price-based meat and energy demand indices and argue that quantity-based indices produce more accurate estimates of changes in beef demand than price-based indices. They argue that the quantity-based index is better at reflecting demand shifts because it effectively removes changes in quantity demanded due to movements along the demand curve. Furthermore, Bekkerman, Brester, and Tonsor
(2019) find that price-based indices are more volatile than the quantity-based indices and often indicate unreasonably large shifts in demand. Therefore, following Bekkerman, Brester, and Tonsor (2019) we construct a quantity-based consumer demand index as:

\[
I_{quantity} = \left( \frac{Q_t}{Q^e_t} \right) \times 100 = \frac{Q_t}{Q_{base} + \left\{ Q_b \times \left( \frac{P_t - P_{base}}{P_{base}} \times \left( \frac{\%\Delta Q}{\%\Delta P} \right) \right) \right\} } \times 100
\]

where \( Q_t \) is per capita quantity of beef consumed in quarter \( t \), \( Q^e_t \) is expected per capita consumption if there were no change in demand in quarter \( t \), \( Q_{base} \) is the base quarter quantity, \( P_t \) is the price in quarter \( t \), \( P_{base} \) is the base quarter price, and \( \frac{\%\Delta Q}{\%\Delta P} \) is the own-price demand elasticity. Thus, the quantity-based index is a ratio of actual to expected quantity demanded if the nature of demand were unchanged. The index isolates changes in demand apart from changes in quantity demanded due to changes in supply. If the actual quantity demanded is larger (smaller) than expected quantity demanded, then demand is assumed to have shifted and the index increases (decreases) by the associated horizontal percentage point shift in consumer demand.

For the U.S. retail beef demand index, \( P_t \) is the Choice retail beef price in $/lb, deflated by the consumer price index (2016 quarter 1=100). \( Q_t \) is the retail per capita disappearance (assumed consumption) in pounds. The demand elasticity is assumed to be -0.54 (Tonsor 2010). The quarterly U.S. retail beef demand index for 1996 QT1 to 2016 QT3 is shown in figure 1 (1996 QT1=100). From 1996 to 2004, U.S. retail beef demand generally strengthened, reaching the highest value, 113.76, in 2004 QT3. Some of this increased beef demand was potentially due to popularity of the Atkins diet (Tonsor, Mintert, and Schroeder 2010). However, beginning around 2006 and continuing through the 2008 recession, retail beef demand declined through 2010. The lowest retail beef demand index value occurred in 2010 QT1 with an index value of 90.81. Retail beef demand gradually improved through 2013 as the U.S. economy recovered.
from the recession. In early 2014, a dramatic increase in retail beef demand is notable, and
remained strong through 2016 QT3.

We also calculate an index for U.S. beef export demand by the rest of the world. \( Q_t \) is the
rest of world per capita consumption of U.S. total beef and veal, and variety meat (beef) exports,
in lbs. \( P_t \) is the real beef export price in $/lb, deflated by the Export Price Index (End Use):
Agricultural commodities (IQAG; where 2016 QT1=100) from the U.S. Bureau of Labor
Statistics (2018). The assumed elasticity of export demand is -0.42 (Zhao, Wahl, and Marsh
2006). The quarterly U.S. export beef demand index for 1996 QT1 to 2016 QT3 is shown in
figure 2 (1996 QT1=100). From 1996 to mid-2003, export demand for U.S. beef increased,
reaching 130.46 in 2003 QT3 before the extreme crash following the BSE discovery in late 2003.
Export beef demand has steadily increased since 2004, but had still not reached pre-BSE levels
by QT3 2016.

The retail and export demand indices are central to answering how changes in U.S. retail
and export beef demand have impacted farm level cattle prices and quantities in the last 20 years.
The retail and export beef demand indices assume elasticities — however, these elasticities are
not known with certainty. Therefore, both the retail and export beef demand indices are treated
as endogenous variables.

**Conceptual model**

The U.S. beef industry is comprised of multiple segments (see figure 1 pp 6 of U.S. Government
Accountability Office 2018; see figure on pp 7 of USDA Economic Research Service [ERS]
2018). An animal is raised for the first 12 to 18 months by operations called cow-calf, stocker,
and backgrounder operations. At this age the animals are referred to as a feeder cattle and we
refer to these operations as feeder cattle suppliers. The feeder calf is then sold to a feedlot (i.e., a
confined feeding operation) and fed a diet primarily of corn for four to six months until they reach harvest weight. At harvest weight the animals are referred to as fed cattle and are then sold to the packer for harvesting and processing the meat. The packer distributes wholesale beef through multiple outlets including traditional domestic retail outlets and exports.

Given the vertical nature of the beef supply chain, derived supply and demand theory can be applied to the U.S. beef industry. Whenever exogenous factors increase (decrease) primary demand, derived demands are also expected to increase (decrease) (Tomek and Robinson 2003). Figure 3 illustrates the derived demand and supply curves following an increase in primary demand, reflecting a shift in retail and/or export beef demand. An increase in primary beef demand induces retailers to increase demand for wholesale beef from packers, resulting in an upward shift from $D_{Fed}$ to $D'_{Fed}$. This increased demand for beef at the fed cattle level, causes feedlot operators to demand more feeder cattle from suppliers (shifting $D_{Feeder}$ upward to $D'_{Feeder}$). Upward shifts in demand result in higher prices and quantities at the fed and feeder cattle levels. The magnitude of the shifts in derived demand curves and changes in prices and quantities following a shock are of central interest in this study.

We model the U.S. beef industry using a simultaneous equations system of inverse demand and supply equations for the U.S. fed and feeder cattle sectors. The system of equations that define the conceptual model of quarterly fed and feeder cattle demand and supply are:

**Fed cattle inverse demand:**

(2) \[ p_t^{LD} = \Psi_1(Q_t^{LD}, RDI_t, EI_t, t, QT2, QT3, QT4) \]

**Fed cattle supply:**

(3) \[ Q_t^{LS} = \Psi_2(E_{t-2}[p_t^{LS}], p_{t-2}^F, p_{t-2}^C, Q_{t-1}^L, t, QT2, QT3, QT4) \]

**Fed cattle market clearing:**

7
(4) \[ p_t^{LD} = p_t^{LS} = p_t^L; \quad Q_t^{LD} = Q_t^{LS} = Q_t^L \]

**Feeder cattle inverse demand:**

(5) \[ p_t^{FD} = \psi_3(Q_t^{FD}, E_t[p_t^{LD}], p_t^C, t, QT2, QT3, QT4) \]

**Feeder cattle supply:**

(6) \[ Q_t^{FS} = \psi_4\left(p_t^{FS}, E_{t-8}[p_t^{FS}], p_t^W, Drought_t, Drought_{t-8}, Q_t^{FS}, t, QT2, QT3, QT4\right) \]

**Feeder cattle market clearing:**

(7) \[ p_t^{FD} = p_t^{FS} = p_t^F; \quad Q_t^{FD} = Q_t^{FS} = Q_t^F \]

**Retail demand index:**

(8) \[ RDI_t = \psi_5(CSS_t, QT2, QT3, QT4) \]

**Export demand index:**

(9) \[ EI_t = \psi_6(AustCube_t, QT2, QT3, QT4) \]

A variable list with descriptions and data sources can be found in table 1. The quarterly lag structure is based on biological considerations of the time required for animal steer to be born, fed, and harvested.

Equation (2) is the derived inverse fed cattle demand where fed cattle price at time \( t \) \((p_t^{LD})\) is a function of fed cattle quantity \((Q_t^{LD})\), retail beef demand quantified by the retail beef demand index \((RDI_t)\), export beef demand quantified by the export beef demand index \((EI_t)\), technological changes, and seasonality \((QT2, QT3, QT4)\). Note, \( QT2, QT3, QT4 \) are quarterly dummy variables. Including the beef retail and export demand indices enable shifts in primary demand to impact beef packer derived demand. A quarterly linear time trend \((t; 1998\ QT1=1, 1998\ QT2=2, \ldots, 2016\ QT3=75)\) is included to account for technological changes.
Fed cattle supply, equation (3), is a function of the expected output price \( (E_{t-2}[P_{t}^{L,S}]) \) at time of placement (time when feeder calf is moved into the feedlot), assuming a two-quarter feeding period. The input prices are feeder cattle \( (P_{t-2}^{F}) \) and corn \( (P_{t-2}^{C}) \) price at placement. All corn is assumed to be purchased at placement. A lagged dependent variable \( (Q_{t-1}^{L}) \) is included to account for asset fixity. As previously defined, quarterly dummy variables and a time trend are included. Equation (4) is the fed cattle market clearing condition.

Equations (5) through (7) are feeder cattle inverse demand, supply, and market clearing equations. In equation (5), feeder cattle price \( (P_{t}^{F,D}) \) is a function of feeder cattle quantity demanded by feedlots \( (Q_{t}^{F,D}) \), expected fed cattle price \( (E_{t}[P_{t+2}^{L,D}]) \) at time \( t \) (expected selling price at the end of the two-quarter feeding period), and corn price at time \( t \) \( (P_{t}^{C}) \). Controls for technological change and seasonality are also included. Retail and export demand implicitly enter this equation through \( E_{t}[P_{t+2}^{L,D}] \).

Equation (6) is feeder cattle supply. The contemporaneous feeder cattle price at time \( t \) \( (P_{t}^{F,S}) \) represents the decision to sell the animal now or to retain the calf for backgrounding. \( E_{t-8}[P_{t}^{F,S}], P_{t-4}^{W}, Drought_{t} \), and \( Drought_{t-8} \) are included to account for the impacts of cow herd expansion and contraction on feeder calf supply. \( E_{t-8}[P_{t}^{F,S}] \), the expected feeder cattle price at time \( t - 8 \), is the opportunity cost of retaining a heifer (i.e., female calf) as a breeding animal rather than selling the heifer as a feeder animal. \( P_{t-4}^{W} \) the cull cow price, represents the opportunity cost of retaining a cow as a breeding animal versus culling (i.e., harvesting). If the cull cow price was relatively higher in period \( t - 4 \), then we would expect more cows to be culled, resulting in fewer breeding animals in period \( t - 4 \) and thus, fewer feeder calves in period \( t \). \( Drought_{t} \) is used to proxy pasture conditions and the decision to sell the feeder calf now or wait and sell next period. \( Drought_{t-8} \) can be used to judge pasture conditions and a
potential indication of herd size (poor pasture conditions generally decrease the herd size). Both $E_{t-8}\left[P^{F,S}_t\right]$ and $Drought_{t-8}$ are included to account for the longer run implications of retaining breeding animals on feeder calf supply. It takes roughly two years from the time a heifer retention decision is made to the sale of the heifer’s first feeder calf. Asset fixity ($Q_{t-4}^{F,S}$), technological change, and seasonality are also important determinants of feeder cattle supply.

Equations (8) and (9) are used to account for the endogeneity of retail and export beef demand. The U.S. consumer sentiment index ($CSS_t$) is used to instrument retail beef demand. The consumer sentiment index measures consumer confidence in the U.S. economy (University of Michigan 2017). Generally, when consumers feel the U.S. economy is doing well, beef demand is stronger (Tonsor, Mintert, and Schroeder 2010). The export competitor beef price ($AustCube_t$) is the instrument for the export beef demand index. The price of Australian beef to Japan, specifically the cube roll price, is used to gauge competition from other beef exporters (Meat and Livestock Australia 2017). This price reflects both the demand situation in Japan, but more importantly the supply factors impacting Australian beef.

Data

Quarterly data for 1996 QT1 to 2016 QT3 was collected from multiple sources. Descriptive statistics of variables for this analysis can be found in table 2. All prices, except $AustCube_t$ and the prices used to create the retail and export demand indices, were deflated by the Prices Paid Index for Commodities and Services, Interest, Taxes, and Farm Wage Rates (PPITW where 2016 QT1=100) (USDA National Agricultural Statistics Service, 2018). $AustCube_t$ was deflated by Australian Export Index: for meat and edible meat offal (where 2016 QT1=100) from the Australian Bureau of Statistics (2018). Specific details regarding data sources and data manipulations are provided in a supplementary appendix online.
Econometric model

The literature is mixed regarding whether naïve or forward-looking expectations most closely mimic producer behavior (Antonovitz and Green 1990). For example, Kastens and Schroeder (1994) found that cattle feeders view past profit as more important in placement decisions than fed cattle futures — supporting naïve expectations. Conversely, Kastens, Jones and Schroeder (1998) found using deferred futures plus historical basis yields the greatest forecast accuracy for major grains, slaughter steers, slaughter hogs, feeder cattle, cull cows, and sows. Furthermore, Antonovitz and Green (1990) found that no one price expectation model outperforms other specifications and found evidence of heterogeneous price expectations in fed cattle supply. Therefore, we tested models with naïve and forward-looking price expectations. The naïve model outperformed the forward-looking model.5

Assuming naïve expectations, the four-equation model (Equations (10) through (13)) below was estimated in SAS 9.4 software (SAS software, 2012) using three-stage least squares in log-log form:

Fed cattle inverse demand:

\[
\ln P^F_t = \alpha_1 + \alpha_2 \ln Q^L_t + \alpha_3 \ln RDI_t + \alpha_4 \ln EI_t + \alpha_5 t + \alpha_6 QT2 + \alpha_7 QT3
\]

\[ + \alpha_8 QT4 + \alpha_9 \text{Recession}_t + \mu^1_t \]

Fed cattle supply:

\[
\ln Q^L_t = \beta_1 + \beta_2 \ln P^F_{t-2} + \beta_3 \ln P^L_{t-2} + \beta_4 \ln P^C_{t-2} + \beta_5 \ln Q^L_{t-1} + \beta_6 t + \beta_7 QT2
\]

\[ + \beta_8 QT3 + \beta_9 QT4 + \beta_{10} \text{dum03Q4}_t + \mu^2_t \]

Feeder cattle inverse demand:

\[
\ln P^F_t = \gamma_1 + \gamma_2 \ln Q^F_t + \gamma_3 \ln P^F_t + \gamma_4 \ln P^C_t + \gamma_5 QT2 + \gamma_6 QT3
\]

\[ + \gamma_7 QT4 + \gamma_8 \text{dum03Q4}_t + \mu^3_t \]
Feeder cattle supply:

\[
\text{(13)} \quad \ln Q_t^F = \delta_1 + \delta_2 \ln P_t^F + \delta_3 \ln P_{t-8}^F + \delta_4 \ln P_{t-4}^W + \delta_5 \text{Drought}_t \\
+ \delta_6 \text{Drought}_{t-8} + \delta_7 \ln Q_{t-4}^F + \delta_8 t + \delta_9 QT2 + \delta_{10} QT3 \\
+ \delta_{11} QT4 + \delta_{12} \text{dum98Q1}_t + \mu_t
\]

The * superscript indicates an endogenous variable. Most variable descriptions are as before. 

\[P_{t-2}^L\], the fed cattle price lagged two quarters, in equation (11), \(P_t^L\), the current fed cattle price in equation (12), and \(P_{t-8}^F\), the feeder cattle price lagged eight quarters, in equation (13) are specific to naïve expectations. Given the lag structure (up to \(t - 8\)) the first observation in the model is 1998 QT1. Furthermore, \(\text{recession}_t\), \(\text{dum03Q4}_t\), and \(\text{dum98Q1}_t\) are included to correct misspecification issues that are detailed below.

Due to the large number of variables and potential degrees of freedom concerns, the instrumentation strategy varies by equation for the three-stage least squares model. The excluded instruments for inverse fed cattle demand (equation (10)) are

\[\ln P_{t-2}^L, \ln P_{t-2}^F, \ln P_{t-2}^C, \ln Q_{t-1}^L, \text{dum03Q4}_t, \text{CSS}_t, \text{ and AustCube}_t.\] There are no endogenous variables in fed cattle supply (equation (11)). The excluded instruments for inverse feeder demand (equation (12)) are \(\ln P_{t-8}^F, \ln P_{t-4}^W, \text{Drought}_t, \text{Drought}_{t-8}, \ln Q_{t-4}^F, \text{ and dum98Q1}_t.\) The excluded instruments for feeder supply (equation (13)) are \(\ln P_t^C\), and \(\text{dum03Q4}_t.\)

The natural log transformation of all variables were checked for stationarity using the Augmented Dickey Fuller (ADF) tests (Dickey and Fuller 1979) and ADF tests accounting for seasonality. For some variables, unit root cannot be rejected. This is consistent with past studies regarding unit root testing in commodity prices (Wang and Tomek 2007). Wang and Tomek (2007) conclude that most agricultural commodity prices are stationary even though unit root is not rejected in the ADF tests. Thus, all models are implemented with level variables. Model
residuals are also checked for stationarity using ADF tests. Residuals for all models are stationary, confirming the decision to proceed without differencing.

Misspecification testing

Following McGuirk, Driscoll, and Alwang (1993) and McGuirk et al. (1995), equation-by-equation individual and joint misspecifications tests are conducted using the reduced form equations. However, due to limited degrees of freedom, system wide misspecification tests cannot be conducted. The D’Agostino third sample moment tests, the Anscombe and Glynn fourth sample moment test, and D’Agostino-Pearson $K^2$ omnibus tests are used to test for normality (Anscombe and Glynn 1983; D’Agostino, Belanger, and D’Agostino 1990).

Functional form is tested using the Ramsey RESET 2, 3, and 4 tests. Static and dynamic homoscedasticity are examined using a RESET2 test and autoregressive conditional heteroscedasticity (ARCH) test, respectively. Independence is checked using the auxiliary regression $\hat{\epsilon}_t = \beta_0'X_t + \Lambda'\hat{\epsilon}_{t-1} + \nu_t$, where $\epsilon_t$ is the residual from the original model, $X_t$ is a $k \times 1$ vector of independent variables, and $\nu_t$ is the estimated residuals from the auxiliary regression (McGuirk, Driscoll, and Alwang 1993). If $\Lambda$ is significant then independence is rejected.

Structural change is tested using the Chow test (Chow 1960).

The model results represent the final specification which best aligned with economic theory and the fewest misspecification issues. $dum03Q4_t$ was added to the fed cattle supply and feeder cattle demand equations, and $dum98Q1_t$ to the feeder cattle supply equations to correct for normality concerns. Furthermore, $Recession_t$ was added to the inverse fed cattle demand equation to account for U.S. recessions. P-values for the misspecification tests in the final model are shown in table 3. Homoscedasticity and autocorrelation were a concern in the two demand equations. Therefore, a heteroscedasticity-consistent covariance matrix estimator (HCCME) was
used to calculate the standard errors. Specifically, the second modification of the HCCME,
\[ \frac{\hat{\varepsilon}_t^2}{1 - \hat{h}_t}, \]
from Davidson and MacKinnon (1993) is used (SAS 2018).

**Simulation**

We use our model results to investigate the impacts of exogenous changes in retail and
export demand on producer welfare. Due to the lag structure in our model, a shock’s impact will
not be immediately realized (the longest lag in our model is \( \ln P_{t-8}^f \)) — thus, it is necessary to
trace the shock for at least nine quarters. Accordingly the time period of the simulation will be
QT3 2014 to QT3 2016, and due to the endogeneity within our system, we need to solve the
equations simultaneously.

The steps followed in the simulation are (further detail is provided in the supplementary
online appendix):

1. Derive predicted values for the base case of no demand shocks for QT3 2014 to QT3
   2016. Actual data values for all the variables except fed and feeder cattle prices and
   quantities will be used. The feeder and fed cattle prices and quantities will be determined
   from within the model one quarter at a time, with lagged values coming from the
   predicted values (calculated the usual way) and simulation results.
2. Repeat the technique in step 1 while shocking the model with retail or export demand
   changes from QT3 2014 to QT3 2016.
3. Calculate the fed cattle and feeder cattle producer surplus in each quarter of the
   simulation period and then sum these values to estimate the changes in producer surplus
   from retail or export demand shocks.

The change in producer surplus formula is:
\[
\Delta PS = \frac{P_1}{P_0} \left( \frac{P_1}{P_0} - 1 \right) -\frac{1}{\varepsilon + 1},
\]

where \( PS \) is producer surplus, \( P_0 \) is the price simulated with no demand shift, \( P_1 \) is the price after the demand shift, \( \varepsilon \) is the long run supply elasticity, and \( Q_0 \) is the quantity simulated with no shift. Because fed and feeder cattle markets are vertically linked, fed cattle producer surplus represents quasi-rents for both the fed cattle and feeder cattle sectors (Alston and James 2002; Just and Hueth 1979). Therefore, the true change in fed cattle producer surplus for the fed cattle market is \( \Delta PS^{Fed} = \Delta PS^{Fed,*} - \Delta PS^{Feeder} \), where \( PS^{Fed} \) and \( PS^{Feeder} \) represent the true fed and feeder cattle producer surplus values and \( PS^{Fed,*} \) is the fed cattle producer surplus calculated using equation (14).

**Results and discussion**

Coefficient estimates from the preferred model are in table 4. Signs are consistent with economic theory and the cattle market structure. In the inverse fed cattle demand equation, table 4 column A, the quantity of fed cattle has a negative and statistically significant impact. Due to the log-log specification, -0.60 is the own-quantity flexibility (or a -1.67, \([1/(-0.60)]\), demand elasticity). This is similar to the own-quantity flexibility estimates of Marsh (2003), -0.69, and Buhr and Kim (1997), -0.61. The retail demand coefficient is 1.52, indicating a 1% increase in retail demand increases fed cattle price by 1.52%. In Marsh (2003), the retail demand index coefficient was 0.60, suggesting the impact of retail demand changes on cattle prices are larger now than during Marsh’s study period (1970-1999). The retail demand coefficient is larger than the export demand index coefficient, 0.05. However, given that the U.S. currently exports approximately 10% of its beef production (and even less earlier in the period examined), and the U.S. exports different lower-value cuts of meat than American’s traditionally eat, the relative impact of
domestic versus export demand is expected (USDA 2017). Therefore, the 0.05% increase in fed
cattle price from a 1% increase in export demand reflects that only a minority of total production
is exported and only a minority of products from a given animal are destined for exports. For
example, expansion of exports to Asia would likely increase wholesale prices of tongue, liver,
and short ribs much more than ground and loin products (which more often are consumed
domestically) – the blend of these effects is reflected in whole animal price impacts. The
recession dummy variable is statistically significant and negative as expected.

The results in column B of table 4 show coefficient estimates for the fed cattle supply
equation. The fed cattle price coefficient, 0.10, indicates if the fed cattle price increased two
quarters ago by 1%, we expect a 0.10% increase in fed cattle quantity supplied this quarter. Both
input prices, feeder cattle and corn, have statistically significant and negative impacts on fed
cattle supply. Given the feeder cattle price coefficient is over four times as large as the corn
coefficient, feedlot operators are more sensitive to a 1% change in feeder cattle price than corn
price. This is expected due to the relative costs of these two main inputs in fed cattle production
and associated impacts on profitability. The lagged-dependent variable coefficient of 0.58
indicates some rigidity in fed cattle supply. This is similar to Marsh’s (2003) estimate of 0.56.
Using the fed cattle price coefficient and the lagged dependent variable, the long-run fed cattle
supply elasticity is inelastic with a value of 0.24 \[0.10/(1-0.58)\].

The coefficient estimates in the feeder cattle demand equation, table 4 column C, are
consistent with expectations. As the feeder cattle quantity increases by 1%, feeder cattle
demanded (price) decreases by 0.66%. This is smaller than the annual feeder flexibilities of
Marsh (2003), Brester and Marsh (1983), and Shonkwiler and Hinckley (1985) of -1.35, -1.61,
and -1.10. Feeder cattle demand is more responsive to an increase in the fed cattle price—the
coefficient estimate of 1.63 is slightly larger than Marsh (2003), 1.20, Shonkwiler and Hinckley (1985), 1.48, and Buccola (1980), 1.36. This may reflect quicker or clearer transmission of price signals consistent with the introduction in 2001 of Mandatory Price Reporting (Parcell, Tonsor, and Schroeder, 2016). The corn price flexibility is also negative and significant.

Treating the fed cattle price coefficient as a transmission flexibility, the impact of autonomous changes in retail and export demand on feeder cattle demand can be calculated. If the retail demand index increases by 1%, the feeder cattle price changes by 2.48% \([1.52 \times 1.63]\). If the export demand index increases by 1%, the feeder cattle price increases by 0.08% \([0.05 \times 1.63]\). These transmissions suggest changes in retail and export demand have a larger impact on feeder cattle price than fed cattle price. The larger transmissions to feeder cattle producers are consistent with Ricardian rent theory (Zhao, Du, and Hennessy 2011; McKendree 2017). Since feeder calves are the scarcest and most widely traded resource in the beef industry, the benefits and losses are largely passed back to the holder of that scarce resource — the feeder cattle producers.

In the feeder cattle supply equation, column D of table 4, the own price supply elasticity is positive, as expected, and statistically significant. This represents the decision to sell the calf this quarter, or wait to sell next quarter. Thus, if the current price increases by 1% then producers increase their calves sold in the current period by 0.17%. The feeder cattle price lagged eight quarters (which represents the naïve price expectation at the time of cow breeding and heifer retention decisions) is significant and positive, as expected (0.09). Thus, a higher price two years prior results in more calves supplied in the current period because more heifers were retained and bred. The negative and significant cull cow price coefficient (-0.16) shows the opportunity cost of culling the cow instead of breeding. If the cull cow price one year prior was higher, then more
cows are culled, resulting in fewer feeder calves in the current period. The two drought variables proxy pasture conditions. The contemporaneous drought variable is insignificant. However, drought conditions two years prior have a negative and significant impact on current feeder calves supplied. Poor pasture conditions cause heifers and cows to be sold instead of retained for breeding in prior periods, resulting in 0.05% less feeder cattle supplied in the current period. The lagged dependent variable coefficient, 0.28, indicates some fixity in feeder supply. The long run feeder cattle supply elasticity is 0.24 \( \frac{0.17}{(1.00-0.28)} \). Buhr and Kim (1997) estimated short and long run feeder cattle supply elasticities of 0.05 and 0.46, respectively. The time trend is statistically significant and negative.

The seasonality coefficients in all equations are consistent with industry operations. The majority of cattle are born in the spring and sold the subsequent fall. This larger number of feeder cattle are then ready for harvest as fed cattle in QT2 and QT3 of the next calendar year.

Sensitivity Analysis

Marsh (2003) assumed the retail demand index was exogenous and did not account for export demand. However, due to uncertainty surrounding the assumed elasticity values used to calculate the demand indices, the retail and export demand indices should be endogenous. Four sensitivity analyses were conducted to consider the robustness of the endogeneity assumptions of the demand indices and the elasticity estimates used in these indices. The retail and export demand coefficients from the sensitivity analyses are found in table 5.

In the first sensitivity model (model A table 5), \( RDI_t \) was replaced with the per capita choice retail beef quantity and \( EI_t \) with the per capita export beef quantity (the quantities used in the respective indices). Both quantities were treated as exogenous. Note that using per capita quantities in our log specification is equivalent to including the log of the demand indices with a
demand elasticity equal to 0. The per capita retail quantity coefficient decreased by 11% to 1.36 and was marginally significant. The export coefficient increased by 95% to 0.10. The second sensitivity treats $RDI_t$ and $EI_t$ as exogenous (model B table 5). The retail demand index coefficient was smaller, 1.37, compared to 1.52 in the preferred specification. The export demand index coefficient was slightly larger, 0.08, compared to 0.05 from the preferred specification. Potentially, the $EI_t$ coefficient is similar to our preferred specification because the BSE event provided more exogenous variation than in the retail demand index. These results show that the demand indices remove much of the endogeneity bias, but should still be treated as endogenous variables in econometric applications. Moreover, the magnitude of sensitivity to estimated retail demand impacts is clear and of central interest in our study.

The next two sensitivity analyses changed the retail and export demand elasticities by ±0.20 keeping the rest of the model specification the same (including endogeneity) to represent the span of estimates available in the literature. Recall the elasticities used in the retail and export demand indices calculations were -0.54 and -0.42. Therefore, the retail and export demand elasticities were -0.34 and -0.22 (adding 0.20, making more inelastic) in model C, and -0.74 and -0.62 (subtracting 0.20, making more elastic) in model D. Note, these are large percent changes in the elasticities (37% change in retail and 48% change in export elasticities) and therefore represent extreme changes in the elasticity estimates. In the more inelastic model (model C) both retail and export demand coefficients increase in magnitude indicating a larger impact on the fed cattle price; the retail demand coefficient increased by over 50% and export demand coefficient by over 90%. In the more elastic model, retail and export demand have a smaller impact on fed cattle price. Furthermore, the export demand coefficient is also no longer statistically significant.
It is encouraging to note that the model coefficients in the other three equations (not shown) were robust to these changes.

**Implications**

Industry wide efforts are made to increase demand for U.S. beef, such as those funded through the beef checkoff program or attempts to implement management practices, like age and source verification, to meet global export market requirements. For instance, recent discussion around possibly increasing the beef checkoff from $1 to $2 could be informed by our analysis. Rather than examine what factors increase retail or export beef demand, our study provides new insights on the implications of shocks to retail or export beef demand on fed and feeder cattle producer surplus.

As discussed previously, debates regarding the need for producer-funded efforts to enhance demand are contentious (Crespi and Marette 2009; Kaiser 2016; Ward 1999). We estimate that the Cattlemen’s Beef Board collected $89.57 million in assessments from producers during QT3 2014 to QT3 2016 (Cattlemen’s Beef Board 2015, 2016). Using the approximate rule that the feeder cattle sector pays an assessment of $1.70/head (average of 1.7 transactions) and the feedlot sector pays $1.00/head (just one transaction), then feeder cattle producers paid $56.40 million of these assessments and feedlot producers paid $33.17 million. Kaiser (2016) estimated that a 10% increase in generic beef promotion expenditures from the beef checkoff program increases per capita beef demand by 0.18%. Therefore, to find the producer surplus changes from increasing the beef checkoff from $1 to $2, resulting in an assumed 100% increase in generic beef promotions, we increase the retail beef demand index observed values by 1.8% from QT3 2014 to QT3 2016. Similarly, to find the impact of...
removing the beef checkoff, a 100% decrease in generic beef promotions, we decrease retail beef demand index observed values by 1.8%.

If the beef checkoff program was cancelled, resulting in a 1.8% decrease in retail beef demand, total producer surplus would decrease by $3.01 billion from QT3 2014 to QT3 2016. Further decomposing this producer surplus change, the feeder and fed cattle producer surplus over this period would decrease by $2.90 billion and $112.71 million, respectively. These producer surplus losses are much larger than the beef checkoff payments of $56.40 million and $33.17 million made by feeder and fed cattle producers, respectively. Although these may seem like large numbers, total estimated revenue during this period was approximately $66 billion and $99 billion for feeder and fed cattle sectors, respectively. Therefore, these producer surplus changes are 4.42% and 0.11% of total revenue for the feeder and fed cattle sectors.

Conversely, suppose the beef checkoff program spending on generic advertising doubled, as proposed in 2014, resulting in a 1.8% increase in retail demand from observed values. Consequently, total producer surplus would increase by $3.07 billion from QT3 2014 to QT3 2016. Of this $3.07 billion, feeder cattle producer surplus would increase by $3.00 billion and fed cattle producer surplus by $69.09 million. Furthermore, to offset the costs of doubling the checkoff from $1 to $2/head ($89.57 million), a 0.05% increase in domestic demand is needed. Looking at checkoff assessments across the feeder cattle and feedlot sectors, a 0.03% and 0.73% increase in domestic demand are needed to offset proposed checkoff costs for feeder cattle and feedlot sectors, respectively.

Consistent with growing interest in food production practices, various traceability systems exist to document processes involved in cattle rearing and beef production. One specific program is source and age verification (SAV) which has a history of being involved in
international trade discussions and at times is required for a country to obtain market access.

Here we use SAV as an example technology, and perhaps part of a related policy, that the industry may consider when seeking to increase export beef demand (Pendell et al., 2010).

Using estimates from Brester et al. (2011), World Perspectives, Inc. (WPI; 2018) concluded that source and age verification (SAV) costs (in 2017 dollars) per head ranged from $2.65 to $4.65 for cow-calf operations currently identifying their animals (visual tagging) and $0.13 to $0.55 for feedlot operations. Using the midpoint of these ranges and the head of cattle sold over our simulation period, we estimated it would cost the feeder cattle sector $172.40 million and the fed cattle sector $17.83 million ($190.24 million total) to implement SAV over the simulation period. Not considering the distributional impacts, a 3.5% increase over observed values to export demand during the simulation would cover the estimated costs of adopting SAV. Considering distributional producer welfare effects, a 3.25% increase over observed values in export demand would be needed to increase feeder cattle producer surplus by the costs of implementation, while an 11.9% increase over observed values in export demand would be needed for feedlot producers to cover their increased costs.

Producer surplus changes are also provided for autonomous ±1% and ±5% shocks to retail demand and ±1% and ±10% shocks to export demand. These estimates could be useful for future policy analyses and industry discussions surrounding demand increasing investments.

As expected, due to the transmission elasticity being greater than one, most of the producer surplus changes, whether positive or negative, accrues to the feeder cattle producers.

Studies surrounding investment costs for traceability, such as Brester et al. (2011), Pendell et al. (2007), USDA Animal and Plant Health Inspection Service (APHIS;2009) and WPI (2018), conclude that cow-calf producers bear higher costs than other members of the marketing chain.
However, our results building from existing cost estimates suggest that cow-calf producers would also accrue the majority of producer surplus gains for increases in export or retail demand (around 97%).

**Conclusion**

Limited empirical work has quantified how changes in primary (retail and export) beef demand impact farm-level demands. The goal of this study was to provide current estimates of these price transmissions. A structural system of equations was estimated to quantify the impacts of U.S. retail and export beef demand on fed and feeder cattle demand and supply.

When retail level beef demand increases by 1%, fed cattle price increases by 1.52% and feeder cattle price increases by 2.48%. Additionally, when export demand increases by 1%, fed cattle price increases by 0.05% and feeder cattle price increases by 0.08%. The larger price transmission at the feeder cattle level is consistent with Ricardian rent theory and rents in the beef system being passed to cow-calf producers, the holder of the scarce resource (Zhao, Du, and Hennessy 2011; McKendree 2017). Therefore, even though cow-calf and stocker/backgrounder producers (primary suppliers) are not directly involved in primary domestic and export demand, it is important to understand how primary demand changes are transmitted through the supply chain and impact demand for their farm level products.

Promotional efforts like the beef checkoff program aim to increase primary retail demand for beef. Simulation results confirmed that both feedlot operations and feeder cattle producers (cow-calf, stocker, and backgrounder) benefit from programs that increase domestic and export demand, but unequally. Given the transmission elasticity is greater than one, feeder cattle producers accrue more of the changes in producer surplus. Both fed and feeder cattle producers should support increases in beef checkoff assessments, as the benefits (gains in producer surplus)
outweigh the additional assessment costs using the estimates of demand response to generic advertising from Kaiser (2016). Furthermore, those in the feeder cattle sector benefit proportionally more from efforts to increase demand. These implications are timely to ongoing discussions around beef checkoff programs (USDA 2014).

Model results were also used in a simulation to determine the increase in export beef demand needed to cover costs of source and age verification, a requirement in many global markets. A 3.5% increase in export demand from observed values is needed to cover aggregate source and age verification costs. However, to cover the feedlot sectors costs fully, an 11.9% increase in export demand from observed values is needed, while a 3.25% increase is needed for feeder cattle sector costs. Although, Brester et al. (2011), Pendell et al. (2007), USDA APHIS (2009) and WPI (2018), conclude that cow-calf producers bear higher costs than other member of the marketing chain for source and age verification, our results indicate they also accrue larger producer surplus benefits. On the other hand, negative shifts at the retail level or in export demand also impact farm level demand. For example, a food safety or alternative adverse event, such as BSE, that decreases beef demand will negatively impact feeder cattle producers and farm level revenues more than the feedlot sector.

Our results are useful in evaluating investment opportunities and impacts of new technologies or policies and the distribution of producer surplus changes between fed and feeder cattle producers. If investment, such as a new technology, is anticipated to increase retail beef demand, an analysis can be conducted using our results to determine whether the increase in demand will offset the costs of implementing the proposed investment. Similarly, when new policies are evaluated that impact domestic or export demand for U.S. beef, our results can be used to assess distributional impacts on fed and feeder cattle producers.
Footnotes

1 Recent examples include efforts to initiate a national second checkoff program in the U.S. beef-cattle industry (voted down, U.S. Department of Agriculture [USDA] 2014); increases in individual state checkoff programs in Minnesota (voted down; Agweek 2014), Ohio (approved; Ohio Beef Council 2014), Oklahoma (voted down; Feedstuffs 2017) and Texas (approved; Texas Beef Council 2016); and ongoing efforts to cease the checkoff program (Ranchers-Cattlemen Action Legal Fund United Stockgrowers of America [R-CALF] 2018).

2 Both price- and quantity-based indices were calculated and used in our modeling. Since quantity-based indices were better behaved, and are theoretically more consistent, they are used.

3 While breeding and retention decisions are more complex, this approach reflects the core roles of in-hand feedstuffs and feeder cattle prices as major input and output price signals.

4 All base periods for the indices were changed to 2016 QT1=100 for consistency and help in interpretation of subsequent simulation results.

5 The naïve model had lower Schwarz Bayesian Criteria (SBC) values and the signs of some coefficients in the forward looking model did not align with theoretical expectations.

6 Tables for unit root test results are not included for space limitations. SAS code for unit root tests is available in supplementary online appendix.

7 dum03Q4_t is not related to the BSE event. Instead, this observation was an outlier because of the lower number of animals slaughtered in November 2003.

8 Derivation of the producer surplus formula is in the supplementary online appendix.

9 Note, the KS feeder cattle price is used. Thus, the drought conditions in KS are also used.

10 Therefore, the specification is the same as our preferred specification except that $CSS_t$ (consumer sentiment index), and $AustCube_t$ (cube roll price) are not used as instruments.
Beef checkoff dollars are allocated over different items, including promotional activities, foreign marketing, consumer information, research, producer communication and other overhead. The elasticity used from Kaiser (2016) is for generic beef advertising. Therefore we are assuming that if checkoff assessments are doubled, spending will be allocated the same across all items (all will double), including promotional activities.
References


SAS. 2018. “PROC MODEL: Heteroscedasticity - 9.3.” *SAS*. Available at: 


Texas Beef Council. 2016. “What is the Texas Beef Checkoff.” *Texas Beef Council*. Available at: 


Figure 1 Quarterly retail beef demand index (QT1 1996=100)
Figure 2 Quarterly export beef demand index (QT1 1996=100)
Figure 3 Effects of increased primary beef demand on fed and feeder cattle prices and quantities
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<tr>
<th>Variable</th>
<th>Description</th>
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<td>$P_t^L$</td>
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<tr>
<td>$P_t^F$</td>
<td>Feeder steer price, weighted average price (500-600, 600-700, 700-800, 800-900 lb), Kansas, $/cwt</td>
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</tr>
<tr>
<td>$Q_t^L$</td>
<td>Fed cattle quantity, federally inspected steers and heifer harvested, thousands of lbs</td>
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<tr>
<td>$Q_t^F$</td>
<td>Feeder cattle quantity (feeder cattle placements), thousands of lbs</td>
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<td>$RD_{1t}$</td>
<td>Quantity-based retail demand index (QT1 1996=100)</td>
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<td>$EI_{1t}$</td>
<td>Quantity-based export demand index (QT 1 1996=100)</td>
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<td>Feed corn price, U.S. average, $/bu</td>
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<td>$P_t^W$</td>
<td>Cull cow price, boning utility, Sioux Falls, $/cwt</td>
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<td>$CSS_t$</td>
<td>Index of consumer sentiment (QT1 1960=100)</td>
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<td>AustCube$_t$</td>
<td>Australian cube roll price from Australia to Japan, cents/lb</td>
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<tr>
<td>Drought$_t$</td>
<td>Dummy variable to indicate severe drought in KS, =1 if Modified Palmer Drought Index $\leq -2$</td>
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<td>$t$</td>
<td>Linear time trend (QT1 1998=1, QT2 1998 =2, ..., QT3 2016 = 75)</td>
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<td>QT1 1998 dummy variable =1 in QT1 1998 and =0 otherwise</td>
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Table notes: a A=Livestock Marketing Information Center (LMIC); B=Author calculated using data from LMIC; C=University of Michigan; D=Meat and Livestock Australia; E=National Oceanic and Atmospheric Administration; F=Author created; G=Author created using data from U.S. Bureau of Labor Statistics. See more details in Appendix A; b The KS feeder cattle price is used. Thus, the drought conditions in KS are also used; # variables were added because of misspecification concerns;
Table 2 Descriptive Statistics for QT1 1996 to QT3 2016 (n=83)

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Table 3 Reduced Form Misspecification Tests P-Values

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<th>Feeder Demand</th>
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**Conditional Variance**

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<td>0.24</td>
<td>&lt;0.01</td>
<td>0.20</td>
</tr>
</tbody>
</table>
Table 4: Three-Stage Least Squares Naive Coefficient Estimates (n=75)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient estimate (A)</th>
<th>Coefficient estimate (B)</th>
<th>Coefficient estimate (C)</th>
<th>Coefficient estimate (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverse Fed Cattle Demand</td>
<td>-0.60*</td>
<td>0.10**</td>
<td>-0.66**</td>
<td>0.17**</td>
</tr>
<tr>
<td>Fed Cattle Supply</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$lnQ^L_t$</td>
<td>(0.42)</td>
<td>(0.06)</td>
<td>(0.24)</td>
<td>(0.10)</td>
</tr>
<tr>
<td>$lnP^L_{t-2}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$lnRDI_t$</td>
<td>1.52***</td>
<td>-0.13***</td>
<td>1.63***</td>
<td>0.09**</td>
</tr>
<tr>
<td>$lnE^L_t$</td>
<td>(0.25)</td>
<td>(0.05)</td>
<td>(0.14)</td>
<td>(0.05)</td>
</tr>
<tr>
<td>$lnP^C_{t-2}$</td>
<td>0.05***</td>
<td>-0.03***</td>
<td>-0.06**</td>
<td>-0.16***</td>
</tr>
<tr>
<td>$lnP^L_t$</td>
<td>(0.03)</td>
<td>(0.01)</td>
<td>(0.04)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>$t$</td>
<td>-0.0004</td>
<td>0.58***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$lnQ^L_{t-1}$</td>
<td>(0.0007)</td>
<td>(0.08)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$recession_t$</td>
<td>-0.08***</td>
<td>-0.0004***</td>
<td>-0.0005</td>
<td>-0.05**</td>
</tr>
<tr>
<td>$t$</td>
<td>(0.03)</td>
<td>(0.0002)</td>
<td>(0.0005)</td>
<td>(0.03)</td>
</tr>
<tr>
<td>$dum03Q4$</td>
<td>-0.14</td>
<td>$dum03Q4$</td>
<td>-0.28*</td>
<td>$lnQ^F_{t-4}$</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th></th>
<th>QT2</th>
<th>QT2</th>
<th>QT2</th>
<th>QT2</th>
<th>QT2</th>
<th>QT2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.06</td>
<td>0.08***</td>
<td>0.02</td>
<td>-0.18***</td>
<td>-0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.04)</td>
<td>(0.01)</td>
<td>(0.02)</td>
<td>(0.05)</td>
<td>(0.02)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.07*</td>
<td>0.06***</td>
<td>0.19***</td>
<td>0.08***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.05)</td>
<td>(0.01)</td>
<td>(0.04)</td>
<td>(0.02)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.02</td>
<td>-0.003</td>
<td>0.11***</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td>(0.01)</td>
<td>(0.03)</td>
<td>(0.02)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>7.27</td>
<td>6.84***</td>
<td>7.21**</td>
<td>10.36***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(7.24)</td>
<td>(1.42)</td>
<td>(3.87)</td>
<td>(1.69)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBC</td>
<td>-385.67</td>
<td>-528.51</td>
<td>-387.12</td>
<td>-410.67</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table note: Standard errors in (). * p<0.15, ** p<0.10, *** p<0.05
**Table 5** Sensitivity Analysis Coefficient Estimates and Percent Changes

<table>
<thead>
<tr>
<th></th>
<th>Indices replaced with quantities;</th>
<th>Indices treated as exogenous (B)</th>
<th>+0.2 (more inelastic);</th>
<th>-0.20 (more elastic)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>exogenous (A)</td>
<td>exogenous</td>
<td>endogenous</td>
<td>endogenous</td>
</tr>
<tr>
<td></td>
<td>Coefficient</td>
<td>Percent change</td>
<td>Coefficient</td>
<td>Percent change</td>
</tr>
<tr>
<td>$lnRD_t$</td>
<td>1.36*</td>
<td>-11%</td>
<td>1.37***</td>
<td>-10%</td>
</tr>
<tr>
<td></td>
<td>(0.89)</td>
<td></td>
<td>(0.18)</td>
<td></td>
</tr>
<tr>
<td>$lnEI_t$</td>
<td>0.10*</td>
<td>95%</td>
<td>0.08***</td>
<td>55%</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td></td>
<td>(0.02)</td>
<td></td>
</tr>
</tbody>
</table>

Table note: Standard errors in (). * p<0.15, ** p<0.10, *** p<0.05
**Table 6** Changes in Fed and Feeder Cattle Producer Surplus from Shocks to Retail and Export Demand

<table>
<thead>
<tr>
<th>Retail Demand</th>
<th>No Beef</th>
<th>Increase Beef</th>
</tr>
</thead>
<tbody>
<tr>
<td>Checkoff</td>
<td>-1.80%</td>
<td>1.80%</td>
</tr>
<tr>
<td>Checkoff to $2</td>
<td>-1%</td>
<td>1%</td>
</tr>
<tr>
<td>$ΔP_{Feeder}$</td>
<td>$-2,901,839,183$</td>
<td>$3,003,161,186$</td>
</tr>
<tr>
<td>$ΔP_{Fed}$</td>
<td>$-112,709,460$</td>
<td>$69,088,528$</td>
</tr>
<tr>
<td>Total $ΔP$</td>
<td>$-3,014,548,643$</td>
<td>$3,072,249,715$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Export Demand</th>
<th>Cover aggregate</th>
<th>Cover cow-calf</th>
</tr>
</thead>
<tbody>
<tr>
<td>traceability costs</td>
<td>3.5%</td>
<td>3.25%</td>
</tr>
<tr>
<td>$ΔP_{Feeder}$</td>
<td>$184,626,623$</td>
<td>$172,404,100$</td>
</tr>
<tr>
<td>$ΔP_{Fed}$</td>
<td>$5,610,035$</td>
<td>$5,244,279$</td>
</tr>
<tr>
<td>Total $ΔP$</td>
<td>$190,236,658$</td>
<td>$177,648,379$</td>
</tr>
</tbody>
</table>

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