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RESEARCH ARTICLE

Describing Variation in Formula Base Prices for U.S.-Fed Cattle: A Hedonic Approach

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Abstract

The United States Department of Agriculture Agricultural Marketing Service (USDA AMS) began publishing formula base price information in August 2021. Considerable variation in the types of cattle priced via formula has raised questions about the level of base price transparency that can be gleaned from formula base price reports. This study employs 6 years of transactions to estimate hedonic models assessing the capability of existing data to describe variation in formula base prices. Results suggest factors beyond those reported to USDA AMS by packers influence base prices. We offer suggestions for improved data collection to make hedonic modeling of base prices more effective for reporting market information.

Keywords: fed cattle; formula base price reporting; market transparency

JEL classifications: Q13; Q18

1. Introduction

Market transparency enhances market efficiency as buyers and sellers incorporate available information to discover prices. One of the most substantive market transparency initiatives ever enacted by Congress was the *Livestock Mandatory Reporting Act of 1999* (LMR) which required qualifying meatpackers to report daily livestock purchases and meat sales data to the United States Department of Agriculture Agricultural Marketing Service (USDA AMS).[1] LMR built upon voluntary price reporting, in place for more than 50 years, by publicly providing more expansive livestock market information (Greene, 2019; Maples and Burdine, 2021; Koontz and Ward, 2011).

More than 20 years have passed since LMR enactment. Over that time, consumer beef preferences have shifted toward specialized and differentiated beef products. This shift accelerated the use of marketing agreements and formula pricing of fed cattle (Schroeder, Coffey, and Tonsor, 2022; Schulz, Schroeder, and White, 2012).[2] Marketing cattle using formula pricing involves adjusting a base price and applying grid premiums and discounts to determine net prices

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[1]See https://www.ams.usda.gov/rules-regulations/mmr/lmr/background for LMR details.

[2]Formula-based trade refers to fed cattle transactions that are not negotiated cash, negotiated grids, or forward contracts.

(USDA AMS 2021).[3] The result of the increased importance of formula pricing was a recognized dearth of information about base prices. Little is known about base prices other than they exhibit considerable variation during any given week. Formula base prices are an important determinant of producer profitability (McDonald and Schroeder 2003) and are the price to which grid premiums and discounts are applied for over 60% of fed cattle (Livestock Marketing Information Center; USDA AMS 2021). The purposes of this study are to determine if more informed weekly base price reporting could be accomplished using existing data reported by packers to USDA AMS and assess whether additional information is warranted to improve base price transparency.

To address stakeholder requests for more market information regarding formula-traded cattle, USDA AMS introduced new market reports in August 2021. The new reports include daily and weekly publications summarizing formula base prices. Although cattle transacted under formula agreements likely include branded and differentiated cattle, LMR data collection and price reporting largely resemble cash-negotiated and conventional commodities that characterized cattle and beef in the early 2000s (Schroeder, Coffey, and Tonsor, 2022). That is, base price reports provide limited information on value-differentiating determinants. To help address this concern, this study demonstrates how hedonic modeling can be applied to existing formula base transactions data collected under LMR to: 1) determine the level of base price variation statistically explainable using data currently collected by USDA AMS from packers; 2) quantify characteristics statistically impacting individual transaction base prices; and 3) assess unexplained variation in formula base prices to infer limitations of available data in explaining base price variability. We provide suggestions for additional data to be collected from packers to illuminate weekly base price variation and make reported base prices more informative to market participants.

2. Current LMR Data Collection and Market Reporting

USDA AMS uses the *LP-113: Live Cattle Daily Report*[4] to collect fed cattle prices and related data from meatpackers. Under the authority of LMR, qualifying meatpackers[5] are required to submit all transaction information indicated on the LP-113 twice daily. Table 1 provides brief descriptions of transactions data currently collected. Qualifying meatpackers purchasing cattle provide a plant ID code, transaction date, and purchase method (negotiated cash, negotiated grid, forward contract, or formula). Transaction characteristics reported by packers include number of head, cattle sex (steer, heifer, mixed steer/heifer, etc.), selling weight basis (live or dressed), delivery method (delivered or FOB[6] feedlot), average cattle weight, percentage grading Choice or higher, and average dressing percent. USDA AMS leverages data collected using the LP-113 form to publish 44 cattle market reports. We assess how well data collected from meatpackers using the LP-113 form can be used to describe formula base price variability.

Figure 1 illustrates a section of a USDA AMS daily formulated base purchases report. Formula base price transactions are summarized according to their estimated percentage Choice category by number of head and weighted-average dressing percentages and weights. In Figure 1, the column labeled "Avg Net Price" is the formula base price before premiums and discounts have been applied. Price and weight ranges identify the maximum and minimum base prices and average weight for each choice percentage category.

[3]Example grids being used in fed cattle purchase programs include https://www.nationalbeef.com/-/media/files/nbweb/cattle-procurement-information/nbp-grids-definitions.ashx; https://www.uspb.com/DocumentItem.aspx?ID = 34; https://www.nextgenbeefcompany.com/wp-content/uploads/2021/02/SMB-Grid-v2020.11.20.pdf

[4]https://mpr.ams.usda.gov/mpr/manuals/help/lsFormInfo.htm?selItem = lp-113&formName = LS113&product = livestock

[5]Beef packers that slaughter at least 125,000 head of cattle annually are required under LMR to report cattle purchase and beef sales data to USDA AMS.

[6]FOB (or Free on Board) feedlot means cattle change ownership at the feedlot. Buyers are responsible for transportation cost and scheduling in FOB purchases.

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Table 1. Data collected by USDA AMS from qualifying packers in LP–113 live cattle daily report

Data Field	Explanation	Data Field	Explanation
Plant Identification	ID, name, and location of plant purchasing cattle	Weight Premium	Average premium paid for weight
Reporting Date	Date of report	Quality Premium	Average premium paid for quality
Reporting Time	9:30 am or 1:30 pm	Yield Premium	Average premium paid for yield
Source	Domestic or Imported	Other Premium	Average premium paid for other
Purchase Type	Cash Neg.; Formula; Neg. Grid; Fwd. Contract	Weight Discount	Average discount paid for weight
Class	Steer; Heifer; Mixed S/H; Dairy S/H; Mixed S/H/Cow	Quality Discount	Average discount paid for quality
Selling Basis	Live or Dressed	Yield Discount	Average discount paid for yield
Selling Basis – Ship	FOB or Delivered	Other Discount	Average discount paid for other
Head Count	Number of head in the transaction	Packer Financing	Whether packer provided financing
Est. Avg. Weight	Average live animal/carcass weight	Delivery Location	Producer or Packer
Average Price	Live/dressed net (or base) price paid	Delivery Date	If set by Producer or Packer
% Choice or better	Percentage grading Choice or higher	Delivered	1–14 days or 15–30 days (neg. cash only)
Classification Code	Quality code for majority of the cattle in the lot		
Dressing %	Average dressing percentage		
Origin	Feedlot state		

Source: https://mpr.ams.usda.gov/mpr/manuals/help/lsFormInfo.htm?selItem = lp-113&formName = LS113&product = livestock.

The base price information in Figure 1 exemplifies variation in base prices. For example, the national base price range for live FOB steers was $135.94/cwt to $160.00/cwt live, a $24.06/cwt range (over 17% of the weighted-average price). Similarly, dressed delivered steers had a base price range of $215.53/cwt to $255.58/cwt dressed, a $40.05/cwt range (over 19% of the weighted-average price). When disaggregated by region, the typical range in weekly base prices declines for individual states but not for the 5-area combined report. Over the time period, USDA AMS has published base price reports (August 16, 2021 through February 6, 2023). The dressed steer delivered national base price range has averaged 19% of the weighted average price, and the 5-area 18%. Individual regions comprising the 5-areas have average ranges from 5% in KS to 12% in TX-OK-NM of their respective weighted-average base prices. Factors contributing to the base price ranges are not revealed in USDA AMS formula base price publications. However, observed base price ranges are of economic importance to both producers and packers.

3. Previous Research

Past research has demonstrated how hedonic modeling can be applied to report agricultural commodity prices. Brown et al. (1995) developed a hedonic approach for reporting cotton prices, premiums, and discounts referred to as the *Daily Price Estimation System* (DPES). In feeder cattle,

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USDA National Daily Direct Slaughter Cattle - Formulated Base Purchases - Summary

Agricultural Marketing Service
Livestock, Poultry, and Grain Market News

March 15, 2022
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For Primarily Monday, 03/14/2022

	Head Count	Week to Date	Same Day Week Ago	Same Period Last Week	Same Day Year Ago	Same Period Last Year
Formula Base:						
Dressed	132,400	132,400	130,294	130,294	121,335	121,335
Live	19,172	19,172	22,661	22,661	30,665	30,665
Total	151,572	151,572	152,955	152,955	152,000	152,000

FORMULA BASE

	Head Count	Wtd Avg Dress Pct	Weight Range	Avg Wt	Price Range	Avg Net Price
STEERS LIVE FOB						
Over 80% Choice	7,463	62.9	1,325 - 1,600	1,486	137.94 - 160.00	139.81
65 - 80% Choice	5,462	63.2	1,290 - 1,600	1,403	135.94 - 140.94	139.34
35 - 65% Choice	28	63.5	1,300 - 1,300	1,300	138.00 - 138.00	138.00
0 - 35% Choice			-		-	
Total all grades	12,953	63.1	1,290 - 1,600	1,451	135.94 - 160.00	139.61
STEERS LIVE DELIVERED						
Over 80% Choice	78	62.8	1,550 - 1,550	1,550	141.35 - 141.35	141.35
65 - 80% Choice	280	62.8	1,450 - 1,450	1,450	140.85 - 140.85	140.85
35 - 65% Choice			-		-	
0 - 35% Choice			-		-	
Total all grades	358	62.8	1,450 - 1,550	1,472	140.85 - 141.35	140.96
STEERS DRESSED DELIVERED						
Over 80% Choice	17,120	63.5	819 - 1,046	963	216.38 - 255.58	220.96
65 - 80% Choice	9,834	63.7	750 - 1,005	889	215.53 - 225.00	219.63
35 - 65% Choice	1,211	63.9	756 - 887	829	216.38 - 222.44	220.17
0 - 35% Choice			-		-	
Total all grades	28,165	63.6	750 - 1,046	931	215.53 - 255.58	220.46

Figure 1. Example of a portion of USDA AMS slaughter cattle formulated base purchases report. Source: https://www.ams.usda.gov/mnreports/ams_3496.pdf.

hedonic modeling has been used to construct basis and price forecasting tools on the website BeefBasis.com (Dhuyvetter et al., 2008).

Several prior studies have estimated hedonic models for fed cattle transaction prices. Jones et al. (1992) estimated a hedonic model of 1,366 fed cattle negotiated cash transactions collected from selected Kansas feedlots 1990. Factors affecting live-weight selling prices included average estimated weight, percentage Choice grade, dressing percentage, yield grade, uniformity, number of head, breed, feedlot seller, packer buyer, day-of-the-week, and number of bids received. Schroeder et al. (1993) estimated a hedonic-fed cattle model testing impacts of changes in forward contracting levels on cattle prices. In addition to similar hedonic price determinants as Jones et al. (1992), statistically significant, economically small, impacts of forward contracting volumes on negotiated cash transaction prices were estimated.

Ward (1992) estimated a hedonic model of 656 fed cattle cash negotiated transaction prices collected from selected feedlots located in the southern plains during June 1989. Transaction prices were affected by live cattle futures and boxed beef prices, cattle sex, estimated percentage

Choice, day-of-the-week, days between purchase and delivery, number of bidders, and packer-buyer fixed effects. Schroeder (1997) estimated a hedonic model of 103,442 dressed-fed cattle transaction prices over March 1992 through April 1993 from 28 packing plants. Cattle sex, dairy-bred, yield grade, dressed weight, number of head, days between purchase and delivery, wholesale value adjusted for quality grade, and average plant price affected prices. Daily hedonic model-adjusted prices across plants were generally cointegrated. Love, Capps, and Williams (2010) investigated how concentration in the meat packing industry impacted fed cattle prices using hedonic modeling. The data included transactions collected from 43 steer and heifer packing plants spanning April 1992 to April 1993. Yield grade, Select quality grade, breed, and average weight factors affected transaction prices.

The U.S. General Accounting Office (2018) estimated a hedonic model of negotiated cash-fed cattle transaction prices to determine the impacts of regional packer concentration on prices paid. The study used data collected from the four largest U.S. beef packers, comprising 23 plants and 127,103 transactions over 2013–15. Quality and yield grades, dairybred, live-weight of cattle (<1,050 and >1,500 were tested with only the lighter-weight category statistically significant), a large feedlot dummy variable, and regional packer concentration measured by the Herfindahl–Hirschman Index had statistically significant impacts on transactions prices. Packing plant, county, and purchase date fixed effects were included in the model but not reported.

Recent work by Schroeder, Coffey, and Tonsor (2022) is closely related to our study. They estimated hedonic models using negotiated cash prices (224,882 observations) and net prices paid for formula-fed cattle (575,238 observations) transactions using LMR data obtained from USDA AMS over 2016–October 2021. The purpose of their study, similar to ours, was to determine if existing data being collected by USDA AMS under LMR could be used to provide greater price transparency through use of hedonic models to estimate implicit market premiums and discounts and use estimates to publish new market reports. They concluded that although hedonic modeling shows promise for increasing transparency in fed cattle price reporting, current data being collected under LMR from beef packers is not sufficient for this purpose. They recommended more detailed data for each transaction in net formula trade especially on quality grade; yield grade; heavy- and light-weight carcasses; special programs and certifications; and other details be collected from packers and used to estimate more robust and informative hedonic models to use for price reporting.

Though conducted for varying purposes and conditioned by available data, past hedonic studies of fed cattle transactions provide important information to guide our model development. Past studies commonly find factors we utilize in our models including quality grade; cattle weight and sex; head included in the transaction; and plant effects as cattle price determinants. However, unique aspects about base prices relative to prices analyzed in past studies distinguish our work. All previous studies have estimated hedonic models using net prices paid, most have been negotiated cash prices, and more recent work included net formula prices. Base prices differ from net prices in that premiums and discounts are used to adjust net prices after cattle are delivered to the packer. Thus, we expect base prices to have quite different implicit price determinants than net prices. For example, we expect typical important cattle net price hedonic factors such as quality grade and weight would be less important base price determinants and other factors such as plant effects and cattle origin to be more important. As such, our study provides the only analysis of base price transactions we are aware of to better understand factors causing the large range in observed base prices reported by USDA AMS. Past studies together with our analysis also help inform our conclusions regarding additional data needs.

4. Data and Methods

To achieve the objectives of this study, formula base price transactions data were obtained from USDA AMS. The transactions data span January 4, 2016–October 22, 2021, collected under LMR using the LP-113 form. Data filters were applied to remove outliers. USDA AMS identifies transactions that are excluded from formulated base purchase reports due to irreconcilable errors and also removes transactions that involve fewer than 11 heads. Also removed from our data were observations with greater than 5,000 head as well as trades including cows, nondomestic origin, and dairybred cattle. Live-weight cattle base prices and cattle weights were adjusted to a dressed weight basis using the dressing percentage collected in each transaction.[7] To remove additional outliers that we expect were errors, any base price falling outside the range of ±2.5 median absolute deviations around the corresponding weekly median base price for each week was removed (Leys et al., 2013; Bina, Schroeder and Tonsor, 2022). We also removed influential observations from the models as noted later. The above filters led to the removal of 29,133 observations. The dataset used in our analysis contained 527,294 formula base price transactions spanning 303 weeks.

Hedonic models used in our analysis include only data currently collected by USDA AMS from qualifying meatpackers. The primary focus was to estimate how current data collected in the LP-113 explains formula base price variation. An additional point of emphasis was to identify data that could potentially enhance fed cattle market transparency. To achieve our objectives of determining how well existing LMR formula base transactions data describe variation in base price, three hedonic equations were used. Our approach was modeled after Brorsen, Grant, and Rister (1984) who utilized four sequential hedonic models to estimate variation in rice transaction prices. Hedonic models were constructed to sequentially incorporate specific variable groups associated with formula base transactions as

$$Formula\ Base\ Price_{it} = f(Plant_{it}, \varepsilon_{it}) \tag{1}$$

$$Formula\ Base\ Price_{it} = f(Plant_{it}, Origin_{it}, \varepsilon_{it}) \tag{2}$$

$$\begin{aligned} Formula\ Base\ Price_{it} = f(&Plant_{it}, Origin_{it}, Quality_{it}, Head_{it}, Dressing_{it}, Weight_{it}, Cattle\ Sex_{it}, \\ &Delivery_{it}, Weight\ Basis_{it}, \varepsilon_{it}) \end{aligned} \tag{3}$$

Where (i) refers to an individual formula base transaction, (t) refers to a single week for which the transaction occurred, and (ϵ) is the error term. Variable definitions for hedonic equations (1) – (3) are provided in Table 2. Formula base price was modeled first as a function of the plant where cattle were purchased and slaughtered. This isolated effects of purchasing plant on base price variation to assess the level of variation explained by plant effects alone. If base prices adjusted for time are relatively constant within a plant, but vary across plants, then plant effects alone would explain a large share of base price variation at a point in time. Alternatively, if time-adjusted plant effects do not explain base price variation well, this suggests plants utilize different base prices or different price formulas within an individual plant.

Our second hedonic equation modeled base price as a function of both purchasing plant and cattle state-of-origin. Plant effects are likely embedded somewhat in state-of-origin effects. However, the reason for including the two separately was to assess average base price differences in fed cattle-producing states where at least a single LMR reporting plant was located and states where no such plants currently operate. If model (1) suggests varying base prices within a plant, model (2) determines if such variation is associated with state-of-origin of the cattle.

Formula base price was modeled in the third hedonic equation as a function of purchasing plant, cattle state-of-origin, and pen attributes;[8] incorporating all relevant and available formula base transaction data currently collected under LMR. Number of head and average weight of the

[7]We dropped transactions that reported carcass or live weights that were outside the range of weights reported by USDA AMS in the *National Weekly Direct Slaughter Cattle Formulated and Forward Contract Domestic* LM_CT151 report for formulated beef steers and heifers during the time period of our study.

[8]Pen attributes data includes quality (percent Choice or higher), number of head, average dressed weight, delivery method (delivered or FOB feedlot), cattle sex (steer, heifer, or mixed steer/heifer), and selling weight basis (live or dressed).

Table 2. Variables used in weekly hedonic models

Variable	Description
Price	
Base Price	Base price reported on a dressed basis ($/cwt)
Quality	
Choice	Percentage grading Choice or higher (%)
Head	
Head50	Binary variable $=1$ if lot size is ≤ 50
Head100	Binary variable $=1$ if $50 <$ lot size ≤ 100
Head175	Binary variable $=1$ if $100 <$ lot size ≤ 175
Head175+	Binary variable $=1$ if lot size is >175 (default)
Dressing	
Dressing	Dressing percentage of cattle carcass (%)
Weight	
Weight1	Binary variable $=1$ if average dressed weight ≤ 800 lbs.
Weight2	Binary variable $=1$ if 800 lbs. $<$ average dressed weight ≤ 900 lbs. (default)
Weight3	Binary variable $=1$ if average dressed weight >900 lbs.
Cattle Sex	
Steer	Binary variable $=1$ if sex $=$ steer (default)
Heifer	Binary variable $=1$ if sex $=$ heifer
Mixed	Binary variable $=1$ if sex $=$ mixed steer/heifer
Delivery	
Delivered	Binary variable $=1$ if cattle delivered to plant (default)
FOB	Binary variable $=1$ if cattle purchased FOB feedlot
Weight Basis	
Dressed	Binary variable $=1$ if cattle purchased on dressed weight basis (default)
Live	Binary variable $=1$ if cattle purchased on a live weight basis
Origin	
$State_K$	Set of binary variables $=1$ for each cattle state-of-origin (TX as default)
Plant	
$Plant_J$	Set of binary variables $=1$ for each plant J purchasing cattle (one as default)
Weekday	
Monday, etc.	Set of binary variables $=1$ for each day of the week (Monday as default)

cattle in the transaction were each specified as categorical rather than continuous variables as is often done in hedonic models. This was done because categorical variables are more conducive to price reporting than continuous head and weight variables.

Formula base prices are tied to externally discovered prices, so we did not expect pen attributes to be economically important drivers of base price variability. We included pen attributes in our analysis because these data are used to describe base price variation in existing LMR base price

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reports. Hedonic equations (1)–(3) were estimated using ordinary least squares for each of the 303 weeks contained in our dataset. The models were estimated separately for each week, as opposed to combining weeks into a single panel data model, because models estimated each week are more conducive to price reporting. The goal here is not to estimate an encompassing hedonic model explaining base price variation across the entire panel data set, but rather to assess the use of hedonic models in reporting weekly market information. Binary weekday variables were included in each model to account for base price variation across days during the week. Weekly models had an average of 1,736 with a range from 840 to 2,438 formula base transactions per week after adjusting for influential observations.

To assess whether there were influential observations potentially present in our estimates, we tested each of the 303 weekly models using DFFITS statistics using the most general model (equation 3).[9] We did this only for equation 3 and applied that same data set to the other models to maintain identical data across specifications. Any observation with a DFFITS statistic greater than the cutoff value recommended by Belsley, Kuh, and Welsch (1980) of $2(p/n)^{1/2}$, $p =$ number of parameters and $n =$ the number of observations in the weekly models, was removed and not used in the reported models. Across the 303 weeks, 3% of the more than 500,000 observations were considered influential for model 3 ranging from 1 to 6% across weeks. Results including and excluding influential observations were qualitatively the same with only minor differences. This resulted in using 511,486 of the 527,294 total transactions in the model results reported.

To analyze the output for each hedonic equation over the 303 weeks contained in our data, an average coefficient estimate and standard deviation were calculated for each of the independent variables included in the corresponding model. That is, equation (1) included 31 independent binary plant variables with one as default; when equation (1) was estimated weekly, there were 30 plant variables with 303 coefficient estimates per binary plant variable, one for each week the model was estimated. Model explanatory power was assessed using goodness-of-fit statistics of adjusted R^2 and Root Mean Square Error (RMSE).

Summary statistics of dressed steers and heifers marketed on formula between 2016 and October 2021 used in our hedonic models are presented in Table 3. The national weighted-average formula base price was \$184.90/cwt with a standard deviation of \$14.87/cwt. The weighted-average dressed cattle weight was about 856 lbs. Number of head per transaction were included as four categorical variables (Table 2) each representing roughly 25% of the transactions. Percentage grading Choice or higher averaged 77.4%. Dressing percentage averaged 63.6% with a standard deviation of 1.0%. Due to infrequent formula base transactions in some low-volume states-of-origin (primarily located in north and southeast regions), origin coefficient estimates can vary, and represent a small number of transactions in any given week. To maintain confidentiality, we provide model statistics only for the top 10 states marketing cattle on formulas (out of 38 total included in our models). The top 10 formula cattle states represented more than 96% of total formula base price transactions from 2016 to October 2021.

5. Results

Goodness-of-fit summary statistics for the 303 weekly models for each of the three hedonic equation specifications are presented in Table 4. Modeling base price as a function of fixed plant effects alone (equation 1) explained 53% of base price variation on average with an average RMSE of \$1.87/cwt. The fact that plant effects alone, allowing for aggregate day-of-week effects, only explained roughly half the base price variation in the typical week suggests plants have several base prices at a point in time and/or base prices vary across plants relative to each other across days. To determine how much plant base prices varied across transactions within plants, base prices were regressed as a function of binary weekday variables by plant and week, for each of

[9]We acknowledge an anonymous journal reviewer for recommending this.

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Table 3. Summary statistics of formula base transactions used in models after removing potentially influential observations, 2016–October 2021, $N = 511{,}486$

Variable	Mean	Minimum	Maximum	Std Dev	Skewness	Kurtosis
Base Price ($/cwt)	184.90	NA	NA	14.87	0.09	−0.25
Carcass Weight (lbs.)	856	436	1231	68	0.0	−0.4
Dressing Percentage (%)	63.6	50	69.9	1.0	−0.4	2.7
Choice or Higher (%)	77.4	0	100	13.2	−0.8	1.3
Number of Head	128	11	4982	104	6	115
NA - not reported to maintain confidentiality						

Table 4. Average weekly model goodness-of-fit summary statistics for formula base transactions (303 total weeks), 2016–2021, $N = 511{,}486$

Variable Groups	Hedonic Equation	Variables Included	Adj. R^2	RMSE ($/cwt)
(A) = Plant	(1)	$P = f(A)$	0.53	1.87
(B) = State-of-Origin	(2)	$P = f(A + B)$	0.55	1.83
(C) = Pen Attributes	(2) excl. plant	$P = f(B)$	0.31	2.30
	(3)	$P = f(A + B + C)$	0.59	1.75
	(3) excl. plant	$P = f(B + C)$	0.41	2.11

the 303 weeks. Average, minimum, and maximum RMSEs were extracted for each plant-wise regression across the 303 weekly models (31 plant average, min, and max RMSEs). For plants that reported formula base prices during at least 200 of the 303 weeks (21 plants): 1) the average RMSEs of the regressions ranged from about $0.50/cwt to greater than $2.00/cwt with an average of $1.44/cwt.; 2) nine plants had minimum RMSEs of $0.00 meaning the base price each day that week, adjusted for day, was the same across transactions; and 3) 10 plants had maximum RMSEs exceeding $7/cwt during some weeks. These results indicate plants had various base prices across transactions which varied by economically important amounts during some time periods. Attempting to describe the unexplained variation in these models motivates equations (2) and (3).

Including cattle state-of-origin fixed effects in weekly models, equation (2), contributed little to model explanatory power as average adjusted R^2 only increased two percentage points and the average RMSE declined by only $0.04/cwt. This suggests variation in plant base prices was not strongly associated with cattle state-of-origin when plant effects were included in the model. Cattle feedlots located in states without an LMR reporting beef packer did not generally realize differential base prices associated with their specific state.

Importance of fixed plant effects in describing base price variability was assessed by removing them from equation (2) and estimating just state-of-origin effects including day-of-week fixed effects. Average adjusted R^2 declined to 0.31 and the average RMSE increased to $2.30/cwt (Table 4). This indicates plant effects were more pronounced base price explanatory factors than cattle state-of-origin, and plants located in the same state had different base prices.

Equation (3) modeled base price as a function of purchasing plant, cattle state-of-origin, and pen attributes. Incorporating all available formula base transactions data in weekly hedonic models explained 59% of base price variation on average with an average RMSE of $1.75/cwt. This demonstrates adding available quality information and other pen attributes modestly increased

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Table 5. Formula base coefficient comparisons for fixed plant effects in weekly models (equations (1), (2), and (3)); 10th/90th percentiles and standard deviations are for 31 plants across 303 weekly models; one plant as default

Hedonic Equation	10th Percentile	90th Percentile	Average Std Deviation
(1) Plant	−4.30	4.45	3.87
(2) Plant, Origin	−5.16	4.11	4.53
(3) Plant, Origin, Lot Attributes	−4.86	4.01	4.24

goodness-of-fit. This also implies other factors beyond those reported by packers under LMR-influenced base prices.

When fixed plant effects were removed from equation (3), a similar story to equation (2) was observed. The average adjusted R^2 decreased from 0.59 to 0.41, while the average RMSE increased from \$1.75/cwt to \$2.11/cwt. F-tests of joint significance of variables eliminated from the unrestricted model (equation (3)) on average across 303 weekly models indicate each variable group were as a set statistically significant at the 0.01 significance level. We elaborate further in the following section, but findings suggest key market information related to formula base purchases is not currently being collected under LMR.

Summary statistics for fixed plant effects in the three weekly hedonic models are presented in Table 5. LMR plant coefficient estimates were combined to produce a distribution of base price differentials for 30 LMR plants across 303 weeks compared to the default plant (i.e., a distribution of base price differentials across time, not within a week). Presenting base price variation relative to the default plant at the 10th and 90th percentiles provides the typical variation over time without disclosing confidential data. For equation (1), formula base price coefficients had a 10th and 90th percentile range of \$8.75/cwt. Plant coefficient 10th and 90th percentile estimated ranges increased when additional explanatory variables were added to the models going from a range of \$8.75/cwt with just plant effects, to more than \$9/cwt in (2) and \$8.87/cwt in (3). Furthermore, the standard deviation of plant estimates increased by 17% from equation (1) to (2) and by about 10% from (1) to (3). This suggests there was correlation between fixed plant effects and other variables included in the models that increased plant effect magnitudes when other variables were included.

This result brings us to the argument for more detailed information regarding the types of reference prices being used in formula agreements (Peel et al., 2020). The type of formula used in a given transaction has not been included in the data packers report to USDA AMS for the transaction data analyzed. However, the recently introduced Cattle Contracts Library Pilot Program (USDA AMS 2023) provides a breakdown of base price sources and adjustments summarized across all active contracts (181 in recent published reports). The base price information provided in the Contracts Library is useful for understanding aggregate base price tendencies and sources. Whether the Contracts Library report will replace the existing base price report illustrated in Figure 1 is unclear. But information similar to that is being collected in the Contract Library, if utilized in base price reporting, could enhance information published in the example report in Figure 1. We suggest additional data that could further enhance base price reports in our conclusions.

Average coefficient estimates and standard deviations for cattle state-of-origin effects in weekly models for equation (3) including and excluding plant effects are provided in Table 6. Fixed origin effects were notably smaller (in absolute value) when plant effects were included. For example, NE had a premium to TX of \$0.97/cwt when plant effects were excluded, and this declined to \$0.48/cwt when plant effects were included. ID, SD, OR, and WA each received small premiums (less than \$0.50/cwt) on average when plant effects were excluded but discounts of up to \$0.66/cwt when plant effects were included. This indicates plant effects are related to, and can somewhat mask, origin price effects. As such, we focus on results for equation (3) excluding plant effects from here forward.

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Table 6. Formula base coefficient comparisons for fixed state-of-origin effects in weekly models (equation 3 including and excluding plant effects); averages and standard deviations across 303 weekly models

	(3) Origin, Pen Attributes, (Excl. Plants)		(3) Plant, Origin, Pen Attributes	
State-of-Origin	Avg Coefficient Estimate	Standard Deviation	Avg Coefficient Estimate	Standard Deviation
KS	−0.14	0.75	−0.23	0.75
TX	BASE	BASE	BASE	BASE
NE	0.97	2.07	0.48	1.05
CO	0.71	2.04	−0.02	1.12
OK	−0.23	0.66	−0.31	0.73
IA	0.48	2.27	0.20	1.06
ID	0.45	1.95	−0.58	2.67
SD	0.23	2.39	−0.17	1.28
OR	0.32	7.76	−0.66	3.12
WA	0.14	2.24	−0.64	3.10

Average coefficient estimates and standard deviations for effects of pen attributes in weekly hedonic models using equation (3) excluding plant effects are provided in Table 7. Percentage grading Choice had little impact on average base prices received in any given week as expected since quality grade premiums are likely added to base prices after slaughter and grading occur. A one percentage point increase in dressing percentage was on average associated with a \$0.43/cwt decrease in base prices. Dressing percentage and percentage grading Choice or higher is generally not known at the time a base price is established. While we do not know how estimates of these values are compiled by packers, for each transaction, they could reflect plant averages, previous history with the producer, or some other source.

Table 7 further demonstrates formula base transactions designated as FOB feedlot averaged 1.06/cwt lower than those delivered to the plant. However, standard deviations indicated a substantial variation of about \$1/cwt in FOB coefficient estimates across 303 weeks. Binary head count variables indicate lots with 50 or fewer head received base prices of \$0.28/cwt less, while lots with 51 to 100 and 101 to 175 head received \$0.24/cwt less compared to lots over 175 heads. Binary weight estimates suggest base prices were not strongly associated with average weight of the pen. The 800–900 lb. default (containing more than 55% of formula transactions from 2016 to October 2021) received base prices \$0.02/cwt lower than average weights of less than 800 lbs., and \$0.03/cwt lower than average weights greater than 900 lbs. Mixed steer/heifer lots received base prices \$0.09/cwt higher than steer only lots on average. Steer and heifer specific lots had similar base prices on average. Estimates for live-weight versus dressed cattle were difficult to interpret, given variation in live-weight coefficients across time. The average coefficient estimate for live-weight transactions suggests their dressed base prices were \$0.75/cwt lower on average. However, standard deviation of the live coefficient indicates this varied in any given week. We suspect this result reflects differences in the type of formula cattle delivery arrangements across regions (i.e., live vs. dressed and FOB vs. delivered combinations).

6. Formula Base Price Reporting

To demonstrate how hedonic modeling can be applied to provide a weekly summary of formula base prices, a simulated formula base purchase report for a week in September 2021, is presented

Table 7. Formula base coefficient comparisons for pen attributes in weekly models (equation (3) excluding plant effects); averages and standard deviations across 303 weekly models

Variable	Avg Coefficient Estimate ($/cwt)	Standard Deviation
Choice	−0.002	0.017
Dressing	−0.43	0.31
FOB	−1.06	0.98
Head50	−0.28	0.67
Head100	−0.24	0.952
Head175	−0.24	0.35
Weight1	0.02	0.33
Weight3	0.03	0.35
Heifer	−0.02	0.32
Mixed	−0.09	0.32
Live	0.75	2.10

in Table 8.[10] To construct the report, formula base transactions for the week were estimated using hedonic equation (3) excluding plant effects and replacing binary *state*-of-origin variables with binary *region*-of-origin variables as defined in Table 8. Regionalization was done to provide market information for thinly traded regions since individual states can represent few observations and may be subject to confidentiality constraints that preclude reporting. Hedonic regression results for the week produced an adjusted R^2 of 0.58 and an RMSE of $2.75/cwt. A head-weighted average base price was calculated for formula base transactions using TX-OK-NM steers, 80% Choice or higher, dressed, with an average dressing percentage of 63.64 and delivered to the packer as the reference pen. Base price differentials are the coefficient estimate associated with each transaction characteristic compared to the default.

Utilizing hedonic modeling to report formula base prices shows promise to improve upon currently reported weighted-average base prices under LMR. Confidentiality was effectively maintained as a head weighted-average base price was calculated for all transactions falling within the reference pen criteria, keeping reported base prices undisclosed. Hedonic modeling of reported formula base prices facilitates additional price transparency by estimating the market value of specific attributes of each transaction. Furthermore, reporting base prices by region provides more detailed information than current USDA AMS base price reports.

7. Conclusions

Transparency and timely distribution of dependable market information are foundational for an efficient market. As market information evolves, so too should the mechanism through which information is disseminated. LMR was implemented over 20 years ago to provide buyers and sellers of livestock in the United States with accessible and reliable market information. In the 20 years since LMR enactment, cattle, and beef have evolved from functioning as conventional commodities to an expansive array of specialized and differentiated beef products. Increased use of formula marketing agreements has facilitated industry shifts by effectively aligning production incentives with consumer demands. Consequently, new and different types of market information contained in formula agreements are also more expansive. LMR data collection and reporting

[10]The specific week is not identified to maintain confidentiality.

Table 8. Example formulated base purchases weekly summary using hedonic equation (3) excluding plant effects, for a week in September 2021 ($/dressed cwt)

Transaction Variable	Base Price ($/cwt)	Price Differential ($/cwt)	Transaction Variable	Base Price ($/cwt)	Price Differential ($/cwt)
% Choice			**Lot Size**		
90% or Higher	$198.50	$0.02	Head ≤ 50	$198.69	$0.21
80% or Higher	$198.48	BASE	50 < Head ≤ 100	$198.32	($0.16)
70% or Higher	$198.46	($0.02)	100 < Head ≤ 175	$198.11	($0.37)
60% or Higher	$198.44	($0.04)	Head > 175	$198.48	BASE
50% or Higher	$198.42	($0.06)			
40% or Higher	$198.40	($0.08)	**Average Weight**		
30% or Higher	$198.37	($0.11)	Weight < 800#	$198.24	($0.24)
			800# ≤ Weight ≤ 900#	$198.48	BASE
Cattle Sex			Weight > 900#	$198.92	$0.44
Steer	$198.48	BASE			
Heifer	$199.03	$0.55	**Cattle Region**		
Mixed S/H	$198.80	$0.32	TX-OK-NM	$198.48	BASE
			KS	$197.69	($0.79)
Delivery Method			NE	$203.45	$4.97
Delivered	$198.48	BASE	CO	$202.20	$3.72
FOB Feedlot	$196.49	($1.99)	IA-MN-MO	$201.85	$3.37
			Eastern Corn Belt	$200.00	$1.52
Weight Basis			North Central	$202.33	$3.85
Live	$198.59	$0.11	Western	$200.65	$2.17
Dressed	$198.48	BASE	Northeastern	$197.90	($0.58)
			Southeastern	$203.66	5.18
North Central States			*MT-ND-SD-WY*		
Eastern Corn Belt			*IL-IN-KY-MI-WI*		
Western States			*AZ-CA-ID-NV-OR-UT-WA*		
Southeastern States			*AL-AR-FL-GA-MS-NC-SC-TN-VA*		
Northeastern States			*CT-DE-MA-MD-ME-NH-NJ-NY-OH-PA-RI-WV-VT*		

practices for formula transactions still largely assume an undifferentiated and predominantly cash-negotiated commodity.

Employing 6 years of formula base transactions data collected under LMR using the LP-113 form, we illustrated how hedonic modeling can be applied to enhance fed cattle market transparency via reporting. We also demonstrated how more useful and interpretable market information could be provided to decision-makers extending beyond currently reported weighted-average base price ranges. Plant effects alone described roughly 50% of variation in base prices within a week while state-of-origin and pen attribute effects contributed little to model explanatory power. In

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other words, factors beyond those reported by packers under LMR substantially influenced base prices. Cattle feedlots located in states without an LMR reporting beef packer did not realize differential base prices associated with their specific state. Pen attribute estimates identified implicit base price values related to selling weight basis (live/dressed), delivery method (delivered/FOB feedlot), and sex of the pen (steer/heifer/mixed). Variation in these estimates across weekly models though suggests either varied values across these traits across time, or model specification concerns making coefficients unstable.

If models such as we have presented were to be used for price reporting, we recommend the models be reviewed specifically to ensure reported coefficients represent sufficient observations to be reliable. Establishing thresholds for reliability may be somewhat arbitrary and beyond the scope of this study, but they should be considered and dealt with if present. In addition, we recommend using influence statistics each week to assess whether any observations are influential to the estimated parameters.

Results suggest weaknesses associated with current LMR data collection and reporting for formula base transactions. Hedonic models used in our analysis likely suffer from omitted variable bias due to constraints of available data. Several factors, we anticipate could affect base prices and be part of the roughly 50% of variation in base prices we could not explain in our models, are not available in existing data USDA AMS collects. To address this, we suggest USDA AMS add new fields to the LP-113 form to capture the following formula base transaction data from qualifying beef packers:

The source of base prices being referenced in formula agreements (national/area market cash price, plant average price, live cattle futures price, wholesale beef price, or other)

Whether formula base transactions include:

a. Cattle qualifying for specialty breed/branding programs (CAB, Wagyu, etc.)
b. Cattle qualifying for specialty production programs (All Natural, NHTC, Grass-fed, etc.)
c. Cattle that are process verified, age verified, or export certified, etc.

The source of base prices used in formula agreements likely varies within and across plants and cattle-producing regions/states. Knowing the base price source would provide a greater understanding of formula base prices and their associated variation both within a week and across time. Data related to specific cattle programs are meant to supplement current pen attributes given factors such as expected quality and average weight may be impacted by the nature of the program (e.g., Grass-fed cattle may also be lighter weight on average; higher quality expectations associated with CAB). Important to identify is whether premiums associated with various program cattle are realized in formula base prices, or if they are accounted for solely in the associated grid used in the agreement.

If the additional formula base transaction data were collected from qualifying meatpackers and incorporated into live cattle market reports, we expect it would provide important benefits to buyers and sellers of formula cattle. Plants purchasing formula cattle likely already collect these data and would therefore incur little to no additional cost to report this information (Schroeder, Coffey, and Tonsor, 2022). Furthermore, this study has demonstrated that, given the level of variation in the types of cattle marketed on formula, formula base price reports could be modified to provide a more refined understanding of variation in base prices within a week. For example, providing specific base price sources would likely shed light on the variation and encourage additional base price discovery. Whether hedonic modeling is used to report formula base prices, the recommended additional formula base transaction data could be used to enhance market reports and improve overall formula cattle market transparency.

Data availability statement. The data utilized in this study were obtained by the researchers from the U.S. Department of Agriculture, Agricultural Marketing Service under a strict confidentiality agreement. Because the data contain proprietary transactions information, the data cannot be shared externally.

Author contributions. Conceptualization, SGR, TCS; Formal analysis, SGR, TCS; Data curation, TCS, GTT, BKC; Writing—original draft, SGR, TCS, Writing—review and editing, SGR, TCS, GTT, BKC; Supervision, TCS; Funding acquisition, TCS, GTT, BKC.

Competing interests. Sheppard Rogers, Ted Schroeder, Glynn Tonsor, and Brian Coffey declare none.

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