Cattle Cycle Dynamics in a Modern Agricultural Market: Competition in Holstein Cattle Procurement

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Selected Paper prepared for presentation at the 2020 Agricultural & Applied Economics Association Annual Meeting, Kansas City, MO
July 26-28, 2020

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June 3, 2020

Abstract

Concerns surrounding horizontal concentration, vertical coordination, regional procurement areas, and resultant thinly traded input markets have beset the U.S. beef industry for decades. In late 2016, Tyson Foods, Inc. announced to its suppliers that it would no longer purchase Holstein cattle at its Joslin, IL harvest facility. Plant closure decisions made by multi-plant firms have the ability to significantly alter supply chain dynamics and the nature of competition. This alteration to Tyson's procurement policy provides a unique opportunity to estimate the degree and extent to which a firm-level decision impacted the beef supply chain. Results indicate that Tyson's decision resulted in a 5.5% (3.5%) reduction in live (dressed) Holstein prices. This impact was immediate, and the updated equilibrium price relationship has persisted. Price impacts were more significant upstream; Holstein feeder cattle prices were reduced by 22% initially and struggled to find a new equilibrium level for more than two years – ultimately stabilizing 4.8% below pre-announcement levels. We extend the price adjustment analysis to estimate impacts on U.S. Holstein feeder operations' revenues and gross margins; quantifying losses totaling $610 million annually.

Keywords: beef, Holstein, private-sector policy, relative price of a substitute
JEL Codes: Q11, Q13, L11

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1 Introduction

Few agricultural industries in the history of the United States have generated more interest, controversy, or competitive concerns than the beef industry. Since the beginning of the 20^{th} century critics accused the red-meat packing industry of manipulating markets, restricting throughput, reducing competition, and harming producers and consumers (Myers, Sexton and Tomek, 2010). Early expressions of unease with the competitiveness of the industry, coupled with a critical report summarizing the findings of an investigation by the U.S. Federal Trade Commission, provided motivation for the Packers and Stockyards Act (PSA) of 1921, regulatory oversight of the industry that remains in place to this day.

The 1970s and 1980s brought dynamic structural changes to the industry that induced efficiency gains and economies of scale, which also precipitated rapid consolidation (Crespi and Sexton, 2004). In 1976 the largest four beef processors accounted for 25% of steer and heifer slaughter in the U.S.; a mere 20 years later the four-firm concentration ratio (CR4) had increased more than three-fold (Ward, 2002). Since then meatpacking has remained a tight structural oligopsony with CR4 values stabilizing around 85% (Azzam and Anderson, 1996; U.S. Department of Agriculture Agricultural Marketing Service, 2019). Given that fed cattle are perishable commodities and can only be transported limited distances, procurement markets are regional in nature (Xia and Sexton, 2004; Xia, Crespi and Dhuyvetter, 2019). As a result national concentration statistics are likely to severely understate concentration in regional markets (Saitone and Sexton, 2017).

While almost a century has passed since the PSA was enacted, concerns surrounding beef packers' potential market power as fed cattle buyers persist; the impact that such power could have on producers and ultimately the viability of rural America remains of paramount importance (Crespi, Saitone and Sexton, 2012; DOJ, 2010). Former Secretary of Agriculture Vilsack, during listening sessions conducted by the Department of Justice (DOJ) focused on competition issues in agriculture, summarized "Over the years, I have traveled around the country, I have heard that there is increasing concern that there are, essentially, fewer buyers to do business with and that some are saying that producers or feeders have a hard time getting bids or contracts for their livestock" (DOJ, 2010).

The beef industry's evolution toward increased horizontal concentration has generated significant interest and numerous studies focusing on competition issues. Azzam and Anderson (1996), Ward (2002), U.S. Government Accountability Office (2009), and Wohlgenant (2013) collectively summarize much of the literature examining competitive conduct and oligopsony power. Much of this work found either no evidence of meatpackers exercising oligopsony power or that efficiency gains associated with increased concentration outweighed any market power effects.[1] Wohlgenant (2013) ultimately summarizes that the available empirical evidence indicates that increases in consolidation and concentration have not adversely affected prices received by producers. With a few noted exceptions, this work ignores regional procurement markets for fed cattle and suffers from significant econometric issues (e.g., Corts (1999); Sexton and Xia (2018)).[2]

Crespi, Saitone and Sexton (2012), Sexton (2013), and Adjemian, Saitone and Sexton (2016) provide a potential conceptual explanation for the findings that consistently document limited exercise of oligopsony power by processors. These authors argue that increasing concentration among buyers may actually benefit producers if the packer-feeder relationship becomes "symbiotic" such that packers rationally forgo potential short-run market power in favor of the long-run benefit of preserving the stock of available suppliers.

These salient concerns surrounding horizontal concentration, regional procurement areas, and the resultant thinly traded input markets motivate the present paper. We analyze the impact of a firm-level procurement policy that reduced the number of buyers in the market

[1] A few studies have been published after these reviewers were completed. Some of this work finds departures from competition in procurement when allowing for negotiating behavior to change over time such that market power is exercised in some periods but not in others (e.g., Cai, Stiegert and Koontz (2011*a*,*b*)). Others find that time-varying factors (e.g., seasonality, cattle cycle) cause variation in the degree of oligopsony power exercised (e.g., Crespi, Xia and Jones (2010); Ji, Chung and Lee (2017)).

[2] A limited number of studies were privy to transaction-level data as part of the Congressionally mandated Livestock and Meat Study (e.g., Muth et al. (2008)) or as part of USDA Grain Inspection, Packers, and Stockyards Administration investigations (e.g., Crespi and Sexton (2004)) allowing the authors to focused on a well defined procurement area.

for fed cattle. In late 2016 Tyson Foods, Inc., one of the three largest beef packers in the U.S., announced to its suppliers and customers that it would no longer purchase fed Holstein steers for processing at its harvest facility in Joslin, Illinois (Natzke, 31 January 2017). Given the regional nature of fed cattle procurement markets, plant closure decisions made by multi-plant firms may significantly alter supply chain dynamics and the nature of competition (Crespi, Saitone and Sexton, 2012). Despite agreement that processor demand is critical in cattle procurement markets, almost no research has been conducted to investigate the implications of processing plant closures. The Tyson decision provides a unique opportunity to address this void. Although the plant itself did not close, Tyson's decision to limit procurement of Holstein cattle acted, in effect, as a plant closure for this breed, thereby significantly altering the regional competitive landscape for Holstein procurement.

Concomitant with increases in packer concentration has been a trend toward increased vertical coordination (Greene, 2019; Ward, 2010). At the beginning of 2002, nearly 50% of cattle were procured on a negotiated basis; by 2019 only 25% were purchased via the same method (Greene, 2019).[3] The noted increase in packer procurement of fed cattle through alternative marketing agreements (AMAs) has been a substantial concern for stakeholders, policymakers, and economists for decades.[4] Numerous studies, using a variety of methodologies, have shown that purchasing fed cattle via contracts may mitigate competition and reduce prices in the spot market (e.g., Azzam and Anderson (1996); Crespi and Xia (2015); Schroeder et al. (1993); Xia and Sexton (2004); Zhang and Brorsen (2010)).[5] Equally important is that the growing use of AMAs works to make spot markets increasingly thin. In thinly traded markets– those with few buyers, low trading volumes, and low liquidity

[3]In this context, a negotiated purchase is defined as a cash or spot purchase made by a packer when the base price is determined by buyer-seller negotiation and agreement. These figures are national averages. In some areas of the country, the percentage of cattle procured on a negotiated basis is substantially lower than the national average.

[4]Alternative marketing agreements (also referred to in the literature as "captive supplies") include forward contracts, formula contracts, and packer-owned cattle.

[5]Crespi and Sexton (2004) demonstrate that if contract price terms are tied to the cash price, then cash prices can be reduced through contract pricing. Xia, Crespi and Dhuyvetter (2019) show that contract clauses that are not linked directly with cash markets can still impact cash markets through avenues outside of the effect caused by fewer buyers.

–producers have few selling opportunities, which often leads to concerns about price manipulation and the exercise of oligopsony power (Adjemian et al., 2016; Adjemian, Saitone and Sexton, 2016).

These thin market concerns directly relate to Tyson's decision. While Tyson continued to harvest Holstein cattle supplied via existing long-term supply agreements, the procurement policy change reduced the number of buyers competing in the spot market for dairy-breed cattle from three to just two in the relevant procurement region (Frericks, 2017). Further, in private communications, Tyson indicated that they would phase out dairy-breed cattle from their contract procurement portfolio in the future (Robb, 2016). We posit that the reduction in buyers (and slaughter capacity) in the region would have short-run impacts on the market via the spot market, while Tyson's choice to phase Holsteins out of their procurement portfolio would have long term implications as existing supply agreements sunset.

Tyson's decision to alter its Holstein procurement policy at its Joslin, IL plant provides a unique opportunity to consider how a plant-specific decision, that reduced competition for and increased supply of dairy-breed cattle available for harvest at remaining processing facilities, impacted input suppliers (i.e., Holstein feedlots and feeder cattle sellers). This shock also facilitates investigation into whether or not spatial linkages among regional U.S. cattle markets exist.[6] Our study contributes to the existing literature by quantifying the price impact associated with Tyson's alteration in procurement policy at multiple transaction points in the Holstein supply chain. We apply the relative price of a substitute (RPS) method, pioneered by Carter and Smith (2007), to weekly "traditional" beef and Holstein cattle prices at the dressed, live, and feeder levels.[7] This framework improves on prior event studies investigating the impact of beef industry shocks that utilized a dummy-variable approach

[6] Fackler and Goodwin (2001) provide a comprehensive summary of the spatial price transmission literature as it pertains to livestock and meat markets in the U.S. For example, Goodwin and Schroeder (1990), Schroeder and Goodwin (1990) and Goodwin and Schroeder (1991) conclude that exogenous shocks to regionally distinct markets tended to generate responses in other spatial markets; on balance showing strong spatial linkages between regional cattle markets.

[7] While Holstein cattle are bred specifically for dairy production, Holstein steers contribute significantly to beef supply in the U.S. and can be viewed as a substitute for traditional beef cattle breeds (e.g., Angus, Hereford).

within structural models (e.g., Cai, Stiegert and Koontz (2011*b*)). The RPS approach uses the additional price information from a substitute good in order to avoid the misspecification issues inherent to structural models (Carter and Smith, 2007; Corts, 1999; Sexton and Xia, 2018).

Our results show that, prior to Tyson's announcement, "traditional" beef-breed prices and Holstein prices were co-integrated at all levels of the supply chain investigated (i.e., dressed, fed, and feeder). We identified structural breaks in all of these price relationships in late 2016, following the announcement. Using bivariate vector-error correction models and pre-announcement data, we estimate how different segments of the supply chain adjust to the exogenous shock.

The full effects of Tyson's procurement policy change were felt in the dressed and fed Holstein markets immediately — fed live and dressed prices declined by 5.5% and 3.5%, respectively. Expanding out-of-sample impact window testing indicated that these relative price changes have persisted nearly three years post announcement. Holstein feeder prices were also impacted significantly following the policy (reduced by 22%).[8] Holstein feeder prices also took much longer to stabilize at a new equilibrium level – 4.8% below pre-announcement levels nearly two years later. Finally, we extend our price adjustment analysis to estimate the average annual impact of Tyson's procurement policy on Holstein cattle producer operations' revenues and gross margins, finding that the industry lost over $610 million in revenue in a single year.

Holstein cattle, with genetics developed specifically for dairy production, have been significant contributors to beef supplies; 13% of beef in 2018 was derived from Holstein cattle (Geiser and Boetel, 2019). Tyson's decision to alter their procurement strategy came at a time when the traditional beef cattle herd expansion had increased the availability of beef-breed cattle, allowing Tyson to substitute away from Holstein cattle in favor of cattle that could supply their branded beef channels (e.g., Certified Angus Beef®) without fear of

[8] This is consistent with findings from McKendree et al. (2019) who found that feeder cattle prices react proportionally more than fed cattle prices to market shocks.

limited supply in the region. Our work suggests that cyclical increases in cattle supplies alleviated Tyson of its incentive to preserve the current stock of available suppliers in favor of shifting its input supplier mix to traditional beef-breed cattle. Even though beef procurement markets may have evolved toward "Modern Agricultural Market" status wherein processors have a vested interest in preserving the viability of their suppliers (see Adjemian, Saitone and Sexton (2016)), Holstein cattle did not represent an essential source of supply to Tyson, especially as the consumer segment at both retail and food service have shifted toward quality branded beef products generally and Certified Angus Beef®, specifically (Zimmerman and Schroeder, 2011).

The remainder of this article is organized as follows. Section 2 provides an overview of the U.S. beef industry and Tyson's decision to end Holstein purchases at their Joslin, Illinois facility. In Section 3, we develop an empirical model to measure the impacts of Tyson's decision on U.S. Holstein fed and feeder cattle prices. Section 4 presents price impact results, and Section 5 deduces implications for industry revenues and producer returns. Section 6 concludes.

2 Background on Cattle Feeding and Processing

2.1 "Traditional" Beef-Breed Cattle

The traditional beef-breed supply chain consists of multiple segments.[9] First, calves are born, raised and then weaned from their mother's at cow-calf operations across the U.S. Depending on the region and time of year, calves are typically sold to "backgrounding" operations where they are placed on pasture and may slowly be introduced to a grain-based diet. When entering the feedlot, as feeder cattle, animals typically weigh between 600 and 800 lbs. Feeder cattle are fed an intensive grain-based diet in a confined feeding area for four to six months. At harvest time, cattle (referred to as fed cattle) weigh between 950 and

[9] See U.S. Government Accountability Office (2018), Figure 1, pp 6.

1400 lbs. The feedlot sells fed cattle to beef packers for harvesting and processing before the beef is sold to wholesalers, and then multiple domestic and export outlets.

Cattle production is known to follow a dynamic cyclical pattern (i.e., the cattle cycle) driven by profitability considerations (Crespi, Xia and Jones, 2010). In 2014, in response to bullish demand signals, U.S. cow-calf producers entered an expansion phase of the cattle cycle. In the short run, this expansion *reduced* the availability of fed beef-breed cattle for processing as more heifers were retained on cow-calf operations to produce more calves. During this period, beef packers filled line space with dairy-breed (i.e., Holstein) fed cattle. However, as herd expansion efforts translated into increased availability of beef-breed cattle, packers were able to be more selective about the cattle they harvested. Alongside these cattle cycle dynamics, consumer demand started shifting toward branded beef products, especially Certified Angus Beef® (Zimmerman and Schroeder, 2011). As a consequence, Holstein cattle were forced to compete for packers' line space not only with an expanding traditional beef-breed herd but also with a greater share of branded beef products for which delivery is typically pre-committed under alternative marketing agreements.

2.2 Holstein Cattle and the Beef Supply Chain

The dairy industry is an important contributor to beef supply. When dairy cows have calves, most females are retained for the milking herd, but the male (bull or steer) calves enter the cattle feeding or veal industries. In 2018, about 3.3 billion pounds of beef (12.6%) came from dairy steers (Geiser and Boetel, 2019). The vast majority (89.6%) of dairy operations utilized the Holstein breed (Schulz, Boetel and Dhuyvetter, 2018).[10] There are notable differences in beef production and harvesting between traditional beef steers and Holstein steers. There are two main types of Holstein feeders, calf feeders and yearling feeders. Calf feeders purchase Holstein steers when they are less than two months old and introduce them gradually to a grain diet. These steers will be on feed for around a year until they are

[10]Given the prevalence of the Holstein breed in the U.S. dairy industry, we use the terms "Holstein" and "dairy-breed" cattle as synonymously throughout the paper.

harvested at approximately 14 months of age. Conversely, a yearling feeder operation buys older feeder steers, weighing between 700 and 1,000 lbs., that have been "backgrounded" on pasture. Typically, these yearlings are on feed about four to eight months before harvest. The yearling Holstein market most closely resembles the traditional beef supply chain.

Dairy-breed cattle often sell for a discount, when compared to their beef-breed counterparts (Schulz, Boetel and Dhuyvetter, 2018). This persistent price discount is often attributed to Holsteins requiring more space per animal, needing more days on feed (i.e., lower feed efficiency), and having higher incidences of liver abscesses when harvested (Duff and McMurphy, 2007; Schulz, Boetel and Dhuyvetter, 2018).[11] However, additional production costs are partially offset by the fact that Holsteins often produce more uniform carcasses, having more predictable gain and feed efficiency, and produce high-quality carcasses (Duff and McMurphy, 2007).[12]

Like many agricultural industries, the dairy industry has become increasingly consolidated and concentrated over time (Shields, 2010). At the farm level, the number of dairy operations continues to decline; today fewer, larger operations supply raw milk at higher rates of productivity (i.e., milk per cow) and lower per-unit costs (Gould, 2010; Shields, 2010). MacDonald et al. (2007) show that wide disparities in net returns exist across different dairy sizes, suggesting that structural shifts toward larger operations are likely to continue into the future; with smaller dairy farms being more likely to exit the industry. More recently increasing global supplies of milk, coupled with unfavorable trade policies, have suppressed milk prices and increased dairy farm liquidations (Beck, 2019). But in 2016, at the time of Tyson's procurement policy change, the U.S. milk cow herd was approaching its' largest inventory seen since 1996 – nearly 9.4 million head (LMIC, 2019).

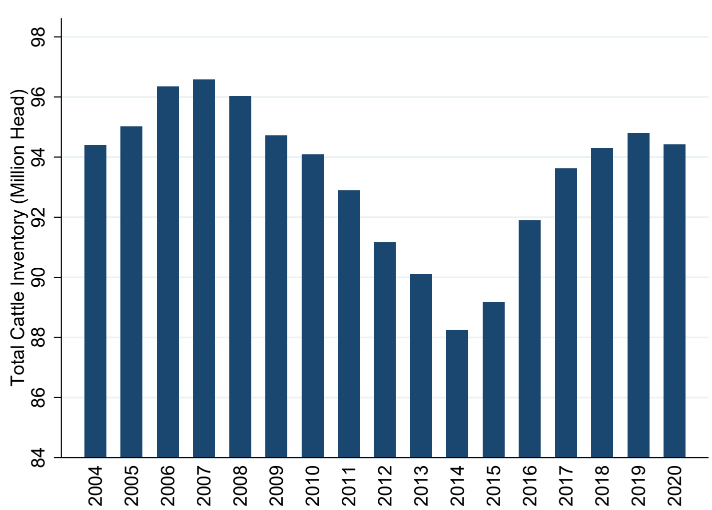
[11] Because processors pay less for Holstein cattle, feeding operations rationally anticipate those discounts and reduce their willingness to pay for Holstein feeder steers at time of purchase.

[12] Holsteins are more likely to grade USDA Prime when compared to their beef-breed counterparts (Boykin et al., 2017).

2.3 Cattle Cycle and Beef Processing

Technological and managerial advances have allowed the cattle industry to produce more beef from fewer animals. January 2014 marked the lowest level of total cattle inventory in the U.S. (roughly 88 million head) since the 1950s and signified the beginning (i.e., trough) of the current cattle cycle (LMIC, 2019). Figure 1 shows the previous (2004 - 2013) and current (2014 - present) cycles of total cattle inventory in the U.S. Total cattle inventory is comprised of both beef-breed and dairy-breed cattle. Expansion in both the traditional beef and dairy sectors caused rapid expansion from 2014 to 2016. By January 2017 (immediately following Tyson's announcement) total cattle inventories had increased by 6.1% (over 93.6 million head) from the 2014 local minimum. The change in inventory levels pivoted the market from a seller's to a buyer's market, likely changing the competitive landscape for cattle feeders (Crespi, Xia and Jones, 2010). The increased availability of beef-breed cattle likely influenced Tyson's decision, allowing the company to substitute away from Holstein cattle in favor of traditional beef-breed cattle that could supply branded beef channels without facing limited supplies in the procurement region of their Joslin, IL harvest facility.

Figure 1: Total Cattle Inventory (January 1)



Source: USDA NASS.

The demand for branded beef products, especially Certified Angus Beef®, has increased (Zimmerman and Schroeder, 2011). Grocery retailers are evolving to satisfy this demand; using meat quality to differentiate themselves. In 2011, Walmart increased the quality of their whole muscle cuts from USDA Select to Choice. In March 2017, Walmart went a step further; differentiating its meat offerings by introducing a 'Verified Angus' program for whole muscle cuts at no additional costs to consumers (Boyle and Wilson, 2017). Tyson Foods, Inc. and Cargill, Inc. are the two main suppliers to Walmart in the U.S. Downstream demand and contractual obligations likely to contributed Tyson's alteration in procurement policy. Walmart's switch to 'Verified Angus Beef' was likely unfeasible prior to 2017 when beef-breed supplies were probably insufficient to fulfill Tyson's obligations to Walmart's grocery business.

In 2018 there were 663 federally inspected plants in the U.S.; the largest 33 plants (with capacity over 300,000 head) harvested 86% of total beef cattle.[13] Figure 2 plots the beef processing facilities registered with establishment size "large" with the Food Safety Inspection Service. The three main companies, owning 20 of these 31 "large" plants, are Cargill, Inc. (6), JBS USA Holdings, Inc. (8), and Tyson Foods, Inc, (6).

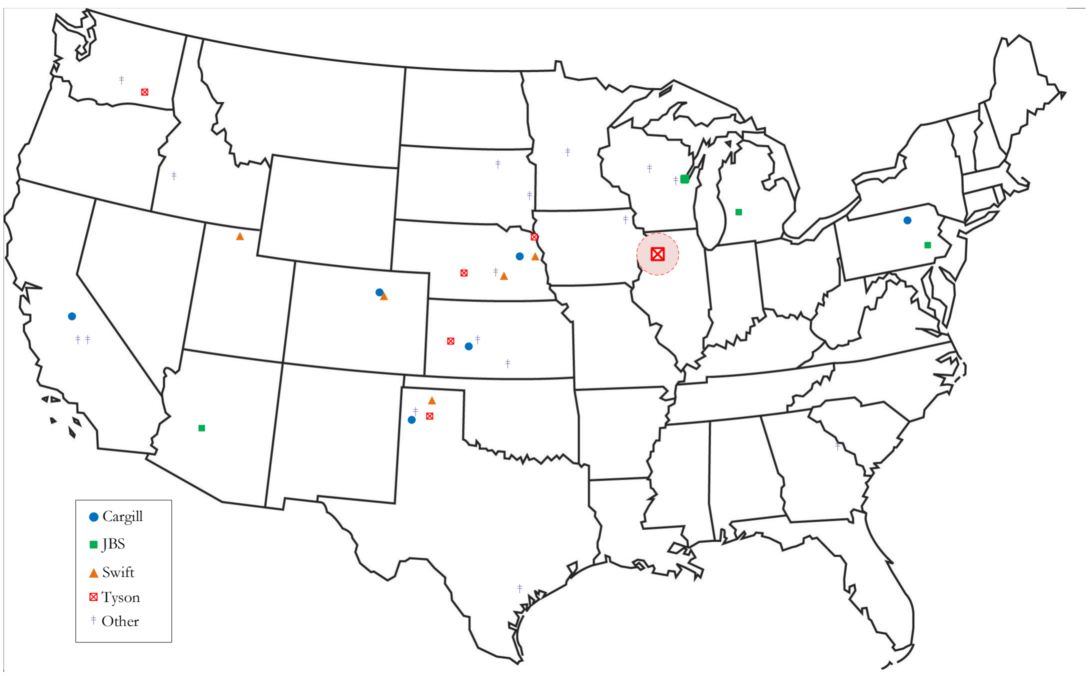
Harvest facility capacity and geographic location are important considerations when analyzing a plant-specific procurement decision given the regional nature of cattle procurement markets. While firm-level cattle transaction data are not available, industry-level survey statistics provide some insight into the geographic extent of feeder and fed cattle markets.[14] When fed cattle are shipped from the feedlot directly to a harvest facility, they are reported to travel an average of 87 miles (APHIS, 2013). Upstream from packers, feedlots procure cattle from a variety of sources (e.g., local sales, satellite video auctions, individual cow-

[13]The 13 plants in the U.S. with capacity over 1 million head harvested 56% of all cattle (United States Department of Agriculture, National Agricultural Statistics Service, 2019).

[14]In 2011 USDA's Animal and Plant Health Inspection Service (APHIS) conducted a comprehensive survey of feedlots. Out of this effort, they produced two reports summarizing their results: Part I focused on "large" feedlots (capacity of over 1,000 head) while Part II focused on more moderate sized feedlots (capacity for 1,000 head or less). Given the geographic area of interest for this paper and the higher percentage of dairy-breed cattle reported by the more moderate-sized feeding facilities, we utilize summary statistics reported in Part II.

calf operations). The average distance traveled from shipment source to feedlot location for feeder cattle is 101 miles (APHIS, 2013). Aggregating across these two averages suggests that most cattle remain within a 200 mile area surrounding a given harvest facility; broadly confirming the extreme regional nature of procurement areas.

Figure 2: Beef Packing Plant Locations



Note: Locations are approximate. *Source:* USDA Food Safety and Inspection Service. November 2019. "Meat, Poultry, and Egg Product Inspection Directory," available at https://www.fsis.usda.gov/wps/wcm/connect/a5c2b5c8-92e0-4565-8999-f2fb75bfdb05/MPI_Directory_Establishment_Number.pdf?MOD=AJPERES

3 Methodology

In this section, we construct an econometric model to investigate how Tyson's alteration in procurement policy impacted Holstein fed and feeder cattle prices across the United States. Using data from the Livestock Marketing Information Center (LMIC), we apply the Carter and Smith (2007) relative price of a substitute (RPS) method to weekly Holstein and traditional beef prices at the fed (both live and dressed) and feeder levels. The RPS method employs time series analysis of the relative price of the commodity of interest (Holstein prices) with respect to a substitute good (traditional beef prices) in order to make inferences regarding the impact of a market event (Tyson's announcement).

3.1 Data

Live and dressed fed cattle prices, obtained from LMIC (2019), are average weekly negotiated national prices for direct slaughter cattle, mixed steers and heifers. Feeder cattle prices are weekly average prices for 400–700 lb. feeder steers from Kentucky and Missouri (Holstein-large frame #3; beef- medium and large frame #2–3) (LMIC, 2019).[15] For purposes of the analysis, we use all available weeks in which both Holstein and traditional beef prices are available. Live and dressed fed cattle prices run from November 17, 2002 to September 29, 2019. Feeder cattle prices run from November 3, 2012 to September 28, 2019.

Given that spot markets for cattle are often thinly traded, especially for fed cattle, it is not surprising that there are some instances (e.g., regions, weeks) where prices are not reported.[16] Each series includes a few weeks of missing data. Because our estimation procedure requires a complete time series, we fill in these gaps via linear interpolation. Dressed and live Holstein series, respectively, include seven and four weeks of interpolated data. Dressed and live traditional beef prices each include three weeks of interpolated price data.[17] Feeder prices include four interpolated Holstein prices and two interpolated traditional beef prices.[18]

Figure 3 shows the dressed fed cattle (panel a), live fed cattle (panel b), and feeder

[15]The weight range for feeder cattle is fairly broad for a number of reasons. First, this allows us to present impacts that are relevant for the feeder sector broadly defined (e.g., backgrounding, calf feeders). Second, the thinness of regional procurement markets means that there are often weeks when prices will not be reported across disaggregate weight categories. Aggregating across weight classes for feeders increases weekly observational frequency such that imputation is minimized. Given that cattle are priced based on weight, some may be interested in how Tyson's decision impacted lighter (i.e., 400 - 500 lb.) or heavier (i.e., 600 - 700 lb.) feeder cattle. Supplemental online appendix A provides these results for the interested reader.

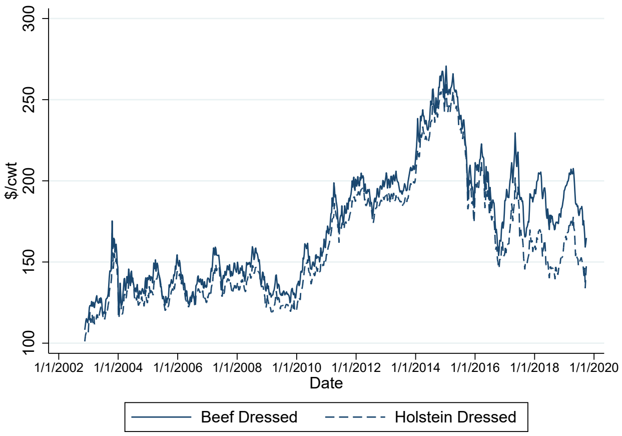
[16]If an inadequate number of sales of cattle of a particular class occur at an auction, USDA's Agricultural Marketing Service (AMS) will suppress those price reports to preserve anonymity. LMIC data is derived from AMS reports and data will thereby be missing when price observations in a particular week or location are inadequate.

[17]Three of these missing data points are the result of the U.S. government shutdown in October 2013.

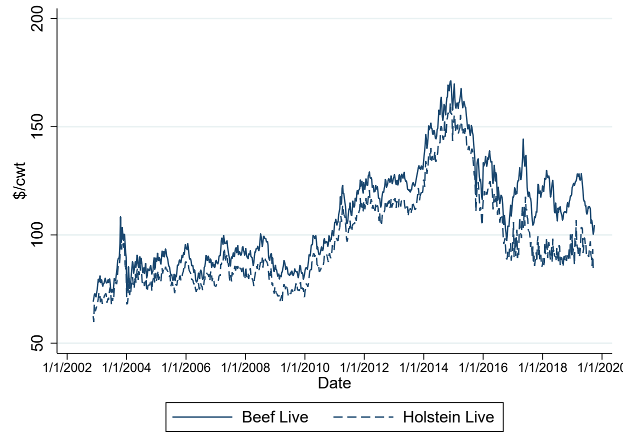
[18]Disaggregating feeder cattle by weight class substantially increases the amount of missing data. Please see Table A1 for details.

cattle (panel c) weekly prices used in the analysis. All prices are quoted in dollars per hundredweight (cwt). Panel d of Figure 3 plots Holstein-to-beef price ratios for fed and feeder series over the period of analysis.

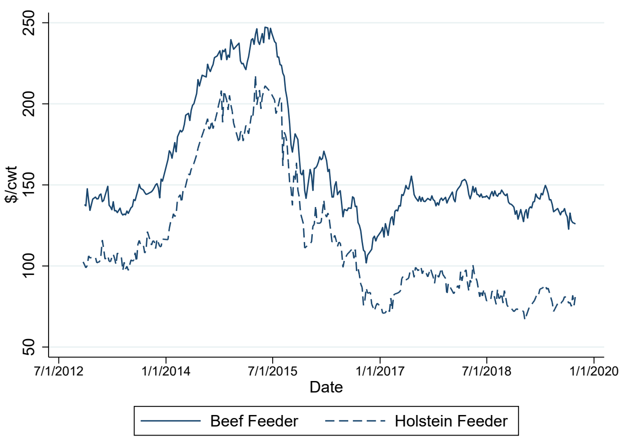
Figure 3: Beef and Holstein Prices



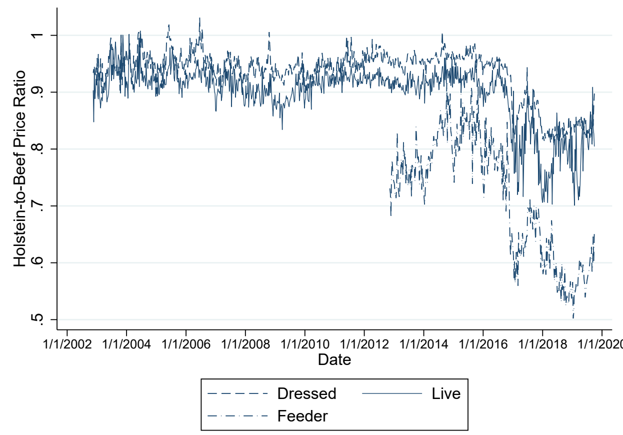
(a) Dressed Prices



(b) Live Prices



(c) Feeder Prices



(d) Holstein-to-Beef Price Ratios

3.2 Empirical Model

We estimate price impacts by applying the RPS method with Holstein and traditional beef prices in Figure 3. The RPS approach is highly desirable in the current context for three reasons. First, as discussed in Section 2, factors influencing both supply and demand conditions within the U.S. beef industry have changed dramatically over the last decade (e.g., feed costs, export bans due to disease concerns). By focusing on relative prices, the RPS method filters out structural industry changes that are common to both the beef and Holstein prices without specifying a full supply and demand system. Second, as is common among commodity price series, our price series (both in absolute levels and natural logarithmic form) exhibit non-stationarity. The presence of unit roots can lead to incorrect inference in many event study designs. The RPS method accounts for unit root processes in subject price series. Finally, the RPS method is most powerful when the commodity of interest and the chosen substitute are highly correlated. Such is the case for Holstein and traditional beef prices. Prior to the announcement of Tyson's decision, the correlation coefficients for Holstein and beef prices were 0.997, 0.996, and 0.984 for dressed, live, and feeder prices, respectively.[19] Although the RPS method has been applied in a few studies related to grain markets (Adjemian, Smith and He, 2019; Schmitz, 2018) and oil markets (Ye and Karali, 2016), to the authors' knowledge, this is the first application of the technique in the livestock domain.

Separately for dressed, live, and feeder series, we proceed according to the RPS method as follows: (i) we first test the cointegrating relationship between Holstein and beef prices prior to Tyson's decision, (ii) we then test for the presence of a structural break in this relationship that aligns with the timing of Tyson's decision, and (iii) we use an error-correction model (ECM) to forecast relative Holstein and traditional beef prices before and after the break. After applying the RPS method over the entire sample, we iterate the procedure over an expanding post-event impact window to assess the sensitivity of our estimates with respect to length of run.

Using only pre-event data, we use the augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1979) and Phillips-Perron (Phillips and Perron, 1988) tests to determine if unit roots are present in the individual Holstein and traditional beef prices series and the Holstein-to-beef

[19]Following Tyson's announcement, the correlation coefficients for Holstein and beef prices were 0.615, 0.911, and 0.621 for dressed, live, and feeder prices, respectively.

price ratios.[20] If the individual price series exhibit unit-root processes but the log relative price is stationary, the two series can be said to be co-integrated.

The RPS method requires the existence of a mean-stable relationship in the log Holstein-to-beef price ratio prior to Tyson's announcement. In other words, the Holstein and traditional beef price series must be cointegrated with a (1,-1) co-integrating vector. Thus, the relative price relationship can be expressed as:

$$\ln\left(\frac{P_{Ht}}{P_{Bt}}\right) = \mu + \beta' Z_t + \epsilon_t \tag{1}$$

where P_{Ht} and P_{Bt} are, respectively, the prices for Holstein and traditional beef in week t and Z_t denotes supply and demand shifters that impact the individual prices in different ways.[21] If Tyson's decision impacted U.S. Holstein prices, one would expect to see a change in this relationship around the time of the announcement. To determine if and when Tyson's decision impacted the market, we test for the existence of a structural break in the log Holstein-to-beef price ratios for dressed, live, and feeder series. We consider both the Supremum Wald and Supremum Likelihood Ratio (LR) tests for a structural break (Andrews, 1993), conducted with a 15% trim.[22]

Having established that Holstein and traditional beef prices are co-integrated at the dressed, live, and feeder levels and upon identifying the date Tyson's announcement caused a break in the co-integrating relationship, we estimate bivariate vector-error correction models, using pre-event data. For each series, lag length is specified as prescribed by the Schwarz-Bayesian Information Criterion (SBIC) (Schwarz, 1978).[23] The analysis is run only on the pre-announcement sample, running through the last week of July 2016. For each series, we

[20] The Phillips-Perron test is similar to the Dickey-Fuller test but is more robust because Newey and West (1987) standard errors are used to account for serial correlation.

[21] Carter and Smith (2007) note that consdieration of Z_t is only required if the log of relative prices is not stationary. Because supply and demand shifters may offer insights into price dynamics, we provide a brief discussion of possible Z_t and their impacts on our anlaysis in Appendix B.

[22] Supplemental appendix B confirms the robustness of our results to allowing for multiple structural breaks via Bai and Perron (2003) structural break tests.

[23] The optimal lag length as specified by the SBIC was equivalent to that prescribed by the Hannan-Quinn Information Criterion (Hannan and Quinn, 1979).

estimate the following VEC model (Engle and Granger, 1987):

$$\Delta H_t = \alpha^H z_{t-1} + \sum_{i=1}^{j} \left(\gamma_i^H(L)\,\Delta H_{t-i} + \delta_i^H(L)\,\Delta B_{t-i}\right) + e_t^H \tag{2}$$

$$\Delta B_t = \alpha^B z_{t-1} + \sum_{i=1}^{j} \left(\gamma_i^B(L)\,\Delta H_{t-i} + \delta_i^B(L)\,\Delta B_{t-i}\right) + e_t^B \tag{3}$$

where $\Delta k_t; k \in \{H, B\}$ is the difference between price k (expressed in natural logarithmic form) at time t and $t-1$ and j is the optimal lag length as determined by the SBIC. Functions $\gamma_i(L)$ and $\delta_i(L)$ are polynomials in the lag operator; and $z_{t-1} = H_{t-1} - B_{t-1} - \phi$ is the error correction term. This specification allows the Holstein price and the beef price to move together according to a long-term equilibrium. However, in each week, each market experiences an exogenous shock. The other market adjusts to this exogenous shock over the following j weeks. Short- and long-run coefficients are estimated using the Johansen (1995) maximum likelihood method.

The impact of Tyson's decision on Holstein prices is estimated as the mean forecast error generated by forecasting Equation (2) over the post-event period. The standard error of the estimate under the null hypothesis of no impact is obtained by generating forecast errors via iterated dynamic forecasting of Equations (2) and (3) on pre-event data.[24] Consistent with Carter and Smith (2007) and Schmitz (2018), this iteration procedure is as follows. Let h denote the number of post-event weeks in our sample. Data from before Tyson's decision are used to make l one-period forecasts using each potential start week in the pre-event data. The same data are then used to make l two-period forecasts using each potential start week. This process is repeated until h different sets of l forecasts are made from Equation (2) for the log Holstein price and h different sets of l forecasts are made from Equation (3) for the log beef price. The length of the forecasts l is set to equal the total number of pre-event weeks available, minus h, minus the number of lags used in the VEC model. The errors from

[24] Note that this approach implicitly assumes that the forecasting model is unbiased.

these different forecasts are put into an $l \times 2h$ dimensional matrix where the first h columns are associated with the log Holstein price forecasts and the next h columns are associated with the log beef price forecasts. The variance of the impact estimate is obtained as the $2h \times 2h$ variance-covariance matrix associated with the pre-event forecast errors.

Finally, we use an expanding window to assess the sensitivity of our estimated impacts to the specification of the post-event period (h) and, thus, length of run. To do so, we iterate the VEC forecasting steps described above beginning with a post-event period (h) of two months immediately following the estimated break. After obtaining the impact estimate and associated standard errors for this post-event period, we re-estimate the impact including an additional two-month window of post-event data. We repeat this procedure until our post-event window includes all data available at the time of writing (i.e., through September 2019). We define the long-run impact as that estimated over the entire out-of-sample window. A statistically significant finding over this length of run would suggest that the impact of Tyson's decision has persisted, whereas a statistically insignificant finding would suggest that the effects dissipated over time.

4 Results

Results of the tests for non-stationarity are reported in Table 1. We fail to reject non-stationarity in the Holstein and traditional beef price series before August 2016. These findings hold under both the ADF and Phillips-Perron tests, and for prices at the dressed, live, and feeder levels. In contrast, when tests for non-stationarity are run on the log Holstein-to-beef price ratio, we reject unit root processes at 99% confidence level.[25] Together, these factors suggest that Holstein and beef prices are co-integrated of order (1,-1) for the dressed, fed, and feeder levels. In other words, the price series satisfy the stable mean relationship necessary to proceed with the RPS method for identifying Holstein price impacts.

Results of the structural break tests are reported in Table 2. The Supremum Wald and

[25] Therefore, Z_t is not needed in the strucutral break analysis.

Table 1: Tests for Stationarity and Co-Integration of Price Series

Augmented Dickey-Fuller Test

	Optimal lag	Z(t) test statistic	MacKinnon p-value	Conclusion
Dressed Price				
Ln Holstein	3	-1.74	0.41	Unit root
Ln Beef	3	-1.71	0.43	Unit root
Ln Rel. Price	3	-6.77	<0.01	Cointegration
Live Price				
Ln Holstein	1	-2.08	0.25	Unit root
Ln Beef	3	-1.70	0.43	Unit root
Ln Rel. Price	4	-6.12	<0.01	Cointegration
Feeder Price				
Ln Holstein	1	-1.30	0.63	Unit root
Ln Beef	1	-0.83	0.81	Unit root
Ln Rel. Price	2	-4.09	<0.01	Cointegration

Phillips-Perron Test

	Optimal lag (Newey-west)	$Z(\rho)$ test statistic	Z(t) test statistic	MacKinnon p-value	Conclusion
Dressed Price					
Ln Holstein	6	-4.98	-1.93	0.32	Unit root
Ln Beef	6	-5.35	-1.95	0.31	Unit root
Ln Rel. Price	6	-234.33	-11.74	<0.01	Cointegration
Live Price					
Ln Holstein	6	-5.49	-1.95	0.31	Unit root
Ln Beef	6	-5.22	-1.91	0.33	Unit root
Ln Rel. Price	6	-374.47	-15.11	<0.01	Cointegration
Feeder Price					
Ln Holstein	4	-2.49	-1.20	0.67	Unit root
Ln Beef	4	-1.59	-0.87	0.80	Unit root
Ln Rel. Price	4	-46.09	-5.28	<0.01	Conintegration

Notes: Optimal lag length determined by SBIC. All models include a constant and no trend.

Supremum LR tests both identify breaks for all series in late 2016 at 99% confidence. For the dressed series, both tests identify a break date in late December 2016. The live fed cattle series appears to exhibit a slightly earlier break–either the first week of December (according to the Supremum Wald test) or the last week of November (according to the Supremum LR test). Interestingly, the feeder series identifies the earliest break date. Both the Wald and LR tests identify the final week of November 2016 as the most likely break date. If information about Tyson's decision came to light before Tyson's spot purchases of Holstein ended, one would expect the feeder price to adjust because newly sold feeders — which require many months to reach maturity—would have to be sold into a market with fewer buyers and increasingly limited harvesting options. In this interim period, the future value of these Holstein feeders would be lower than the present value of finished Holsteins.

Table 2: Structural Break Tests

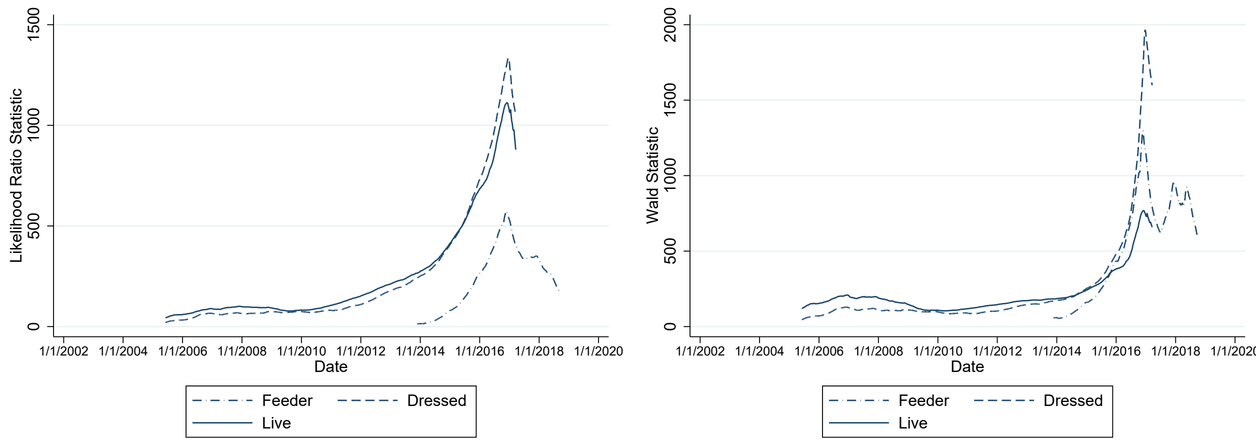
	Supremum Likelihood Ratio Test			Supremum Wald Test		
Price Series	Break Date	χ^2 Stat	p-value	Break Date	χ^2 Stat	p-value
Dressed	18-Dec-16	1336.13	0.00	25-Dec-16	1965.87	0.00
Live	27-Nov-16	1112.25	0.00	4-Dec-16	768.45	0.00
Feeder	26-Nov-16	574.44	0.00	26-Nov-16	1297.86	0.00

Figure 4 plots the Wald (panel a) and Likelihood Ratio (panel b) statistics for all feasible break dates. Under both tests, the Wald and LR statistics appear to exhibit a fairly stark peak in late 2016 (perhaps with the exception of the feeder series in the Wald test).[26] While we cannot attribute this break to Tyson's decision with 100% certainty, the fact that break dates for all series align with the timing of Tyson's letter constitutes strong evidence that Tyson's Holstein decision represented a shift in the Holstein-to-beef price ratio and that effects of the decision were experienced across the Holstein supply chain.

Table 3 reports the results of estimating the bivariate VEC model described in equations

[26] Given that both the Supremum Likelihood Ratio test and the Supremum Wald test seek to identify a single structural break, we checked the robustness of our findings by employing the Bai and Perron (2003) (BP) structural break test, which facilitates the identification of multiple structural breaks in a given time series. The BP test results confirm our break date findings for dressed (late November 2016), fed (late November 2016), and feeder (early November 2016) cattle. These results are provided in supplemental appendix B.

Figure 4: Structural Break Tests



(a) Supremum Likelihood Ratio (b) Supremum Wald

(2) and (3) for dressed, live, and feeder prices for data running through July 2016. The error correction terms α^H for each series are negative and significant at 99%. This suggests that weekly Holstein prices adjust downward to correct short-run deviations from the long-run trend. The estimated value of the Holstein error correction parameter in the dressed series $\alpha^H = -0.277$ indicates that (on average) the weekly Holstein price adjusts to correct 27.7% of any deviation from the long-run trend. The magnitude and significance of the Holstein error correction parameter indicate that price deviations from long-run equilibrium are corrected relatively quickly. In contrast, for all series, error correction parameters in the beef equations are statistically indistinguishable from zero at 95%. This suggests that it is primarily Holstein prices that react to restore the long-run equilibrium between the two commodities. Long-run adjustment coefficients γ_1 and δ_1 are statistically significant at 99% in the Holstein dressed and live equations.

Using the parameter estimates from Table 3, we forecast forward to assess the impact of Tyson's decision on Holstein prices. Figure 5 shows the errors generated by forecasting equations (2) and (3) from January 2017–September 2019. Over this period, these forecast errors imply a 3.5% reduction in dressed Holstein prices and a 5.5% reduction in live Holstein prices. The implied price impact for Holstein feeders is -4.8%. We generate standard errors

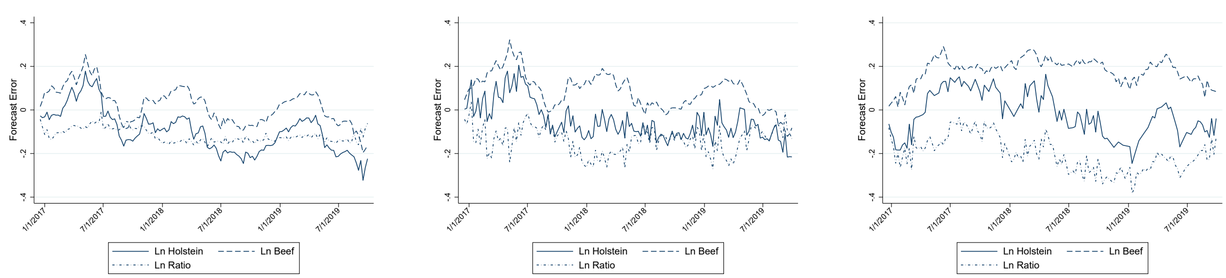
Table 3: Pre-Announcement Error-Correction Mechanism Estimates

	Dressed		Live		Feeder	
	ΔH_t	ΔB_t	ΔH_t	ΔB_t	ΔH_t	ΔB_t
ϕ	-0.050		-0.086		-0.228	
	(0.001)		(0.001)		(0.004)	
α	-0.277	-0.091	-0.166	0.074	-0.440	0.057
	(0.042)	(0.049)	(0.045)	(0.043)	(0.059)	(0.042)
γ_1	-0.295	-0.035	-0.420	-0.021		
	(0.058)	(0.069)	(0.056)	(0.054)		
γ_2	-0.059	0.117	-0.164	-0.025		
	(0.049)	(0.059)	(0.048)	(0.046)		
δ_1	0.471	0.173	0.614	0.190		
	(0.054)	(0.064)	(0.059)	(0.057)		
δ_2	-0.075	-0.358	0.030	-0.247		
	(0.054)	(0.064)	(0.001)	(0.001)		
RMSE	0.019	0.022	0.023	0.022	0.038	0.027
Log Likelihood	3843.90		3595.97		793.46	
Autocorrelation	4.930		4.830		2.791	
(p-value)	0.295		0.305		0.593	

Note: Sample period runs through July 2016.
Standard errors are in parentheses.
Autocorrelation test is Lagrange-multiplier test for first-order serial correlation.

for these predictions using in-sample data as described in Section 3. Based on these standard errors, impacts are statistically significant at 99% confidence for each series. Price impact estimates and corresponding standard errors are reported in Table 4.

Figure 5: Post-Announcement Forecast Errors (Jan 2017–Sept 2019)



(a) Dressed Prices (b) Live Prices (c) Feeder Prices

Figure 6 reports the incremental effects over time (i.e., weeks) of following Tyson's decisions estimated by iterating over an expanding out-of-sample impact window. As shown in

Table 4: Impact on Holstein Prices

	Impact	St Err	p-value
Dressed	-0.035	0.012	0.004
Live	-0.055	0.013	0.000
Feeder	-0.048	0.018	0.008

Figure 6, price impacts for dressed and live Holsteins are extremely stable and insensitive to the definition of the out-of-sample window, ranging from between 1% – 6%. This suggests the full effect of the decision were evident in the fed Holstein market immediately after the announcement and equated to a persistent shift in relative prices over the period for which we have data. In contrast, the reduction in Holstein feeder prices post decision was initially much larger in magnitude (22%) than other cattle market segments experienced. Holstein feeder prices struggled for nearly two years to find a stable equilibrium, eventually stabilizing at just 4.8% below pre-announcement levels.[27], [28]

Our results confirm that the Holstein beef cattle market is transmitting information on market shocks through prices at multiple levels of the supply chain. The finding of a larger impact in the feeder cattle price series is consistent with those of McKendree et al. (2019), McKendree and Tonsor (2019), and Zhao, Du and Hennessy (2011). Further, there is evidence of a persistent shift in the U.S. Holstein beef industry, as the price impact has not dissipated nearly three years hence.

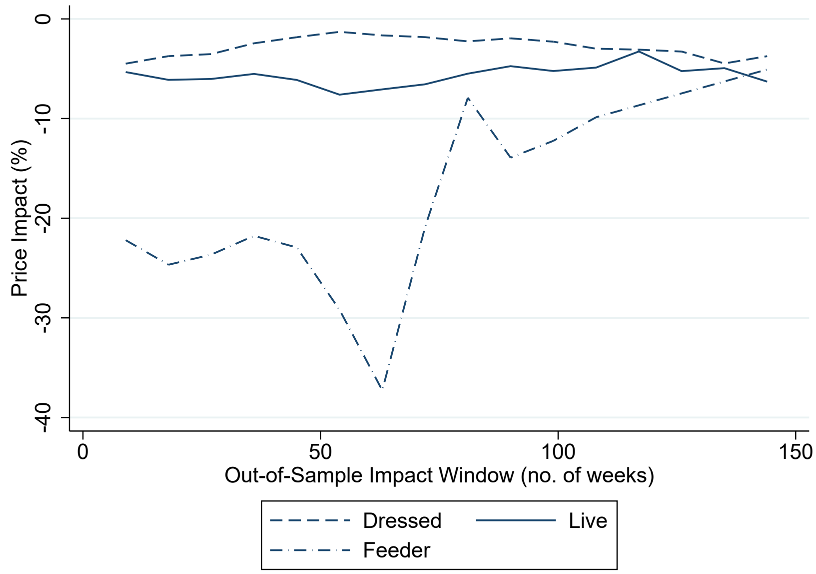
5 Producer Returns

To approximate the impact of Tyson's decision on returns to fed and feeder cattle operations and for the Holstein industry as a whole, we match the price effects reported in Table 4 with annual production data. In order to consider a "representative" year, we use inventory levels

[27]Referring back to Figure 3, panel (d) you can see the sharp decline in the Holstein-to-beef price ratio around the time of Tyson's decision, confirming the empirical results that find a large and immediate impact. In the same Figure you can also see the volatility in the price ratio persists well after the announcement.

[28]Results of this iterative process over an expanding out-of-sample impact window were replicated considering light (400 - 500 lb.) and heavy (600 - 700 lb.) feeder cattle. These results are shown in supplemental appendix A, Figure A2.

Figure 6: Expanding Impact Window



from the two years following Tyson's announcement (i.e., 2017 and 2018).[29] We measure these impacts as the annual change in total and per-head revenue for fed and feeder cattle following Tyson's decision. Feeder cattle producers — either cow-calf producers, dairy producers, or backgrounders — impacts are measured by changes in their total revenue. However, given that feedlot producers and beef packers are in margin businesses, their returns are measured in gross margins, not just changes in revenues. We assess the change in gross margin for the value-added transformations from feeder to live fed cattle — the finishing margin— and from live-fed to dressed-fed cattle — the dressing margin.

Note that a portion of fed cattle are sold to packers on a "live" basis and a portion are sold on a "dressed" basis. Our representation of the finishing margin and the dressed margin reflects that—in the process of transformation from cattle to beef—every head of fed cattle undergoes both a "live" and a "dressed" status, regardless of the state of the animal at the point of sale. The finishing margin accrues to Holstein feedlot producers (i.e. the fed cattle producer). For transactions in which the animal is sold on a "dressed" basis, both

[29]We characterize these impacts as representative of an "intermediate" length of run – some decisions remain fixed given the time it takes for an animal to move through the supply chain (can be 14+ months), while enough time has past for price effects to have found a new stable equilibrium.

the finishing margin and the dressing margin accrue to the feedlot producer, whereas under transactions in which the animal is sold on a "live" basis, the dressing margin implicitly accrues to the packer.

The changes in average annual revenue and gross margin calculations are presented in Table 5 and rely on three primary assumptions. Data from LMIC (2019) suggest that between 2017–18, on average 25,592,400 head of federally inspected fed steers and heifers were harvested annually. However, these numbers are not disaggregated by breed. Based on the National Quality Beef Audit, Holstein cattle represent 15.90% of fed cattle harvested (Boykin et al., 2017). Thus, we approximate total Holstein fed cattle by multiplying the national total (for all breeds) by 15.90%. We arrive at the total number of Holstein feeders by assuming a 2.75% deathloss, as reported by Duff and McMurphy (2007). Annual-average prices and fed cattle weights are averages for 2017–18 from LMIC (2019). The feeder cattle weight is assumed to be 600 lb., close to the midpoint of the LMIC (2019) feeder price series used in this analysis.

Referring to Table 5, based on the assumptions detailed above, the actual feeder price was $84 per cwt versus a counterfactual feeder price of $88 per cwt. Multiplying these actual and counterfactual prices by average feeder cattle weights, we see that Tyson's decision has resulted in an approximate annual revenue loss of $25 per head for feeder operations in 2017 and 2018. At the national level, this corresponds to an annual loss of $106 million. Similarly, actual prices for live and dressed fed cattle, respectively, were $94 and $160 per cwt. Corresponding counterfactual prices were $99 and $166 per cwt. For fed cattle operations, Tyson's decision led to an annual revenue loss for fed Holsteins of $77 per head (live-weight) and $47 per head (dressed-weight). At the national level, these figures correspond to a $311 million in annual revenue losses on a live-weight basis.

We evaluate the impact on gross margins for cattle finishing by subtracting the feeder cattle revenue losses from the revenue losses for live fed cattle. This reflects that decreasing feeder cattle prices, a main input cost, are postive for feedlot producers. Similarly, we derive

Table 5: Average Annual Impact of Tyson Holstein Decision on Producer Returns

	Units	Feeder	Live	Dressed
Production				
Holstein cattle	head	4,184,259	4,069,192[a]	4,069,192[a]
Average weight	lbs	600	1397	814
Prices				
Actual	$/cwt	84.02	94.16	160.00
Counterfactual	$/cwt	88.26	99.64	165.80
Revenue Impact				
Per head	$	$ (25.42)	$ (76.56)	$ (47.24)
National total	$	$ (106,354,722)	$ (311,531,435)	$ (192,217,648)
	%	-4.8%	-5.5%	-3.5%
Gross Margin Impact				
National total[b]	$		$ (205,176,714)	$ 119,313,788
Per head	$		$ (50.42)	$ 29.32
	%		-5.9%	63.3%
Assumptions				
U.S. total fed steers and heifers		25,592,400		
Holstein share of fed cattle		15.90%		
Holstein feeder cattle deathloss		2.75%		

[a]This number corresponds to the total, annual head of federally inspected fed cattle, of which a portion are sold to packers on a “live” basis and a portion are sold on a “dressed” basis. Our representation reflects that—in the process of transformation from calf to to consumer—every head of fed cattle undergoes both a “live” and a “dressed” status, regardless of the state of the animal at the point of sale.
[b]The change in the national gross finishing margin is calculated as the change in the national revenue for live cattle minus the change in the national revenue for feeder cattle. The change in the national gross dressing margin is calculated as the change in the national revenue for dressed cattle minus the change in national revenue for live cattle.
Sources: Data on the average annual head of federally inspected fed steers and heifer is obtained from LMIC (2019); our assumption regarding the share of fed cattle that are Holstein is based on information from Boykin et al. (2017). Assumed Holstein feeder cattle deathloss is based on information from Duff and McMurphy (2007). Prices are obtained from LMIC (2019), and fed cattle weights are averages from LMIC over the post event period. Feeder cattle weight is assumed to be 600 lb, close to the midpoint weight of price series from LMIC (2019).

the gross margin impacts for cattle dressing by subtracting the live cattle revenue losses from the revenue losses for dressed fed cattle. These steps reveal an interesting contrast in the impacts of Tyson's decision on the annual (gross) profitability of finishing versus dressing. In light of the bar on Holsteins at the Joslin facility, finishing margins have fallen by $50 per head, or 6% annually in 2017 and 2018. At the national level, this corresponds to a loss of $205 million annually in gross profits to Holstein finishing operations.

Dressing margins, on the other hand, have risen by $29 per head— or almost 63%—as a result of the decision. At the national level, this corresponds to a $119 million gain in gross profits. A portion of this value accrues to feedlot operations who choose to market their cattle on a dressed, rather than live, basis. The other portion accrues to packers who continue to purchase Holsteins for beef processing. We offer two complementary justifications for the positive impact on dressing margins. The first justification relates to the creation of scarcity rents as a result of the elimination of Holstein processing at the Joslin facility. While Tyson's decision translated into a glut of Holsteins available for processing, it simultaneously reduced the number of agents willing and able to perform Holstein processing and dressing, thereby driving up dressing margins. The second justification for the increase in dressed margins relates to fed-cattle marketing strategy. Because transactions made on a dressed-basis relative to a live-basis allow more information on the quality (and quantity) of meat from a specific animal, dressing an animal prior to sale can be a strategic decision on the part of the feedlot. Tyson's decision may have incentivized sellers of higher-quality carcasses to sell on a dressed basis and induced sellers of relatively lower-quality carcasses to sell on a live basis. If so, this strategic behavior would have driven up the dressed price relative to the live price. Overall, the realized margin for producers who sold on a dressed basis fell by $21 per head (sum of finishing and dressing margin).

In the wake of Tyson's decision, many producers are likely to question U.S. market acceptance of Holstein beef in the future as well as how to adjust in the long run to this market shock. Accordingly, Holstein feeder and fed cattle producers are looking for innovative ways to extract maximum value from dairy calves—a necessary output of dairy production. Some producers are currently exploring cross-breeding of dairy cows with beef-type bulls.[30] In these alternative breeding programs, the top-producing dairy cows are artificially inseminated with high-quality, sexed semen (selecting for female), with offspring being used for replacement milk heifers. Lower producing milk cows, which are not ideal candidates for replacement heifer offspring, are bred to traditional beef bulls. What is yet to be determined is how many producers will adopt these crossbreeding programs, and how these crossbred calves will be valued by the market.

6 Discussion

> *"[Tyson's decision] has had monumental and domino ramifications."* Frank Sullivan, Haas Livestock Auction, Cannon Falls, MN (Moore, 2017)

Concerns surrounding the beef industry's horizontal concentration, vertical coordination, regional procurement markets, and the resultant thinly-traded spot markets for cattle have been debated and researched for decades. Yet, almost no research has investigated the impacts of a processing plant closure, despite assertions that multi-plant firms can make unilateral decisions that may significantly alter supply chain dynamics (Crespi, Saitone and Sexton, 2012). This paper has sought to fill this void by quantifying the market wide impacts associated with Tyson's decision to no longer harvest Holstein cattle at a single facility, creating a *de facto* plant closure for this breed.

Tyson's procurement policy altered the regional competitive landscape for Holstein procurement. Our findings suggest that Tyson's decision resulted in a structural break in the historical co-integrating relationship between Holstein and traditional beef prices throughout the supply chain. The resulting price impact was a 5.5% (3.5%) reduction in Holstein live (dressed) cattle prices. This price impact was immediately following Tyson's announcement;

[30] See Halfman (2018) and Rusche (2019) for review of cross-breeding program considerations.

these updated equilibrium price relationships have persisted nearly three years hence. The pass-through upstream was more substantial, in the immediate aftermath of the decision – a 22% reduction in Holstein feeder prices.[31] The Holstein feeder market did not find a new equilibrium for more than two years post announcement. Once stabilized, the updated equilibrium price relationship in the Holstein feeder market was 4.8% below pre-announcement levels.

The Tyson procurement policy decision came at a time that could easily be considered a "buyer's market" in the cattle cycle (Crespi, Xia and Jones, 2010). This allowed the company to substitute away from Holstein cattle in favor of traditional beef-breed cattle that could supply branded beef demand (e.g., Walmart's 'Verified Angus') without fear of limited supplies. Our results suggest that the cyclical increase in cattle supplies (Figure 1) alleviated Tyson of its vested interest in preserving the Holstein stock of regional cattle supplies by ensuring their economic viability, as the "Modern Agricultural Markets" paradigm would suggest.

While this paper has focused on feeder, fed, and dressed cattle prices, the breeding-stock segment of the supply chain has not been considered and offers an opportunity for future work. Both beef-breed cow-calf operations as well as dairies have made substantial capital investments in their breeding stock (i.e., cows). Yet, the estimated price impacts have reverberated throughout the supply chain and changed the derived demand for beef-breed and Holstein cattle. Our results showing the magnitude and persistence of Holstein price discounts could be used to evaluate the impacts on beef-breed cow-calf operations and dairy operations under alternative cattle cycle scenarios.

[31] This is consistent with the exisiting literature that shows feeder cattle prices react proportionally more than fed cattle prices to market shocks (e.g., McKendree et al. (2019), McKendree and Tonsor (2019), Zhao, Du and Hennessy (2011)).

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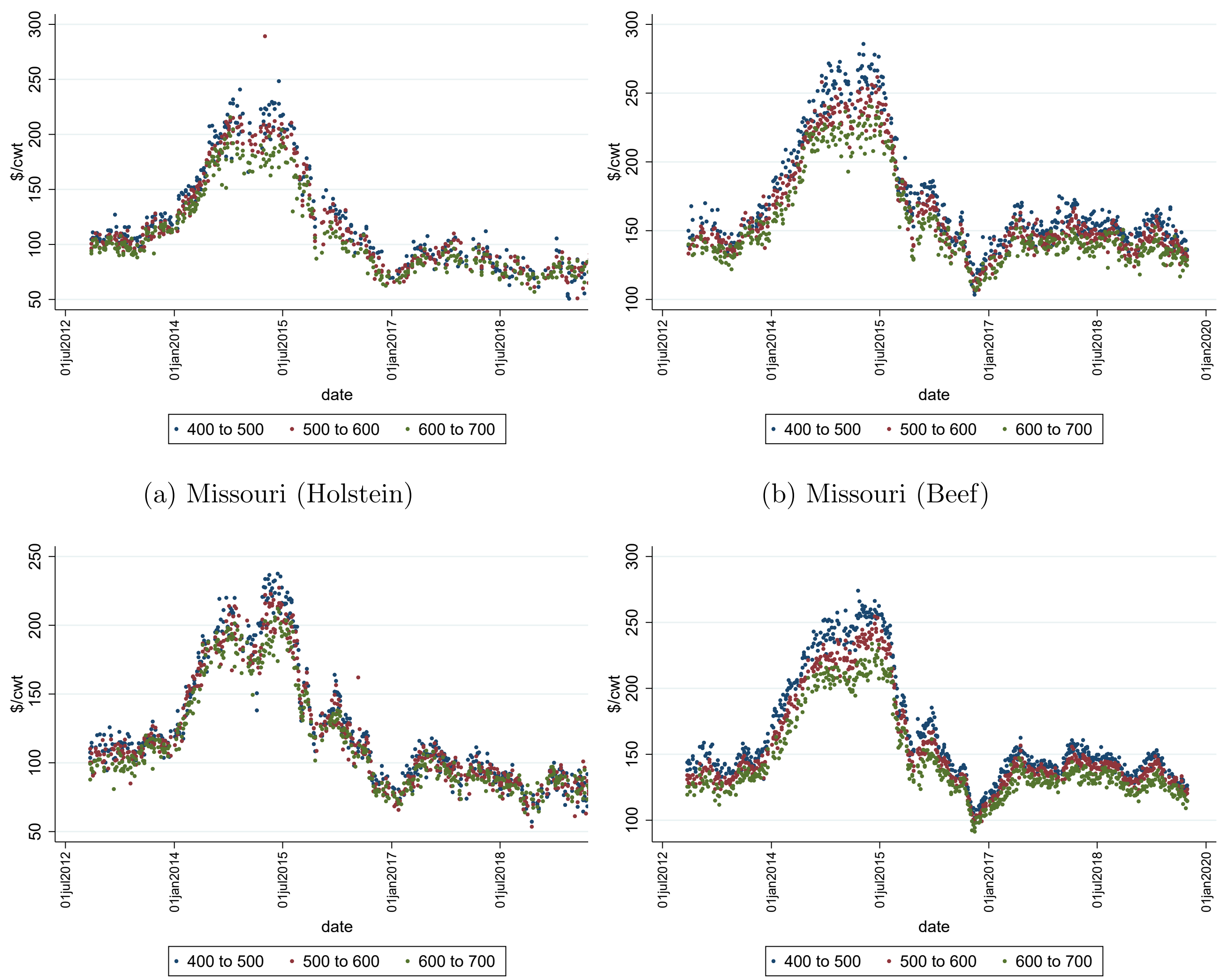
A Construction of Feeder Cattle Prices

In this appendix, we provide additional information on the data aggregation process across regions and weight classes for feeder cattle prices. As discussed in Section 3 of the main manuscript, we construct our feeder series by averaging prices across 400-700 pound cattle in Missouri and Kentucky. Figure A1 plots prices for Holstein and traditional beef cattle by hundred-pound weight categories in both of these markets.[32]

Figure A1: Prices for Feeder Weight Ranges



(a) Missouri (Holstein) (b) Missouri (Beef)

(c) Kentucky (Holstein) (d) Kentucky (Beef)

[32]Note that even these data are aggregated from the raw LMIC data, which report prices on a 50-pound weight category basis.

As shown in Figure A1, within a given market, prices are highly correlated across the different weight categories. Moreover, prices in Missouri (panels a and b of Figure A1) move together with prices in Kentucky (panels c and d of Figure A1). Thus, aggregation across weight categories and markets vastly reduces our need to interpolate date without sacrificing useful economic information within the data. Table A1 reports the number of weeks of missing data for each of the weight categories and for the composite series used in the main analysis. By aggregating across weight categories, we reduce data missingness from 62 and 20 weeks for Holstein and beef, respectively, in the 400-to-500 weight class, to 4 and 2 weeks in the composite series.

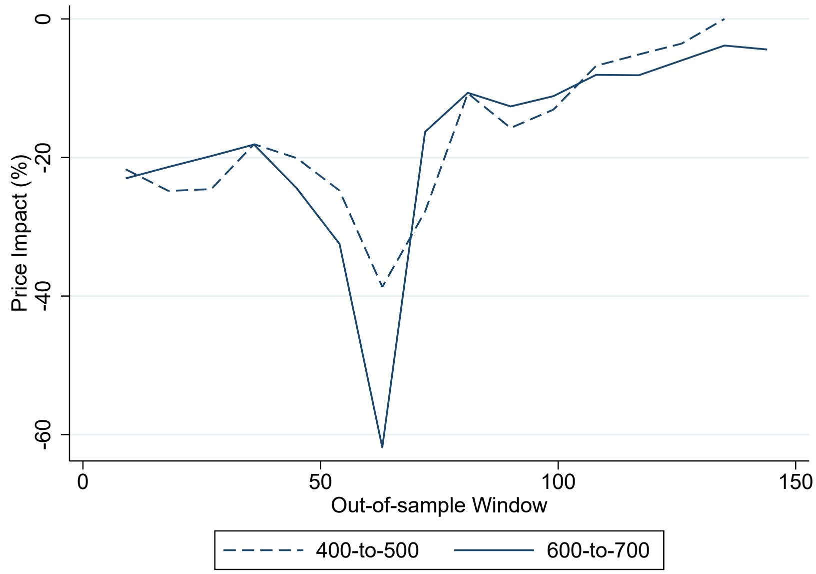
Table A1: Weeks of Missing Data

	Price Series	
Weight Range	Holstein	Beef
400 to 500	62	20
500 to 600	50	22
600 to 700	58	30
Composite	4	2

To assess the robustness of our price impact results to different weight-class definitions for the feeder series, we re-estimate the expanding price impact window analysis using feeder prices alternatively specified as including only 400-to-500 pound animals (i.e., the lightest animals used in the analysis) and 600-to-700 pound animals (i.e., the heaviest animals used in the analysis). Figure A2 shows price impact results for these alternate specifications. Referring to Figure A2, we see that the price impact estimates are robust to these alternative feeder weight definitions. The evolution of price impacts follow closely between the lighter and heavier series, and both mirror the estimated impacts reported in Figure 6 in the main body of the paper.[33]

[33]Note that—as shown in the Figure—we are unable to estimate the full out-of-sample window for the 400-to-500 weight price impact due to missing data.

Figure A2: Expanding Impact Window, by Feeder Weight Range



B Additional Structural Break Tests

In this appendix, we assess the sensitivity of our structural break results in two ways. First, we analyze the impacts of including of corn prices (expressed in natural logarithmic form) as potential demand shifter (i.e., the Z variable from equation 1). Second, we allow for the possible existence of additional breaks in the beef-to-Holstein data generating process using the Bai and Perron (2003) structural break test. The results of these robustness checks are reported in Table A2 and are consistent with our main findings (reported in Table 2 in the body of the manuscript).

Carter and Smith (2007) discuss a special case of the relative-price-of-a-substitute approach, where supply and/or demand shifters need to be included in the structural break analysis. If such factors impact the two prices in different ways, they could cause the relative price relationship to be unstable, which would confound the cointegration analysis. In our setting, this would occur if some market shocks other than the Tyson decision were impacting traditional beef and Holstein cattle prices differently around the time of the Tyson decision. If this were the case, the confounding variable would need to be included in vector Z to

Table A2: Additional Supremum Wald Structural Break Tests

Price Series	Break Test	Estimated Breaks	F Stat	Break Date
Dressed				
	Sup Wald		1527.20	4-Dec-2016***
	Sup LR		1219.31	4-Dec-2016***
	Bai-Perron	1	49.15	25-Nov-2016***
Live				
	Sup Wald		742.44	4-Dec-2016***
	Sup LR		1129.39	4-Dec-2016***
	Bai-Perron	1	273.87	25-Nov-2016***
Feeder				
	Sup Wald		1164.42	19-Nov-2016***
	Sup LR		558.58	19-Nov-2016***
	Bai-Perron	0	3.46	11-Nov-2016

***p<0.01, **p<0.05, *p<0.1.

isolate the impacts of the Tyson decision. As Carter and Smith (2007) explain, the inclusion of vector Z is unnecessary in our setting because our three log relative price relationships are stationary. Nevertheless, based on economic reasoning and industry knowledge, we examine whether the inclusion of corn prices (also expressed in natural logarithmic form) as a demand shifter materially impacts our findings.[34] Robustness of our structural break tests to this additional factor serves to confirm that we are isolating the impact of Tyson's decision.

Comparing our supremum Wald and Likelihood Ratio test results in Table A2 with those in Table 2 in the main body of the manuscript, we find that our structural break findings are robust to the inclusion of the log corn price as an exogenous demand shifter. Under our robustness specification, Wald and LR tests identify 4-Dec-2016 as the most likely break date for both live dressed and live prices (statistically significant at 99%). Similarly, these tests identify 19-Nov-2016 as the most likely break date for feeder prices (also statistically significant at 99%).

[34] The relationship between the corn and feeder cattle price is well established. See McKendree et al. (2019), Tonsor and Mollohan (2017), and Zhao, Du and Hennessy (2011). Given that traditional beef feeder cattle and Holstein feeder cattle have different feed conversion ratios (Holsteins are on feed longer), plausibly, this could impact the price ratio causing it to exhibit a unit root process. Since corn and feeder cattle are the largest variable costs for the feedlot, when the corn price is higher, a feedlot will be willing to pay a lower price for feeder cattle, ceteris paribus.

Next, we note that our supremum Wald and supremum Likelihood Ratio tests allow for only one break over the sample period. We assess the sensitivity of our results based on these tests to the possible presence of multiple breaks occurring at unknown dates using Bai and Perron (2003) — hereafter BP— tests. Multiple options can be specified during BP tests: the maximum number of allowable breaks (m; resulting in $m+1$ regimes), the minimum percent of observations in a regime or trim (v), assumptions about the distributions of errors and regressors, as well as heteroscedasticity- and autocorrelation-consistent (HAC) estimators. We base our testing specification on Carter and Smith (2007), Tonsor and Mollohan (2017), and Twine, Rude and Unterschultz (2015).[35] Note that we include the log corn price as an additional exogenous shifter, but allow only the intercept (i.e., the long-run mean relative price) to vary, as with the other break tests reported in Table A2.

The BP results reported in Table A2 are also consistent with our primary analysis. The BP tests identify a single break for both live and dressed prices, occurring in late November 2016. The feeder cattle BP results are mixed. The WDmax and UDmax tests suggest there is at least one structural break in the feeder price series. However, the Supremum F statistic does not find a statistically significant break. The BP test does identify 11-Nov-2016 as the most likely candidate break date for the feeder series, though it is statistically insignificant.

[35] See these articles for a more comprehensive description of the methods. We use SAS 9.4 to conduct the partial structural change BP tests with $m = 5$, $v = 0.15$, and HAC (prewhitening). Furthermore, we assume both errors and regressors have heterogeneous distributions across regimes. Therefore, in SAS we specify the options HAC(prewhitening), HE, and HR. Carter and Smith (2007) use $m = 6$; $v = 5$ and AR(1) prewhitening. Twine, Rude and Unterschultz (2015) and Tonsor and Mollohan (2017) use $m = 5$; $v = 15$. However, as noted in Twine, Rude and Unterschultz (2015), BP caution against using a v that is too small in the presence of serial correlation and/or when allowing different variances across regimes. BP suggests using the sequential method for identifying the number of breaks over the BIC and LWZ procedures.