Journal of Agricultural and Resource Economics 46(3):425–446 ISSN: 1068-5502 (Print); 2327-8285 (Online)

doi: 10.22004/ag.econ.304769

Packer Procurement, Structural Change, and Moving Average Basis Forecasts: Lessons from the Fed Dairy Cattle Industry

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Changing market fundamentals have made fed dairy cattle basis more variable. Our study estimates empirical models of fed dairy basis and utilizes tests that endogenously identify structural breaks following one large packer's decision to exit the fed dairy cattle market. We quantify the impact and find sale type, cattle weight, seasonality, ground beef prices, by-product values, and fed cattle slaughter capacity utilization to be important basis determinants, although the impact of some of these factors has changed over time. Finally, we assess multiyear moving average basis forecast accuracy and draw implications for formulating basis expectations.

Key words: cattle cycle, Holstein steers, live cattle futures prices, livestock economics, packer capacity utilization, price risk management

Introduction

Fed dairy cattle are an integral component of U.S. agriculture. Sales of dairy calves provide additional income for milk producers, and beef derived from dairy cattle contributes to the U.S. beef supply. Fed dairy cattle, like beef breeds, are marketed through auctions and various types of direct sales to packers, though fewer buyers typically exist for fed dairy cattle (Boetel and Geiser, 2019). Research shows that Holstein steer hedging strategies need not differ from beef-type steer hedging strategies (Buhr, 1996). Producers' effective use of marketing and risk management opportunities, however, requires accurate forecasts of basis.[1] Broadly speaking, initiating an effective hedge necessitates an accurate basis forecast (Tonsor, Dhuyvetter, and Mintert, 2004). Similarly, basis expectations are important to fed cattle buyers and sellers when they make decisions regarding forward pricing (Parcell, Schroeder, and Dhuyvetter, 2000); fed dairy cattle producers are no exception.

Moving averages of historical basis values provide a useful method for forecasting basis in livestock. Fed cattle basis follows seasonal patterns, so producers are often advised to use historical basis levels to help forecast basis (Mintert et al., 2002). These forecasts often take the form of moving averages of various lengths (3-year, 5-year, etc.), which are appealing due to data availability and straightforwardness of implementation (Hatchett, Brorsen, and Anderson, 2010). In a study of moving average forecasts for crop basis, Hatchett, Brorsen, and Anderson (2010, p. 32) generalize their results: "When a location or time period does not undergo structural change, longer moving averages produce optimal forecasts. But when a structural change has occurred, the previous year's basis or an alternative approach should be used."

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This work was supported in part by the USDA National Institute of Food and Agriculture Hatch project 1010309.

Review coordinated by Darren Hudson.

[1] As is common practice in the industry and literature, fed cattle basis is defined as the difference between the cash price for fed cattle and the nearby live cattle futures price (i.e., *Basis = Cash Price – Futures Price*).

This rule is generalizable to many commodity markets, including fed dairy cattle, but recent events indicate a structural change. Fed dairy cattle are typically discounted compared to beef breeds, so basis is generally weaker for fed dairy cattle. That said, since 2016, the difference between the fed dairy cattle cash price and the nearby Chicago Mercantile Exchange (CME) live cattle futures price has weakened, which corresponds with one large packer moving away from fed dairy cattle slaughter around the end of 2016. Identifying a structural change must often be done subjectively (Hatchett, Brorsen, and Anderson, 2010), but our study rigorously establishes a structural change in fed dairy cattle basis by utilizing structural break tests that choose break dates endogenously. We employ tests that select an unknown break date while accounting for other explanatory variables that can impact basis.

The last 7 years in the fed dairy cattle market provide an excellent setting for identifying and analyzing structural change and market fundamentals as sources of impacts on basis and basis forecasts. Specifically, we have four main objectives: (i) to rigorously test for the presence of a suspected structural change in the fed dairy cattle basis; (ii) to quantify the impact of sale characteristics and market forces on basis; (iii) to quantify the impact of beef packing industry changes in the procurement of fed dairy cattle on basis; and, (iv) to assess moving average basis forecast accuracy.

Background and Literature Review

Fed dairy cattle comprise a sizable proportion of the total U.S. fed cattle supply. CattleFax beef audits for 2012–2016 indicate that fed dairy steers and heifers averaged 10.2% of total U.S. cattle slaughter, and fed dairy-beef production averaged 13% of total fed beef production (Brix, 2017). Although a by-product of the commercial milk production system (Burdine, 2003), dairy steers—Holstein steers in particular[2]—have a number of desirable characteristics for beef production. Unlike beef breeds, dairy calves of all weights are available year round (Buhr, 1996). Further, early weaning of Holstein steers can reduce medication requirements upon arrival at a feedlot (Grant, Stock, and Mader, 1993). Offspring of Holsteins bred for milk production have relatively less genetic variation, which leads to relative uniformity in feed intake and daily gain (Grant, Stock, and Mader, 1993). Schaefer (2005) also indicates that a Holstein's hide comprises less of its total body weight and has more value as a by-product than beef-breed hides.

Despite these qualities, beef packers discount fed dairy cattle relative to beef breeds for a variety of suspected reasons. First, typical beef-breed steers have an average dressing percentage of 62%–64%, while, despite a lighter hide, dairy steers have an average dressing percentage of 58%–60% (Fluharty, 2016). Second, many facilities and/or buyers that slaughter Holstein steers also slaughter cull cows, which leads to the perception that beef from Holstein fed cattle is low quality (Burdine, 2003). Burdine challenges this association, but these long-held perceptions likely contribute to the Holstein discount. Third, research shows that fed Holsteins have higher incidences of liver abscesses (Herrick, 2018), and liver condemnation reduces by-product value for packers.[3]

While these factors help explain historical fed dairy cattle price discounts relative to beef breeds, these discounts have increased in recent years. On July 25, 2017, the USDA Agricultural Marketing Service (AMS) launched the *National Weekly Fed Cattle Comprehensive* report,[4] which includes week-to-week and year-over-year differences (spreads) between all beef-type and dairy-breed cattle.

[2] Holsteins comprise approximately 86.0% of all U.S. dairy cows (U.S. Department of Agriculture, 2016). Hence, as Buhr (1996) highlights, most fed dairy steers are Holstein steers.

[3] Beef packer net margins, on a per head slaughtered basis, represent the value of the carcass plus the value of the by-products, less the value of the animal, less operating costs, less fixed costs. Beef packer margins, at times, are carried by by-product values that averaged $170/head from 2012–2019 with a range of $116/head–$234/head, according to the *USDA By-Product Drop Value (Steer) FOB Central U.S.* report (NW_LS441), which provides the hide and offal value from a typical slaughter steer.

[4] The most recent report and historical data for the *National Weekly Fed Cattle Comprehensive* report are available at https://www.ams.usda.gov/market-news/national-direct-slaughter-cattle-reports.

These reports demonstrate the aggregate spread has widened over the last several years. For example, on September 27, 2016, the spread for dressed cattle was $2.87/cwt; on September 26, 2017, the spread had jumped to $12.27/cwt. On March 26, 2019, the spread was $25.56/cwt, double what it had been 18 months prior (U.S. Department of Agriculture, 2019b).

Popular press articles attribute this widening to beef packing companies' changes in fed cattle procurement. For example, on February 13, 2017, *Dairy Star* reported that changes in the packing industry had led many beef-packing plants to reduce or discontinue Holstein slaughter (Coyne, 2017). Specifically, they quote the USDA as saying that one packer announced in mid-2016 it would stop purchasing and processing Holstein cattle, which, in part, led to the recent decline in Holstein prices (Coyne, 2017). While the *Dairy Star* article did not indicate that the USDA had named the particular packer, Tyson Foods, Inc. (Tyson) exited the Holstein market around this time (Coyne, 2017; Moore, 2017; Natzke, 2017). While similarly not naming Tyson specifically, a Michigan State University extension article published in March 2018 attributed a $250/head decline in fed Holstein steer values in the Midwest to "one packer's decision to not harvest Holstein steers" any longer, beginning roughly 15 months prior (Gould and Lindquist, 2018). This provides *ex post* corroboration of the general timing of a single large packer—Tyson—exiting the fed dairy cattle market. Tyson's slaughter plant in Joslin, Illinois, had previously operated as a major purchaser of Holstein steers in the Midwest (Natzke, 2017).

During this general period, neither Cargill nor JBS Foods discontinued Holstein steer slaughter (Jibben, 2017). Additionally, annual surveys of the top 30 U.S. beef packers by *Cattle Buyers Weekly* indicate no change in fed cattle type by known Holstein fed cattle buyer American Foods Group. That said, there is anecdotal evidence that major packers besides Tyson reduced fed dairy slaughter volume (Jibben, 2017), and it is possible that the details of the procurement activities of other fed dairy cattle buyers changed. An individual packer's proportion of negotiated, formula, forward contract, and negotiated grid purchases could have changed, as could have provisions of certain purchase arrangements. For example, the prevalence of short-term formulas versus long-term formula arrangements, the use of basis contracts versus fixed price contracts, etc., could have changed. Such information is proprietary, so admittedly we have little direct evidence of any changes and their impacts, but we conservatively want to acknowledge their possible existence. Consequently, later in the article we use the term "procurement impact" to quantify the change in basis after the structural break with Tyson exiting the fed dairy cattle market being the most salient cause.

It is likely that changing consumer demand also influenced the Holstein market. USDA-certified branded-beef programs, such as the Certified Angus Beef (CAB) program, have increased in both prevalence and prominence in recent decades (Drouillard, 2018). These programs offer vertical alignment benefits to participating producers (Drouillard, 2018), but cattle demonstrating dairy-breed characteristics are specifically excluded from many certified branded-beef programs (U.S. Department of Agriculture, 2020). These and other shifts in the beef demand profile may have driven Tyson's decision regarding Holstein fed cattle procurement.

Increasing beef-type cattle supplies could have additionally influenced the timing of the change. The most recent cattle cycle started in 2014 when the cattle and calf inventory was only 88.2 million head (U.S. Department of Agriculture, 2019a), the smallest it had been since 1952. The combination of tighter supplies and improved beef demand initiated a period of unprecedented profitability for the cow-calf industry and encouraged producers to expand their herds starting in 2015 (Tonsor and Schulz, 2015). The current cycle entered its 6th year in 2019, and inventory estimates suggest that expansion of the U.S. beef herd was at its peak (U.S. Department of Agriculture, 2019a). Therefore, it is unsurprising that players in the beef packing industry decided to move away from Holstein slaughter as fed cattle inventories grew, especially given the manner in which plants often utilize beef from fed dairy cattle.

Carcass characteristic differences between beef-breed and dairy-breed fed cattle have resulted in some plants specializing in slaughter, fabrication, and marketing of dairy beef (Boetel and Geiser, 2019). Plants that do not specialize in processing fed dairy cattle may still procure them, but they typically use fed dairy cattle to fill existing market obligations, especially when the supply of beef-breed cattle is tight and prices are high. Conversely, these plants decrease fed dairy cattle slaughter when supplies increase and prices moderate (Boetel and Geiser, 2019).

Despite various reports in the popular press, it is difficult to date, exactly, Tyson's decision to exit the fed dairy cattle market. The *Daily Livestock Report* indicates that Tyson signaled to cattle feeders in mid-September 2016 that it would not be renewing Holstein contracts (Steiner Consulting Group, 2016). In January 2017, *Progressive Dairyman* reported that northeastern Wisconsin livestock market managers stated Tyson sent a letter to buyers and customers in late December 2016 announcing it would stop buying Holstein steers (Natzke, 2017). The same article reports a public relations manager with Tyson declined to comment due to the proprietary nature of Tyson's marketing decisions (Natzke, 2017). Hence, we employ structural break tests that choose a break date endogenously to identify Tyson's exit. Such tests have the advantage of considering changes in sale characteristics and market fundamentals and their impacts on basis for fed dairy cattle.

Basis Modeling

Fed cattle basis and price spread modeling literature extends back more than 5 decades (Ehrich, 1972; Leuthold, 1979; Liu et al., 1994). More recently, Parcell, Schroeder, and Dhuyvetter (2000) use monthly data to model live cattle basis as a function of observable market variables such as cattle weight, a measure of captive supplies, nearby corn futures price, Choice–Select spread, and seasonality.

Especially germane to this study is work in the early 2000s on changes in the fed dairy cattle industry and impacts on prices. Burdine, Maynard, and Meyer (2003) examine the consequences of the 2001 Smithfield/Packerland merger on the live cattle price spread between beef feeder steers and dairy feeder steers in Kentucky. Burdine (2003) presents a very thorough description of the fed Holstein steer market and packing industry and analyzes the impact of the Smithfield/Packerland merger, this time looking at the effect on both fed and feeder Holstein prices. These studies generally find that the aforementioned merger likely impacts the Holstein steer industry—Burdine, Maynard, and Meyer show a \$4.00/cwt increase in the live cattle price spread between beef and dairy feeder steers in the months after the merger, and Burdine shows that the post-merger period corresponds with lower Holstein prices for several price series.

Our study differs from previous research (and the *National Weekly Fed Cattle Comprehensive* report) by considering the fed dairy cattle basis (i.e., cash price minus futures price) instead of the cash price spread or difference between two spot market prices. Specifically, we model several basis series, each of which we construct by differencing a fed dairy cattle cash price with the nearby CME live cattle futures price. We use a hedonic model to estimate the impact of sale characteristics and market factors on fed dairy cattle basis. The basis equation specification is

$$B_t = \alpha_0 + \sum_{j=1}^{J} \beta_j TC_{tj} + \sum_{k=1}^{K} \gamma_k MC_{tk} + \varepsilon_t, \tag{1}$$

where B_t is the basis for the tth week, α_0 represents the intercept with ε_t as a white-noise error term, TC is the jth characteristic of the tth basis, MC is the kth market condition of the tth basis, and β_j and γ_k are parameters to be estimated (Bailey, Brorsen, and Fawson, 1993; Feuz et al., 2008; Schulz, Schroeder, and Ward, 2011).

Data

We obtain fed dairy cattle prices from two sources. The USDA-AMS publishes voluntarily reported prices from sales at auctions (sale barns) through market news reports. We collect weekly slaughter Holstein steer prices from the *Iowa Weekly Weighted Average Slaughter Cattle Report* (NW_LS785) provided by USDA–Iowa Department of Ag Market News.[5] Prices include quality grades of Choice 2–3 and Select 2–3 for Holstein steers for all weight classes reported on a live-weight basis. We difference corresponding weekly Holstein steer auction prices and nearby CME live cattle futures prices (obtained from the Livestock Marketing Information Center, LMIC) to create two auction market basis series delineated by grade, which are shown in the first row of charts in Figure 1. Notably, unreported data for various weekly observations leads to gaps in the line graphs. Aside from the unreported data, the two basis series in the first row of Figure 1 appear to track similarly over time but with the Choice 2–3 basis being stronger (i.e., less negative).

Livestock Mandatory Reporting (LMR) requires beef packers annually slaughtering or processing 125,000 head or more to report prices and other characteristics of their transactions, and this is the source of the direct sale data for our analysis. Specifically, we collect price series for fed Holsteins and other fed dairy steers and heifers (denoted by the USDA-AMS as dairy-bred steer/heifer in reports), including data for formula net, forward contract net, and negotiated grid net sales from the *Iowa-Minnesota Weekly Direct Slaughter Cattle Report—Formulated, Forward Contract, and Negotiated Grid Purchases* (LM_CT147).

Formula, forward contract, and negotiated grid sales have different characteristics worth defining.[6] Formula sales are the advance commitment of cattle for slaughter by any means other than through a negotiated purchase or a forward contract, using a method for calculating price in which the price is determined at a future date. The base price is not negotiated but is based on some other price (such as plant average or weighted average price) or value-determining mechanism that may or may not be known at the time the deal is struck. The formula net price is the final price paid to the producer after premiums and discounts have been applied to the formula base. Forward contract sales are an agreement for the purchase of cattle, executed in advance of slaughter, under which the base price is established by reference to prices quoted on the CME. The forward contract net price is the final net price paid to the producer after any adjustments have made to the forward contract base price. For negotiated grid sales, the base price is negotiated between the buyer and seller and is known at the time the deal is struck, and delivery is usually expected within 14 days. The final net price is determined by applying a series of premiums and discounts based on carcass performance after slaughter.

Negotiated dairy steer and heifer sales, which are cash or spot market purchases where the price is determined through buyer-seller interaction, were not reported by the USDA-AMS for the Iowa/Minnesota region. Negotiated sales of dairy steers and heifers may not occur in the Iowa/Minnesota region or may not be reportable due to confidentiality restrictions.[7]

[5] Beginning June 7, 2019, USDA Market News transitioned this report to the MARS platform and My Market News. In the new platform, this report is called the Iowa Weekly Cattle Auction Summary, with a SLUG ID of 2167. While the USDA-AMS Market News reports provide Holstein steer data according to both grade (e.g., Choice 2–3 and Select 2–3) and weight range (e.g., 1,100 lb–1,300 lb, 1,300 lb–1,500 lb), the new MARS platform reports data for dairy steers of the same grade together, regardless of weight. To make the results of this study applicable for producers going forward, we construct and analyze weighted averages of prices and weights for all Choice 2–3 and Select 2–3 Holstein steers.

[6] The *Code of Federal Regulations*, Title 7: Agriculture, Part 59: Livestock Mandatory Price Reporting, provides the official definitions of these sale types, with the USDA-AMS Livestock, Poultry, and Grain Market News office also providing definitions with further detail in presentations at LMR stakeholder meetings (Pitcock, 2016; U.S. Code of Federal Regulations, 2020).

[7] The USDA-AMS uses what is referred to as the 3/70/20 guideline to ensure confidentiality of reported market information under LMR. More information about this guideline is available at https://www.ams.usda.gov/sites/default/files/media/ConfidentialityGuidelines.pdf. The *National Weekly Direct Slaughter Cattle—Negotiated Purchases* report (LM_CT154) reports negotiated dairy-bred steer and heifer prices at times since aggregation across regions addresses confidentiality constraints, but the head count is notably small.

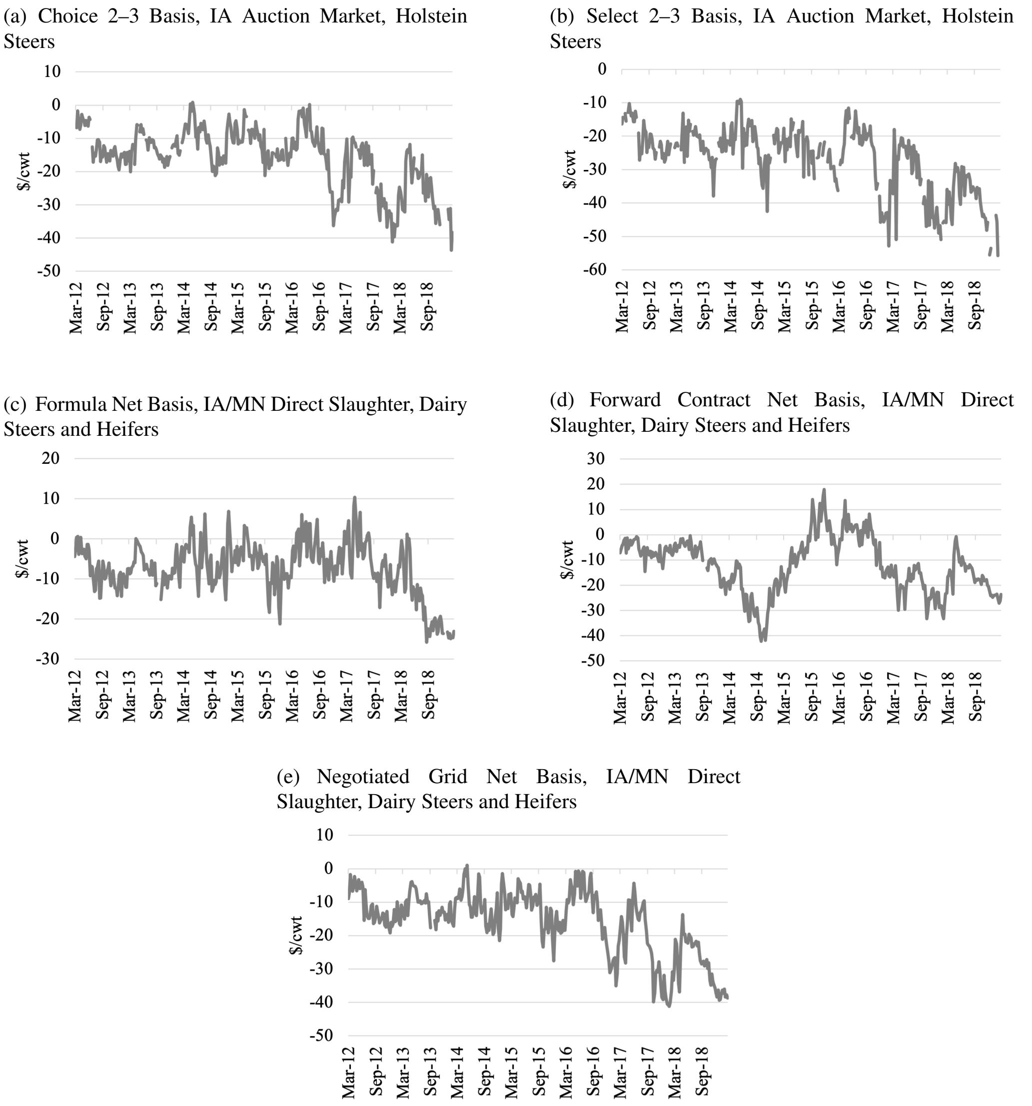

Figure 1. Fed Dairy Cattle Basis by Sale Type, Week Ending March 25, 2012–March 16, 2019

We convert prices to a live-weight equivalent to obtain consistent formula, forward contract, and negotiated grid price series, both within sale type and with that of CME live cattle futures.[8] We also convert weights to a live-weight equivalent. We difference each price series with nearby CME live cattle futures prices to create three direct slaughter basis series. Figure 1 shows the three direct slaughter basis series, which have fewer missing observations than the two auction market basis series. Further, the direct slaughter basis series vary across sale type. The negotiated grid basis appears similar to the auction basis series, while the formula basis widens later in the time series. Forward contract basis widens earlier and seemingly follows a different pattern that may follow from the unique details of forward contract sales.

[8] On majority, only dressed prices are reported by the USDA-AMS for formula, forward contract, and negotiated grid sales. We convert dressed prices to live prices using the reported dressing percentages. In the infrequent cases when both dressed and live sales are reported, we calculate weighted averages of the converted dressed price and live price to create a single live-weight price.

In a forward contract for fed cattle, the CME live cattle futures price and basis are the variables that influence the final base price the seller receives for the cattle, and the two main types of forward contracts—a basis contract and a flat price (or forward price) contract—treat these variables somewhat differently. For a basis contract, cattle are committed to the packer when the basis bid is agreed upon, but the price is not discovered or agreed upon (Ward and Koontz, 2002). The final price remains undetermined if the seller waits until some later date to "lock in" the futures price. After the seller contacts the buyer and picks the futures contract price, then the selling price is discovered by default. In a flat price or a forward price contract, the buyer offers a fixed price for the animals that are to be delivered in the future. How the buyer develops the guaranteed price varies but can be based on a forward futures price and a historical or expected basis. The packer or entity on the buy side of a forward contract can cover their price risk in the contract by hedging the cattle in the futures market. Altogether, these provisions likely explain the different pattern for forward contract basis.

Each weekly basis series cover the 7-year period beginning with the week ending March 25, 2012, the week for which Iowa/Minnesota weekly direct slaughter cattle reports first became available. Ideally, the data would include transaction characteristics (e.g., lot size, location) so we could estimate the effects of these possible basis determinants by including them as variables in the model; however, such granular data is not available. Thus, the weekly auction market and direct slaughter price data is compiled in the sense that it is a summary of multiple transactions over the course of 1 week at multiple locations within the Iowa (auction) and Iowa–Minnesota (direct) reporting regions. This, in turn, means that our only sale characteristic is the weighted average of cattle weight for all relevant sales during a particular week. That said, our data is disaggregated in the sense that the two auction market and three direct slaughter basis series provide more detail compared to an aggregately reported basis. This detail subsequently allows us to estimate factors affecting the fed dairy cattle basis by sale type, something we could not do using aggregate data. Simply comparing basis series by sale type shows the problematic nature of weighted averages. For instance, a weighted average basis for direct slaughter sales would strongly resemble the forward contract basis due to the high volume of dairy steer and heifer forward contract sales. This demonstrates a broader point—a weighted average fed dairy cattle basis akin to the price spread in the *National Weekly Fed Cattle Comprehensive* report may be at best a general barometer since a weighted average masks many of the characteristics (e.g., differences in time, quality, location, and marketing method) that may be important to basis formation.

In addition to sale characteristics, previous studies find that market conditions explain much of the variability in transaction prices within a particular market (see Schulz, Schroeder, and Ward, 2011, for references to the literature). Seasonality is expected to have varied effects on basis depending on seasonal supply and demand conditions, which is accounted for by using monthly indicator variables. We utilize data on the Choice–Select spread, the fresh 50% lean beef price, and the value of steer by-products (drop value) for the relevant 7 years. We calculate the Choice–Select spread by differencing the weekly boxed beef cutout value for choice and select as calculated by the LMIC from USDA Market News report LM_XB403, *National Daily Boxed Beef Cutout and Boxed Beef Cuts—Negotiated Sales—Afternoon*. Parcell, Schroeder, and Dhuyvetter (2000) find that the Choice–Select spread strengthened fed cattle basis. Like Burdine (2003), we include variables to capture the impacts of both ground beef prices and drop value. We obtain data for the fresh 50% lean beef price from USDA Market News report LM_XB460, *National/Regional Weekly Boneless Processing Beef and Beef Trimmings–Negotiated Sales*. USDA Market News report NW_LS441, *USDA By-Product Drop Value (Steer) FOB Central U.S.*, provides drop value data.

We use national fed cattle slaughter capacity utilization as a proxy for state or regional slaughter capacity utilization and calculate it by dividing the national weekly steer and heifer slaughter by the total fed cattle slaughter capacity.[9] In particular, we convert national annual fed beef packer steer and heifer slaughter capacity, as estimated by Sterling Marketing Inc. (Vale, Oregon), into a weekly figure by dividing it by 52 weeks (or 53 weeks where appropriate). We use this weekly measure of slaughter capacity as the denominator. The numerator is the weekly federally inspected steer and heifer slaughter from USDA Market News report SJ_LS711, *Actual Slaughter Under Federal Inspection*, compiled by the LMIC. Steer and heifer slaughter capacity utilization tends to be higher during summer months as demand for (supply of) beef (cattle) seasonally increases. Additionally, since the beginning of 2016, fed cattle slaughter capacity utilization has trended upward.

While, to our knowledge, the effect of packing plant capacity utilization on fed dairy cattle basis has not previously been modeled, it does parallel the approach taken by Parcell, Schroeder, and Dhuyvetter (2000), who considered captive supplies and its impact on live cattle basis. Packing plant capacity utilization is a similar measure of leverage as captive supplies and follows the approach of Schulz, Schroeder, and Ward (2011), who consider packing plant capacity utilization and its impact on fed cattle price spreads.

Structural Break Estimation

One approach to modeling the basis for fed dairy cattle in the presence of a suspected structural break is to include, in addition to sale and market condition variables, an indicator variable into the reduced form model to represent Tyson's exit from the fed dairy cattle market. This approach, however, has several drawbacks. First, as mentioned previously, the exact date of Tyson's exit is unknown, making choosing a date for the indicator variable problematic. Second, the manner in which market fundamentals impact the basis could be different after Tyson's exit in comparison to before, and a simplistic indicator variable formulation does not allow for the possibility of this parameter instability. Interacting the indicator variable with cattle weight and market condition variables accounts for this potential parameter instability, but choosing a date is still problematic.

Structural break tests that endogenously determine unknown break dates have become increasingly popular, and several recent studies utilize this type of test to identify structural breaks in agricultural price series. Rude, Felt, and Twine (2016) use the Bai–Perron (1998; 2003) test, for the detection of multiple structural breaks. This test allows identification of one or more structural breaks at unknown dates in U.S. import demand for Canadian feeder hogs, slaughter hogs, and pork due to the implementation of country-of-origin labeling (COOL) legislation. Twine, Rude, and Unterschultz (2016) use the same Bai–Perron test to look for structural breaks in U.S. import demand for Canadian feeder cattle, fed cattle, and beef as a result of COOL. In both cases, the authors argue that the legislation's long and complicated history makes simply fixing a structural break at the September 2008 implementation inappropriate, and instead they favor the use of a structural break test for an unknown break date. Similarly, Tonsor and Mollohan (2017) examine the U.S. feeder calf market using the Bai–Perron test to determine possible structural breaks with unknown dates in calf prices, yearling prices, and calf–yearling price spreads. Recently, in an evaluation of animal welfare laws in California, Mullally and Lusk (2018) use the Bai–Perron test to identify structural breaks in a time series of egg-laying hen inventory.

In our case, we use the supremum-likelihood ratio (sup-LR) test for a single unknown structural break introduced by Andrews (1993) to identify the hypothesized structural break date

[9] A reviewer aptly points out that state or regional fed cattle slaughter capacity utilization may be a more appropriate measure. We agree. However, we are unaware of any reported value or robust estimate of state or regional fed cattle slaughter capacity. Historical slaughter estimates can be useful as a rough proxy for capacity utilization. For example, we can approximate regional slaughter capacity utilization as the weekly total cattle slaughtered in Regions 5 and 7, as reported by the USDA-NASS, divided by the weekly maximum total cattle slaughter during the same quarter of the year prior. Models were estimated using alternative regional fed cattle slaughter capacity utilization specifications, and the results regarding existence and date of a structural break and coefficient estimates are relatively robust.

Table 1. Structural Break Test Results

	Sup-LR		Bai–Perron	
Basis Series	**Statistic**	**Break Date**	**Break Date**	**Break 95% C.I. Dates**
Auction				
Choice 2–3	350.09***	12/3/2016	12/3/2016	[11/19/2016, 12/24/2016]
Select 2–3	248.61***	12/3/2016	12/3/2016	[11/12/2016, 12/31/2016]
Direct				
Formula	185.83***	8/12/2017	8/12/2017	[8/5/2017, 8/19/2017]
Forward contract	365.46***	12/3/2016	12/3/2016	[11/12/2016, 12/24/2016]
Negotiated grid	334.46***	11/26/2016	11/26/2016	[11/5/2016, 12/17/2016]

Notes: Reported structural break dates are the first date of Regime 2. Triple asterisks (***) indicate rejection of the null hypothesis of no structural break at $p = 0.0000$. The Bai–Perron break date is shown for the restricted case of testing for one structural break. When the Bai–Perron test is unrestricted and allows for multiple structural breaks, the BIC statistics indicate a single break for each basis model (as reported above), except for the forward contract basis model, where four breaks are identified at 1/18/2014, 3/28/2015, 5/14/2016, and 6/3/2017. Similarly, under the unrestricted Bai–Perron test, the LWZ criteria indicate a single break for each basis model (as reported above), except for the formula basis model where 0 breaks are identified.

endogenously.[10] We implement the sup-LR test using explanatory variables that we hypothesize impact basis in the previously detailed hedonic framework, meaning that potential changes in market fundamentals and/or their impacts on basis are critical to identification of the structural break. Hence, our approach solves the issue of not knowing the exact date of Tyson's exit in a manner that allows for, and even relies on, parameter estimate changes across regimes. Table 1 shows results from the sup-LR test, with the test statistic for each basis series leading to the rejection of the null that there is no structural break. Since we are concerned primarily with identifying one structural break and its consequences, we opt to use this test as it is designed specifically to test for a single unknown structural break. Some of the equations may actually have more than one structural break, but the Bai–Perron test chooses the exact same break as the sup-LR test when it is restricted to only allow one break. Further, both the Bayesian information criterion (Yao, 1988) and the Liu–Wu–Zidek (1997) information criterion indicate the existence of only one structural break in four out of the five basis series equations we test. Given this robustness, we proceed with the sup-LR test.

Unit root tests are typically conducted as background before implementing structural break tests. Like Tonsor and Mollohan (2017), we focus on the dependent variables of interest (i.e., each basis series), for which a battery of unit root tests provides contradictory evidence regarding the presence of unit roots. Based on logic and previous empirical work (e.g., Parcell, Schroeder, and Dhuyvetter, 2000), we have a healthy skepticism about the existence of unit roots in basis. The opportunity for arbitrage prevents basis levels from widening explosively. Further, if basis did have unit roots, it would be the case that the best forecast for basis in the future would be the current basis. If this were true, this methodology would be promoted by extension programs and other purveyors of basis information. Clearly, this is not the case, confirming our intuition. As such, similar to Rude, Felt, and Twine (2016), we proceed assuming our dependent variables of interest are stationary.

For the auction market basis, the sup-LR test identifies a structural break for the week ending December 3, 2016, for both Choice 2–3 and Select 2–3 basis, the timing of which corroborates the general time frame indicated by popular press coverage. Variation in the identified break date for the direct slaughter basis series reflects the various idiosyncrasies of the sale types. For instance, long-term formulas are standing agreements between cattle producers and beef packers that aid in supply chain management for both parties, while short-term formulas are not rooted in the same long-term, supply-chain-based considerations (Koontz, 2015). These marketing arrangement agreements are negotiated periodically and can have very long durations (Muth et al., 2005). This likely explains

[10] Specifically, we use the sup-LR test to identify an unknown structural break in equation (1) for each fed dairy cattle basis series. We use a trimming rate of 15%.

the later structural break (week ending August 12, 2017) for formula net basis. For negotiated grid net basis, we identify a structural break for the week ending November 26, 2016, which means the change in negotiated base prices came shortly before a notable change in premiums/discounts or adjustments to base prices that occurred between the weeks ending January 16 and January 23, 2017 (U.S. Department of Agriculture, 2017). Based on individual packers' buying programs, the 5-area weighted average maximum dairy-type discount changed from \$9/cwt to \$14/cwt over this period.

Forward contract net prices report what packers are paying net for cattle slaughtered in the reporting week, but these prices do not necessarily reflect that week's fed cattle market. In other words, reported forward contract prices embody expectations about the current market at the time the contract price was "locked in," but this can occur several months before actual delivery at a date not recorded in LMR data (Schroeder and Tonsor, 2017). The delay between entering into forward contracts and delivery (and therefore reporting) means that our finding of a structural break for the week ending December 3, 2016, for the forward contract fed dairy cattle basis aligns with the *Daily Livestock Report* (Steiner Consulting Group, 2016) reporting that Tyson signaled to cattle feeders that it would not be renewing Holstein contracts several months prior.

Hedonic Model Estimation and Results

Using the structural breaks identified by the sup-LR test, we split our data into two regimes. Specifically, the weeks before the break comprise Regime 1, and the break-week date and weeks after the break comprise Regime 2. In each regime, we model the basis (2 regimes x 5 fed dairy cattle basis series = 10 total basis series) as

$$(2) \qquad Basis_t = Cash_t - Futures_t = f\left(Wt_t,\ Wt_t^2,\ DMON_t,\ Ch\_Sel_t,\ FRSH50_t,\ Drop_t,\ Util_t\right),$$

where t refers to a specific week; *Cash* and *Futures* specify price series; Wt and Wt^2 specify weight and weight squared, respectively; *DMON* represents monthly dummy (indicator) variables; *Ch_Sel* designates the choice-select spread; *FRSH50* indicates the fresh 50% lean beef price; *Drop* denotes the value of steer by-products; and *Util* indicates national fed cattle slaughter capacity utilization. Table 2 provides select summary statistics for the basis series and the explanatory variables used.

Table 3 reports empirical results for the auction market and direct slaughter basis models. Pairs of columns report generalized method of moments coefficient estimates and corresponding Newey–West standard errors for each time series before and after the structural break.[11] Coefficient estimates indicate the \$/cwt change in basis resulting from a one-unit change in the corresponding explanatory variable. Positive coefficients represent a strengthening/narrowing of basis, meaning the fed dairy cattle price is increasing relative to the CME live cattle futures price; negative coefficients indicate a weakening/widening of basis.

Similar to Schulz, Boetel, and Dhuyvetter (2018), testing for parameter instability across regimes entails estimation of a single model with all observations from both regimes and requisite interactions as Clogg, Petkova, and Haritou (1995) outline.[12] Many of the coefficient estimates are statistically different at a p-value < 0.10 level (bold numbers in Table 3) indicating these explanatory variables have differing impacts in Regimes 1 and 2.

We report the model-predicted basis for each regime, which we calculate by averaging the weekly predicted basis for each series using the weekly data and regime-specific coefficients. As

[11] We perform Godfrey Lagrange multiplier tests (Godfrey, 1978a,b) on each regime, which indicate the presence of autocorrelation in nearly every series. Further, White's (1980) test for heteroscedasticity rejects the null of homoskedasticity at a level of $p < 0.0001$ in every series. Therefore, we use Newey–West standard errors with four lags.

[12] Specifically, we add to the model an indicator variable that takes a value equal to 1 for the entirety of the second regime and 0 in the first regime, as well as interactions between this indicator variable and the other explanatory variables. This gives us a test for whether the differences between the first and second regime parameter estimates are statistically different from 0.

Table 2. Select Means of Weekly Data, Week Ending March 25, 2012–March 16, 2019

Basis Series		*N*	Basis ($/cwt)	Cash ($/cwt)	Futures ($/cwt)	Hd (number)	Wt (lb)	Ch_Sel ($/cwt)	FRSH50 ($/cwt)	Drop ($/cwt)	Util (%)
Auction market sales											
Choice 2–3	Regime 1	231	−11.21	122.63	133.83	105.95	1,432.45	9.40	84.25	13.51	82.50
			(4.96)	(16.82)	(16.48)	(60.19)	(41.41)	(4.96)	(29.25)	(1.75)	(5.13)
	Regime 2	111	−24.83	91.85	116.68	77.14	1,444.79	11.21	77.84	10.41	86.98
			(8.37)	(8.22)	(6.95)	(51.43)	(50.44)	(6.61)	(28.75)	(1.07)	(4.78)
Select 2–3	Regime 1	215	−21.87	112.04	133.91	38.16	1,323.29	9.46	85.14	13.57	82.91
			(5.62)	(16.19)	(16.75)	(25.75)	(52.40)	(4.80)	(29.65)	(1.76)	(4.61)
	Regime 2	109	−37.30	79.23	116.53	30.90	1,307.81	11.31	77.58	10.39	86.98
			(8.82)	(9.04)	(6.86)	(27.65)	(60.97)	(6.63)	(28.99)	(1.07)	(4.91)
Direct slaughter sales											
Formula	Regime 1	277	−5.46	126.54	132.00	797.90	1,410.91	9.85	85.84	13.30	82.55
			(5.05)	(16.31)	(16.14)	(433.89)	(30.57)	(5.62)	(31.38)	(1.74)	(5.64)
	Regime 2	80	−13.11	102.44	115.55	730.30	1,395.82	10.60	69.21	9.78	87.22
			(7.68)	(8.60)	(7.40)	(536.20)	(55.86)	(5.84)	(14.20)	(0.64)	(5.66)
Forward contract	Regime 1	241	−8.84	125.03	133.87	1,936.28	1,376.04	9.41	84.21	13.52	82.15
			(11.28)	(10.29)	(16.37)	(1,432.06)	(35.68)	(4.96)	(29.14)	(1.75)	(5.70)
	Regime 2	120	−18.27	98.69	116.96	3,155.11	1,406.05	11.14	76.96	10.36	86.64
			(6.59)	(4.24)	(7.14)	(1,234.47)	(23.67)	(6.71)	(28.99)	(1.09)	(5.31)
Negotiated grid	Regime 1	240	−10.94	123.03	133.97	972.84	1,397.32	9.38	84.37	13.53	82.16
			(5.14)	(16.04)	(16.33)	(440.21)	(33.05)	(4.95)	(29.10)	(1.75)	(5.71)
	Regime 2	121	−26.08	90.81	116.90	833.09	1,425.92	11.18	76.71	10.37	86.59
			(8.99)	(8.20)	(7.14)	(421.78)	(32.26)	(6.70)	(29.00)	(1.09)	(5.31)

Notes: Numbers in parentheses are standard deviations.

Table 3. Regression Results of Fed Dairy Cattle Basis Models across Regimes

	Choice 2–3		Select 2–3		Formula		Forward Contract		Negotiated Grid	
	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
Intercept	**309.05***	**−239.04*****	−171.02	−427.04**	**357.84**	**−518.56****	**724.04***	**−2,828.65*****	−549.12	−681.07
	(184.49)	**(61.23)**	(147.77)	(198.04)	**(228.88)**	**(220.74)**	**(433.79)**	**(980.62)**	(376.91)	(763.53)
Wt	**−0.47***	**0.23*****	0.17	0.50*	**−0.56***	**0.57***	**−0.98**	**3.95*****	0.73	0.85
	(0.26)	**(0.086)**	(0.23)	(0.29)	**(0.33)**	**(0.32)**	**(0.63)**	**(1.39)**	(0.53)	(1.06)
Wt^2	**1.7E-04***	**−8.6E-05*****	−5.7E-05	−1.9E-04*	**2.0E-04***	**−2.1E-04***	**3.5E-04**	**−1.4E-03*****	−2.6E-04	−3.0E-04
	(8.9E-05)	**(3.0E-05)**	(8.6E-05)	(1.1E-04)	**(1.2E-04)**	**(1.2E-04)**	**(2.3E-04)**	**(4.9E-04)**	(1.9E-04)	(3.7E-04)
Feb	0.40	0.66	−0.39	0.25	1.37	0.77	−2.93	0.80	0.98	−0.36
	(1.44)	(1.50)	(1.51)	(2.10)	(1.48)	(1.53)	(1.86)	(2.38)	(1.62)	(1.84)
Mar	1.48	4.82**	0.18	2.58	1.93	5.34*	0.75	5.29**	2.27	4.50***
	(2.08)	(2.14)	(2.16)	(2.11)	(1.85)	(2.79)	(2.27)	(2.31)	(1.99)	(1.63)
Apr	2.95	6.14***	**1.62**	**7.38*****	4.60***	7.70***	**2.66**	**9.14*****	5.37***	7.17***
	(2.02)	(1.94)	**(1.56)**	**(2.47)**	(1.72)	(1.99)	**(1.71)**	**(2.07)**	(1.85)	(2.19)
May	**8.94*****	**17.82*****	**7.68*****	**13.10*****	**7.38*****	**18.38*****	**3.76***	**22.05*****	**8.36*****	**17.14*****
	(1.85)	**(1.89)**	**(1.72)**	**(2.37)**	**(1.67)**	**(1.89)**	**(1.97)**	**(3.00)**	**(1.83)**	**(2.94)**
Jun	**5.37*****	**15.52*****	**3.54***	**11.71*****	4.55**	8.31***	**0.43**	**13.61*****	**6.81*****	**16.43*****
	(2.00)	**(1.98)**	**(1.95)**	**(2.64)**	(2.00)	(1.79)	**(2.20)**	**(2.73)**	**(2.20)**	**(2.81)**
Jul	**4.27****	**14.37*****	**3.92****	**14.51*****	**2.58**	**8.26*****	**0.12**	**11.66*****	**4.66****	**16.33*****
	(1.97)	**(1.27)**	**(1.64)**	**(1.55)**	**(1.62)**	**(1.86)**	**(2.11)**	**(1.92)**	**(1.89)**	**(1.44)**
Aug	**2.40**	**15.34*****	**2.26***	**16.04*****	**2.41**	**7.68*****	**−2.81***	**12.63*****	**3.93****	**17.99*****
	(1.63)	**(1.49)**	**(1.35)**	**(1.94)**	**(1.80)**	**(1.72)**	**(1.61)**	**(2.33)**	**(1.79)**	**(1.87)**
Sep	**0.020**	**11.82*****	**0.19**	**13.82*****	2.07	2.71*	**−0.40**	**5.55*****	**3.47***	**13.68*****
	(1.81)	**(1.50)**	**(1.80)**	**(1.59)**	(1.89)	(1.49)	**(1.95)**	**(1.56)**	**(1.94)**	**(2.19)**
Oct	**−2.76**	**11.09*****	**−2.33**	**10.30*****	**−1.23**	**4.30*****	−3.74	1.20	**−0.65**	**10.14*****
	(2.02)	**(2.22)**	**(2.24)**	**(2.11)**	**(2.02)**	**(1.52)**	(2.96)	(1.99)	**(2.20)**	**(1.51)**
Nov	**−3.33***	**3.63***	**−4.11****	**3.47**	**−0.57**	**4.19****	−2.05	0.75	−0.52	3.47
	(1.73)	**(1.98)**	**(1.84)**	**(2.41)**	**(1.61)**	**(1.58)**	(3.22)	(3.81)	(1.80)	(3.10)
Dec	**−2.53**	**1.72**	−1.92	2.52	0.54	4.49**	2.95	1.90	1.41	4.17**
	(1.81)	**(1.49)**	(2.17)	(1.83)	(1.80)	(1.77)	(2.26)	(1.91)	(1.99)	(1.98)
Ch_Sel	0.052	−0.018	−0.10	0.16	−0.035	−0.093	−0.056	0.0089	−0.056	0.074
	(0.090)	(0.12)	(0.11)	(0.14)	(0.090)	(0.12)	(0.14)	(0.14)	(0.099)	(0.16)
FRSH50	0.024	0.0071	**−0.028**	**0.027***	0.049***	0.048	**−0.091*****	**−0.18*****	0.022	−0.025
	(0.023)	(0.015)	**(0.028)**	**(0.015)**	(0.015)	(0.033)	**(0.029)**	**(0.027)**	(0.025)	(0.022)
Drop	**−0.21**	**3.34*****	**0.66**	**3.18*****	**−0.60****	**9.76*****	**−4.40*****	**1.87*****	**−0.13**	**4.17*****
	(0.35)	**(0.48)**	**(0.50)**	**(0.43)**	**(0.24)**	**(0.95)**	**(0.62)**	**(0.68)**	**(0.36)**	**(0.45)**
Util	0.077	0.24**	0.27***	0.17	0.19***	0.041	**0.31*****	**0.0054**	**0.24*****	**0.069**
	(0.054)	(0.10)	(0.095)	(0.11)	(0.065)	(0.086)	**(0.067)**	**(0.095)**	**(0.060)**	**(0.080)**
R^2	0.57	0.83	0.48	0.76	0.45	0.89	0.78	0.58	0.50	0.82
Adj. R^2	0.54	0.79	0.43	0.72	0.42	0.86	0.76	0.51	0.47	0.79
RMSE	3.24	3.47	4.05	4.28	3.73	2.55	5.32	4.26	3.61	3.83
Basis	−11.21	−24.83	−21.87	−37.30	−5.46	−13.11	−8.84	−18.27	−10.94	−26.08
Total impact	−13.63		−15.44		−7.65		−9.42		−15.14	
Market impact	0.89		−1.63		1.65		15.41		0.82	
	[−1.09, 2.84]		[−4.68, 1.41]		[−0.018, 3.36]		[11.76, 19.05]		[−1.36, 2.98]	
Procurement	−14.52		−13.81		−9.30		−24.83		−15.96	
impact	[−12.55, −16.49]		[−10.54, −17.02]		[−7.49, −11.13]		[−21.25, −28.40]		[−13.56, −18.34]	

Notes: Numbers in parentheses are standard errors. Single, double, and triple asterisks (*, **, ***) indicate [statistical] significance at the 10%, 5%, and 1% level. Bold pairs of coefficients are statistically different across regimes at $p < 0.10$. Numbers in brackets represent 95% confidence intervals.

expected, the average predicted basis for each regime is the same as the average of the raw basis data for each regime. We report the difference between Regime 1 and Regime 2 model-predicted basis as the average total impact of the structural break. This average total impact is decomposed into the average procurement impact and the average market impact, where the former can be generally interpreted as the impact of Tyson exiting the fed dairy cattle market. Finally, we report various measures of goodness of fit for each model. Importantly, presentation of each model demonstrates the sometimes similar, sometimes heterogeneous, impacts across different fed dairy cattle basis series.

For brevity, we focus the discussion of model results on the negotiated grid basis, which has the second-largest volume in terms of number of head (see Table 2). The forward contract basis series has the largest volume; however, as previously discussed, forward contract basis is representative of fed dairy cattle prices established over a period of time. This basis series is still important as it represents the majority of dairy steer and heifer sales reported by the USDA and provides a summary of the basis of forward contracted cattle slaughtered that week. Negotiated grid sales have similar characteristics to negotiated sales, which the USDA does not report due to no transactions in the Iowa–Minnesota region or confidentiality restrictions, in that the base price is negotiated. Negotiated grid basis results are also somewhat similar to our two auction basis series model results.

Seasonality has a meaningful impact on negotiated grid basis. In general, basis tends to narrow in second- and third-quarter calendar months. When compared to January, basis during May narrows by \$8.36/cwt and \$17.14/cwt in Regime 1 and Regime 2, respectively. Since we show these estimates to be statistically different, seasonality in this case narrows the basis more in terms of \$/cwt in the second regime than in the first. While expressing these changes in absolute dollar terms has merit, interpreting them as a percentage change of model-predicted basis is also instructive, since doing so gives a sense of how much the basis narrows proportionally as a result of seasonality. In this case, seasonality causes a proportionally larger basis narrowing compared to the model-predicted basis before the structural break, with the proportional decrease in the first and second regimes in May being $\$8.36/|-\$10.94| = 0.76$ and $\$17.14/|-\$26.08| = 0.66$, respectively. These results differ by month.

The coefficient estimate for drop value is positive after the structural break. For every \$1/cwt increase in drop value, basis narrows by \$4.17/cwt. The result for Regime 2 is in line with Burdine (2003), who finds that drop value has a positive effect on finished Holstein steer prices. National fed cattle slaughter capacity utilization has a positive impact on negotiated grid basis before the structural break. A 1-percentage-point increase in capacity utilization increases basis by \$0.24/cwt in Regime 1. Intuitively, lower capacity utilization in the first regime, when compared to the second regime, reflects the reality that fed cattle supplies are tighter in the first regime. Narrower basis when utilization is low is consistent with the expectation that beef packers are likely bidding more aggressively to procure cattle, regardless of breed, to fulfill beef contracts and to offset fixed operation costs. The biggest takeaway from the capacity utilization results, however, is its relatively small impact. Before the structural break, a 10-percentage-point increase (decrease) in capacity utilization only translates to a \$2.40/cwt increase (decrease) in the basis for negotiated grid dairy steers and heifers. The coefficient on fed cattle slaughter capacity utilization is not statistically significant in Regime 2. This result is consistent across all basis models except for Choice 2–3 Holstein steers at auction.

While the impact of weight is not statistically significant for the negotiated grid basis model, it is significant in several of the other models, which bears some further discussion, especially since the most recent National Beef Quality Audit (2016) ranked weight and size as one of the top six quality challenges. The impact of an additional 1 pound of live weight on Choice 2–3 Holstein steer basis differs across regimes. Because of the squared term in the model specification, the marginal effect of the weight variable is difficult to interpret simply by examining individual coefficients. Therefore, to enhance the interpretation, we use model-predicted basis levels across weights (mean -3 std, mean $+3$ std) to calculate the marginal impact of weight. We hold all other variables at their mean values and monthly indicator variables at the defaults. In Regime 1, basis weakens by \$1.38/cwt as the weighted average of Holstein steer weight increases from 1,308 lb to 1,399 lb and strengthens by \$4.20/cwt as weight increases from 1,399 lb to 1,557 lb. In Regime 2, basis strengthens by \$0.10/cwt as weight increases from 1,293 lb to 1,328 lb and weakens by \$6.19/cwt as weight increases from 1,328 lb to 1,596 lb.

Typically, cattle that meet packers' preferred weight specifications realize higher prices (narrower basis) because lightweight cattle reduce slaughter and processing efficiency and heavyweight cattle produce excessively large wholesale products relative to customer preferences (Schulz, Schroeder, and Ward, 2011). However, as our results show, this impact can vary over time. At times of lower cattle numbers and higher prices, like in Regime 1, both feedlots and beef packers have incentives for increased animal weight. The basis–weight relationship is different in Regime 2, however, in that basis weakens at an increasing rate for weights greater than 1,328 lb. Larger fed cattle numbers increase a buyer's incentive to discount heavyweight cattle for a variety of reasons. Increases in cattle slaughter weight have had a direct effect on the size of many beef cuts (Maples, Lusk, and Peel, 2018). Larger steak sizes, for example, pose a concern for the beef industry as it becomes more difficult to fabricate consistently sized retail cuts and profitably meet the expectations of foodservice and retail consumers (e.g., Behrends et al., 2009; Leick et al., 2012).

Table 3 shows the decomposition of the average total impact on fed dairy cattle basis, by sale type, into the average procurement impact and the average market impact. The average procurement impact is simply the mean of the forecast errors of the Regime 2 weekly forecasts calculated using Regime 2 data and Regime 1 parameter estimates. Assuming White's (2006) "conditional independence given predictive proxies" (CIPP) holds, this average procurement impact is the estimated causal effect of procurement changes in the packing industry on fed dairy cattle basis. Specifically, under CIPP, the average procurement impact is commonly referred to as the average effect of treatment on the treated. White's framework is well suited for the estimation of the impacts of a wide variety of natural experiments, from business decisions to public policy changes and new technologies. For example, White's motivational example is that of the formation of a cartel, while Mullally and Lusk (2018) invoke CIPP in their identification of the average policy impact of animal welfare laws in California. This methodology is considered to be superior to a generally inconsistent simplistic indicator variable approach for estimating the average effect of treatment on the treated (i.e., average procurement impact) (White, 2006). We calculate the 95% confidence interval for average procurement impact following methods described in Mullally and Lusk. In no case does the confidence interval include 0, indicating that procurement changes are estimated to have had a statistically significant negative impact on basis (i.e., widening of basis) in every model.

Table 3 also shows the average market impact, which we find by differencing the average of all Regime 2 weekly forecasts and the average of the Regime 1 basis. Since we construct these Regime 2 weekly forecasts using Regime 1 parameters, we can loosely interpret the average market impact as the average impact that changes in market fundamentals alone would have had on basis had Tyson not exited the fed dairy cattle market. Importantly, average procurement impact and average market impact necessarily add up to the average total impact. For forward contract basis, the 95% confidence interval shows that the average market impact is different from 0. This means that observed market fundamentals, on average, would have actually worked to narrow the forward contract basis in the absence of changes in procurement practices.

In addition to average impacts over the entire Regime 2 period, it is also important to consider weekly impacts. Figure 2 shows actual basis data and the Regime 2 weekly forecasts calculated using Regime 2 data and Regime 1 parameter estimates. Figure 2 resembles figures appearing in Rude, Felt, and Twine (2016) and Mullally and Lusk (2018). Across the various basis series, actual basis nearly always falls outside of the 95% forecast confidence interval, indicating that for most weeks the change in packer procurement of fed dairy cattle had a negative impact on basis. This, in turn, has implications for weekly fed dairy cattle basis forecasts that use historical basis data.

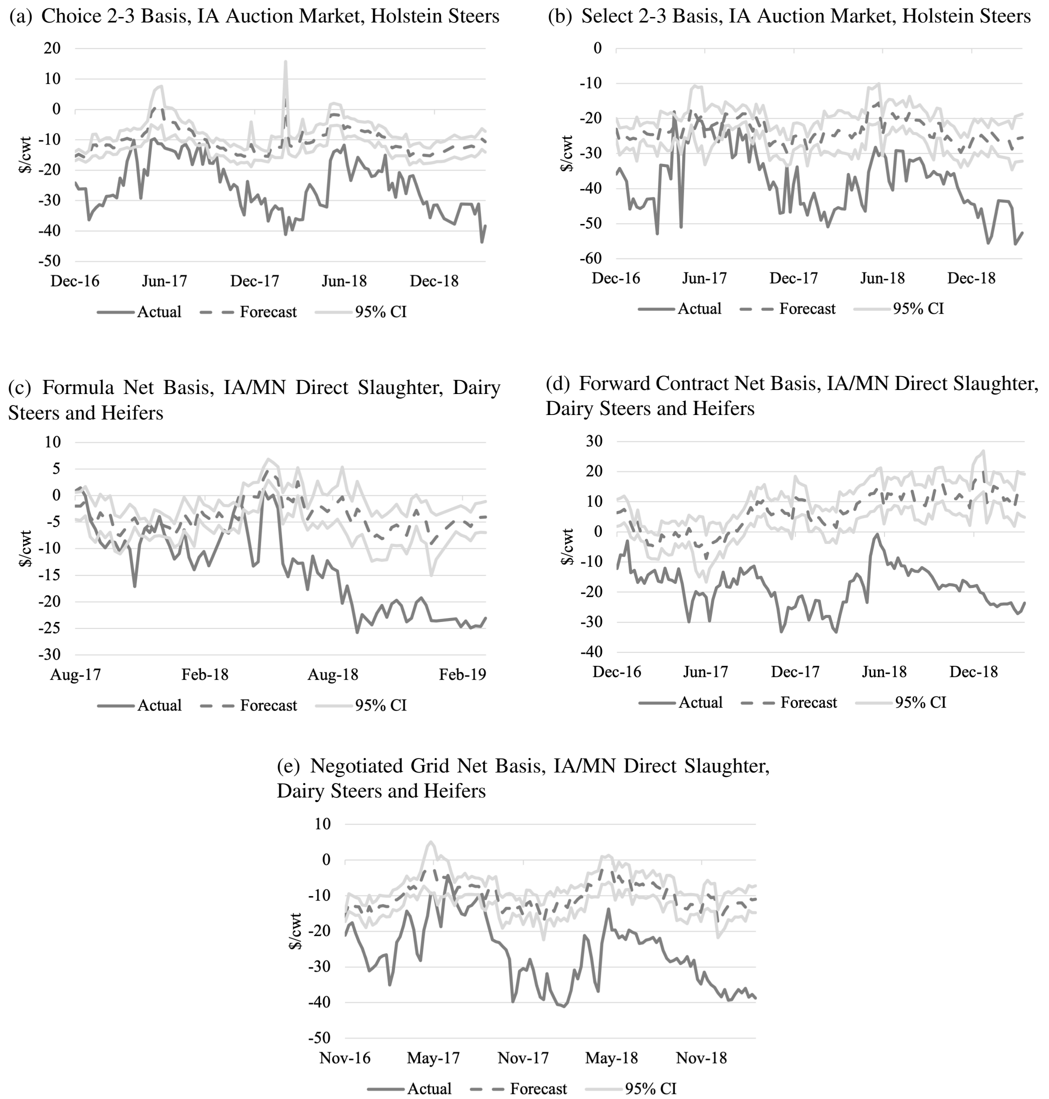

Figure 2. Actual and Forecasted Regime 2 Fed Dairy Cattle Basis by Sale Type

Assessing Basis Forecasts

Basis forecasts are useful when estimating expected sale prices at the conclusion of a futures or options hedge, when evaluating a forward contract bid, and when forecasting cash prices. A basis that is weaker than expected decreases the selling price. This could occur if longer moving averages were used in formulating basis expectations but a structural break occurred in basis unbeknownst to the user. Purveyors of basis information and producers alike can use structural break findings, basis impact estimates, and basis forecasting accuracy assessments to better inform management and marketing decisions.

Previous studies have shown that longer historical moving averages typically perform better as forecasts than shorter moving averages or the previous year's basis. Tonsor, Dhuyvetter, and Mintert (2004) show that the optimal length of a moving average basis forecast for live cattle in Western Kansas over the period 1981–2002 is 4 years, and the optimum length for 1998–2002 is 2 years. Such results are intuitive. Longer moving averages can counterbalance large temporary deviations from long-run basis means. While increasing the number of years included in a moving average decreases the impact of any single deviation, the benefit in terms of forecast accuracy of including additional years decreases quickly (Hatchett, Brorsen, and Anderson, 2010). Further, including more years in a moving average increases the likelihood that a structural break is contained in the series, which can impact accuracy. This quandary causes antecedent studies to conclude that longer moving averages are generally better basis forecasts unless there has been a structural break, in which case shorter moving averages are better forecasts (Taylor, Dhuyvetter, and Kastens, 2006; Hatchett, Brorsen, and Anderson, 2010).

Recall that fed dairy cattle are marketed at auctions and through various types of direct sales. Although producers should maintain their own historical basis data for the markets that they customarily use and for the characteristics of the cattle that they market, historical basis data are often provided by university extension programs, brokerage firms, market analysts, and others. Historical basis information is usually summarized in a table, which displays the average or expected basis for the period based on a moving average of a select number of years (e.g., 3-year, 5-year, etc.). These basis tables typically present historical basis data without commentary regarding or even consideration of forecast accuracy, even when structural breaks have occurred. For example, a 3-year average may always be presented in a table. Admittedly, precisely identifying structural breaks and estimating their impacts is rarely easy and often has to be done subjectively in the short run, even for professionals who provide basis data. Even so, historical basis information should be accompanied by a discussion of which forecasts are optimal to help prevent producers who typically use historical averages for basis expectations from making erroneous decisions.

To determine the optimal number of years for a moving average basis forecast for the fed dairy cattle market, we apply the methods of Tonsor, Dhuyvetter, and Mintert (2004) and Taylor, Dhuyvetter, and Kastens (2006) to identify which forecasts, on average, have the smallest absolute errors for each sale type. The mean absolute error (MAE) is calculated for out-of-sample weekly basis forecasts of 1, 2, and 3 years in length for each basis series.[13] A smaller MAE means that, on average, a forecast is more accurate than a forecast with a larger MAE. To identify which MAEs are statistically different from each other for a given sale type, and thus to identify the most accurate forecast method, pairwise *t*-tests are performed.

Four year-long periods are constructed for each basis series. Annual periods correspond to mid-March to mid-March of the following year beginning in 2015, 2016, 2017, and 2018.[14] Missing basis observations prevent calculation of moving average forecasts and absolute errors for some weeks. When one or more absolute errors was missing for a week in a given basis series, that week was not considered for that series regardless of year. For instance, the absolute error for the 1-year forecast for the 14th week in the March 24, 2018–March 16, 2019, period was missing for the Choice 2–3 Holstein steer basis series, so the 14th week was dropped for all annual periods in that series. This was done to maintain consistent sample sizes across all four year-long periods, which allows for testing forecast accuracy across time.[15]

Results for the alternative moving-average forecasts are summarized in Table 4. Some general patterns emerge. Consider the top panel of Table 4, which shows the MAEs for Choice 2–3 basis.

[13] The first week in each year is set at the week preceding the first Saturday in January. Subsequent weeks are assigned an order based on the first week. All years in the dataset have 52 weeks except for 2016, which has 53 weeks. For 2016, a weighted average is created of basis weeks 52 and 53 by using the number of head reported for each week.

[14] Calculating a forecast error for an n-year average necessitates n + 1 years of data. Previous studies considered moving average forecasts of 4 years or more in length. However, given that the direct slaughter cattle reports used in this study first became available in March 2012, 3 years is the longest moving average that allows for calculation of absolute errors for four full year-long periods. Depending on the location of the structural break, this provides roughly 2 years of weekly basis data before and 2 years after the structural break. Respectively, the four year-long periods are for weeks ending March 21, 2015–March 12, 2016, March 19, 2016–March 18, 2017, March 25, 2017–March 17, 2018, and March 24, 2018–March 16, 2019.

[15] Ancillary to determining the optimal number of years to include in a moving average forecast (i.e., making comparisons across rows in Table 4) is assessing forecast performance over time (i.e., making comparisons down rows in Table 4). Consistent sample sizes between annual periods allows for both assessments.

Table 4. Mean Absolute Errors of Fed Dairy Cattle Basis by Forecast Method and Forecast Period ($/cwt)

			MAE by Forecast Method		
Transaction Type	**Forecast Period March to March**	**Sample Size**	**3-Year**	**2-Year**	**1-Year**
Choice 2–3	2015–2016	40	2.48[a]	3.15[b]	4.01[c]
	2016–2017	40	5.73[a]	6.13[b]	5.53[a,b]
	2017–2018	40	10.17[a]	9.35[b]	8.90[a,b]
	2018–2019	40	10.33[a]	8.65[b]	5.91[c]
Select 2–3	2015–2016	33	4.07[a]	3.95[a]	4.99[b]
	2016–2017	33	6.37[a]	6.33[a]	6.09[a]
	2017–2018	33	10.36[a]	9.30[b]	9.32[a,b]
	2018–2019	33	11.64[a]	10.15[b]	7.86[c]
Formula	2015–2016	47	3.04[a]	3.10[a]	3.84[b]
	2016–2017	47	4.60[a]	4.81[a]	5.11[a]
	2017–2018	47	3.92[a]	4.16[a]	5.66[b]
	2018–2019	47	11.99[a]	12.77[b]	11.76[a]
Forward contract	2015–2016	51	13.81[a]	16.96[b]	22.42[c]
	2016–2017	51	10.51[a]	13.20[b]	11.85[a,b]
	2017–2018	51	11.71[a]	18.84[b]	18.83[b]
	2018–2019	51	8.31[a]	5.06[b]	5.85[b]
Negotiated grid	2015–2016	51	3.45[a]	3.76[a]	4.79[b]
	2016–2017	51	6.60[a]	6.77[a]	5.70[b]
	2017–2018	51	11.96[a]	10.91[b]	10.58[b]
	2018–2019	51	12.09[a]	10.15[b]	6.27[c]

Notes: MAEs are a measure of, on average, how much forecasts differ from the actual value. Hence, MAEs are a measure of forecast accuracy, with more accurate forecasts having smaller MAEs than less accurate forecasts.
[a,b,c]Values within the same row with unique superscripts differ $p < 0.10$ according to pairwise paired t-tests. In some cases, MAEs that are closer in magnitude produce t-statistics that are smaller than MAEs that are relatively more different. This is due to comparatively larger standard errors following from the differences between forecasts of different lengths, which reduce the t-statistic.

The 3-year moving average weekly forecast had the smallest MAE for 2015–2016, while weekly forecasts using the previous year's basis had the largest MAE. Conversely, using only the preceding year's basis resulted in the lowest MAE in 2018–2019, while the largest MAE resulted from the 3-year moving average forecast. In fact, the 1-year moving average forecast on average has an absolute error that is nearly $4.50/cwt less than that for the 3-year moving average forecasts, which translates to roughly $65 per head for a 1,450-pound steer. Similar to Choice 2–3 basis, for every other basis series, longer moving averages (2 or 3 years) on average provide more accurate forecasts than 1-year forecasts in 2015–2016, while in 2018–2019 the previous year's basis on average provides forecasts that are not statistically different or more accurate than 2- and 3-year moving average forecasts.

While results for Select 2–3, formula, forward contract, and negotiated grid basis show a similar pattern in regard to optimal length as Choice 2–3 basis for 2015–2016 and 2018–2019, some variation is present across sale type for 2016–2017 and 2017–2018. For instance, for Choice 2–3 basis, the minimum MAE for 2017–2018 is for the 1-year basis forecast. At the same time, for formula basis, the minimum MAE for 2017–2018 is the 3-year average forecast. This is likely due to differences in the structural break date for the two different series, with the break occurring in formula basis roughly nine months later. That said, for 2017–2018, the minimum MAE for forward contract basis is also the 3-year average forecast even though the structural break for this series was identified to be the same as that for Choice 2–3 basis. This is not the only atypical result for forward contract basis.

Generally speaking, MAEs increase for basis forecasts of all lengths in the years corresponding to the period after the structural break, suggesting basis forecasting using historical averages has become more difficult. This was not found to be the case for forward contract basis, however, as in 2015–2016 and 2016–2017 MAEs were statistically larger than for 2018–2019 for all forecast lengths. There could be several reasons for this, but one explanation could stem from Tyson exiting the fed dairy cattle market. Different packers offer different forward contracts at any given time, and these forward contracts change over time. Recall that there are several nuances to forward contracts including how a buyer develops a guaranteed price in a flat price contract, the agreed-upon basis in a basis contract, and the timing of price discovery. With one fewer major packer offering and entering into forward contracts for fed dairy cattle, the basis or implied basis distribution could have conceivably become narrower providing for greater forecasting accuracy regardless of the number of years used in moving averages. It is also worth noting that the average weekly volume of fed dairy cattle forward contract sales increased by more than 1,000 head per week after the structural break in comparison to before the break. A larger volume of forward contract sales, that are possibly more homogeneous because of one fewer packer, could counterbalance large temporary deviations in basis levels. Further research would be needed to test these hypotheses and if this implication for forecast accuracy has persisted.

Further research is also needed to identify methods to formulate basis expectations and/or to provide alternative sources of basis data to use for forecasts immediately following a structural break. In a year following a structural break, multiyear average forecasts are no longer as accurate, but prior-year data is not yet available, so forecasts on average produce larger errors. Incorporating information regarding current deviations from historical basis is one potential option (Tonsor, Dhuyvetter, and Mintert, 2004; Taylor, Dhuyvetter, and Kastens, 2006), but even such forecasts are still grounded in multiyear averages that may no longer reflect market conditions.

Conclusion

Hedging, forward contracting, and other decisions related to pricing that involve basis expectations necessitate that fed dairy cattle producers have a deep understanding of the factors affecting basis. Inability to accurately account for these factors makes formulating basis expectations more difficult. Our study estimates empirical models to explain the variability in weekly fed dairy cattle basis by marketing method, including auction sales and various types of direct formula, forward contract, and negotiated grid sales. We utilize structural break tests that endogenously choose break dates to identify structural breaks in several fed dairy basis series following the decision by one large packer to exit the fed dairy cattle market. Several conclusions can be drawn from this analysis.

In examining the March 25, 2012–March 16, 2019, period, we find that both sale characteristics and market conditions are important considerations when evaluating fed dairy cattle basis. Namely, marketing method, cattle weight, seasonality, ground beef prices, by-product drop values, and fed cattle slaughter capacity utilization are important basis determinants, although the magnitude and significance of some of these factors change over time. We also find evidence of a structural break in fed dairy cattle basis that corresponds with Tyson exiting the fed dairy cattle market around the end of 2016, which we estimate to have significantly weakened basis. Finally, we demonstrate the viability of conventional wisdom regarding the use of longer moving average basis forecasts before a structural break and shorter moving averages (i.e., 1-year forecasts) after a structural break. This highlights the importance of providing context to historical basis tables, especially when a structural change has occurred.

The fed dairy cattle sector—and the cattle industry in general—needs to be prepared to identify and react to future structural changes. Burdine (2003) suggests Holstein steer prices often respond first to changes in the cattle market and therefore serve as a pulse of the cattle industry. The presence of structural change in the fed dairy cattle market is perhaps indicative of wider conditions that do not seem directly relevant until a major event occurs. Identifying when and why these issues exist and quantifying the impacts is critically important for cattle producers facing volatile prices and persistently tight margins. Although market participants cannot individually affect the forces that drive the cattle market, understanding how varying market conditions affect basis and basis forecasting accuracy can aid in management and marketing decisions.

[First submitted October 2019; accepted for publication July 2020.]

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