Buyer Power in the Beef Packing Industry

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Abstract

We consider the oligopsony competition among beef packers to purchase cattle from feedlots. We explore in particular the competitive implicates of an increasingly popular contract in which the price of a (future) transaction is pegged to future cash market prices. These contracts create an additional incentive for packers to depress cash market prices, and as the largest four packers account for more than 80% of purchases, they likely have an ability to do so. We provide descriptive regressions that show a negative correlation between contract quantities and cash market prices on a week-to-week basis over 2005-2019. We then construct an empirical model and estimate it using data from the same period. The model allows us to assess the extent to which the rise of contracts may have contributed to an increase in the observed spread between the prices that packers pay for cattle and the prices that they receive for beef.

JEL Codes: L14, L42, Q11

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1 Introduction

This paper explores the pricing behavior of beef packers in the United States. Of particular interest is the increase in the *packer spread*—the gap between the prices that packers pay to upstream feedlots and the prices that they receive from retailers—that occurred over 2015-2019. To our knowledge, there is no plausible cost-based explanation for the increase in the packer spread during that period. Thus, it is natural to explore the role of market power, and especially whether the beef packers may have been able to exercise buyer power in the market for fed cattle to a greater degree.

We focus on the alternative market arrangements (AMAs) that increasingly are used to facilitate transactions between feedlots and packer. Under an AMA, the feedlot agrees to sell its cattle to a packer at some future date, with the price being linked to the prices that are realized in the cash market near the delivery date of the cattle. That such arrangements may distort packers' bidding incentives in the cash market is well established in the economics literature (Mahenc and Salanie, 2004; Xia and Sexton, 2004). The reason is that more aggressive (higher) bids raise the price that packers must pay for cattle acquired with AMAs. Thus, economic theory suggests that cash market prices are likely to be lower, the greater the prevalence of AMAs. As the prices that feedlots obtain with AMAs are linked to realized prices on cash market, the presence of AMAs may broadly depress the price paid for cattle.

The paper proceeds as follows. Section 2 describes the institutional setting and the data that we use. We document that between 2005 and 2019, the proportion of cattle sold in the cash market fell from over 60% to just above 20%, reflecting the increase in AMA usage. We also document that the largest four packers account for 80% of industry capacity. This combination—a high reliance on AMAs and packers with an ability to move cash market prices—aligns with the conditions under which economic theory indicates the adverse effects of AMAs may be large. Section 3 shows pricing trends over 2005-2019 and analyzes the incentives created by AMAs in more detail. It also summarizes the results of a time series analysis of weekly prices over 2005-2020. The results are consistent with the economic theory described above: a one percent increase the AMA share of transactions is associated with a five percent decrease in cash market prices.

Section 4 presents an economic model that places the incentives introduced by AMAs into a framework that is amenable to empirical analysis. With some simplification, we show that the markdowns set by each packer scale with AMA usage. In particular, if the ratio of a packer's AMA cattle to the total size of the cash market is 80%, then the profit-maximizing markdown of the packer is 80% higher than it would be without any AMAs. A typical ratio for the largest four packers in 2019 appears to be about 100%. Thus, to an approximation, the model suggests that AMAs roughly double packers' markdowns. Section 5 shows how we estimate the model using industry data, and Section 6 evaluates the results of estimation and discusses the role that contracts may play in driving the observed increase in the packer spread. Section 7 is a placeholder for future counterfactual exercises.

Section 8 discusses the non-strategic benefits of contracts that may obtain for feedlots and packers. It also discusses potential long run implications of contracts that are not informed directly by our empirical work or modeling.

2 The Market for Fed Cattle

2.1 Institutional Details

The supply chain for beef begins with ranchers, who breed cattle and raise calves for beef production.[1] Calves are weaned after six to nine months at a weight of 400-700 pounds. After spending some time on pasture, they are transferred to specialized stocker operations, where they add another 200-400 pounds over three to eight months. The stockers sort the animals into groups of consistent quality and sell them to feedlots, where they eat high energy grain feed over another four to eight months, until they reach around 1250-1350 pounds. At this point, the animals are "fed cattle" and are sold by the feedlots to the packers.[2] The packers slaughter the animals, chill the carcasses, butcher them into various cuts of meat, and the vacuum seal the cuts to form boxed beef. The boxed beef then is sold to retailers and restaurants, both directly and through processors and distributors.

There are thousands of ranchers, stockers, and feedlots, but only a handful of packers. Thus, to study oligopsony power in the industry, we focus on the procurement of fed cattle by the packers. Table 1 provides capacity-based market shares over 2005-2019 for the major packers, along with the national Herfindahl-Hirschmann Index (HHI). The major packers account for 80% or more of industry capacity in each year. One of them—JBS—entered the market by acquiring two others: Swift (in 2007) and Smithfield (in 2008). JBS also proposed to acquire National Beef but was challenged successfully by the Department of Justice. The other acquisition that occurred during this period is that of Iowa Premium Beef, an operator of a small plant in Iowa, by National Beef; the acquisition closed in 2019. Using the thresholds of the Horizontal Merger Guidelines for the HHI, the market could be characterized as "moderately concentrated" at the national level, although this may not be reflective of the more local competition that exists for fed cattle procurement.

Table 2 provides the number of plants, average plant capacity, and total capacity (summing across plants) for each of the major packers and a "fringe" comprised of all other packers large enough to appear in our data, in both 2005 and 2019. Notably, the plants of the major packers are considerably larger than those of the fringe. The conventional wisdom is that some scale economies exist at the plant-level, and this is corroborated by economic research (e.g., MacDonald et al., 2000;

[1] In this section, we draw on our conversations with industry experts as well as on the numerous descriptions of the industry (e.g., RTI International, 2007; MacDonald and McBride, 2009; USDA, 2014).

[2] Most calves are born between February and March. Thus, the variation that is observed in the durations that cattle spend with ranchers, stockers, and feedlots allows for a consistent supply of beef.

Table 1: National Capacity-Based Market Shares and Herfindahl Index

Year	Tyson	Cargill	JBS	National	Swift	Smithfield	Total	HHI
2005	0.30	0.23	.	0.11	0.13	0.07	0.84	1,819
2007	0.29	0.25	0.13	0.11	.	0.07	0.85	1,842
2009	0.24	0.26	0.24	0.12	.	.	0.86	2,016
2011	0.24	0.26	0.24	0.12	.	.	0.86	2,003
2013	0.25	0.22	0.25	0.12	.	.	0.85	1,924
2015	0.25	0.22	0.27	0.11	.	.	0.84	1,934
2017	0.25	0.22	0.24	0.11	.	.	0.82	1,841
2019	0.25	0.21	0.24	0.10	.	.	0.80	1,777

Notes: The table summarizes the capacity-based market shares of the major packers over 2005-2019. JBS purchased Swift in 2006 and Smithfield in 2008. The HHI is based on the capacity shares of all packers. Based on data on large packing plants obtained from *Cattle Buyers Weekly*.

Table 2: Packer Statistics

	Number of Plants		Average Capacity		Total Capacity	
Packer	2005	2019	2005	2019	2005	2019
Tyson	10	6	3,655	4,800	36,550	28,800
Cargill	6	6	4,650	3,983	27,900	23,900
JBS	.	8	.	3,525	.	28,200
National	2	2	6,500	6,000	13,000	12,000
Swift	4	.	3,963	.	15,850	.
Smithfield	4	.	2,081	.	8,325	.
Fringe	17	18	1,103	1,270	18,745	22,855
Total	43	40	2,799	2,894	120,370	115,755

Notes: The table summarizes the number of plants, average plant capacity, and total packer capacity (summing across plants) for each of the major packers and a fringe comprised of all other packers, in both 2005 and 2019. Capacity is measured in head per day. Based on data on large packing plants obtained from *Cattle Buyers Weekly*.

Morrison Paul, 2001a,b). Aside from capacity, marginal costs appear to be constant in output, with labor and energy being the two largest components.[3] To our knowledge, the literature has not documented the existence of scope economies associated with multi-plant ownership.[4]

Figure 1 shows the location of large packing plants in 2019. Most of the capacity is in the High Plains area of the country, including eastern Colorado, western Iowa, Kansas, Nebraska, Oklahoma,

[3]The Sterling Beef Profit Tracker, a proprietary model that estimates the variable costs of feedlots and packers, maintains the assumption of constant marginal costs. See `www.sterlingmarketinginc.com`, last accessed November 10, 2021. Plants schedule operations a number of weeks in advance, with labor being guaranteed a certain number of hours each week. Thus, labor costs may be fixed over time horizons that span only a few weeks, but variable over somewhat longer time horizons.

[4]One industry expert points out that having multiple plants may allow packers to mitigate the impact of unanticipated plant closures that occur at times (e.g., due to food safety issues or other problems). See Pudenz and Schulz (2022) for a discussion.

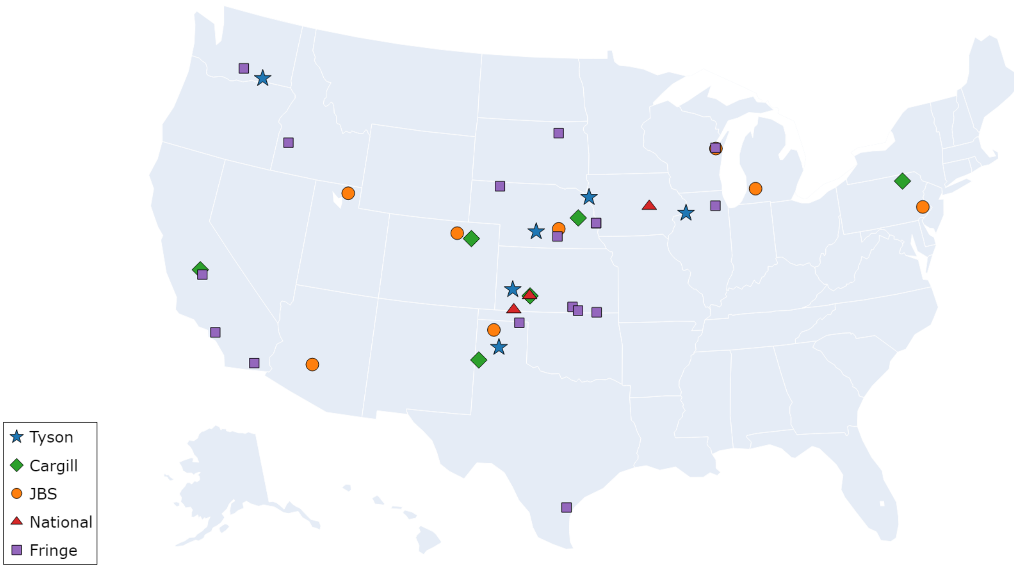

Figure 1: Locations of Large Beef Packing Plants in 2019
Notes: The map plots the locations of large beef packing plants, including those of Tyson, Cargill, JBS, and National Beef, based on data obtained from *Cattle Buyers Weekly*.

and Texas. The transportation of fed cattle can be expensive, both due to the trucking cost and because fed cattle lose weight (and value) during the trip. Thus, packing plants tend to procure cattle from nearby feedlots.[5] For comparison, Appendix Figure B.1 shows the density of fed cattle within counties. Finally, as there are some plant closures that occur during the sample period, Appendix Figure B.2 provides the location of packing plants in 2005.

Many transactions between feedlots and packers are based on negotiations that occur in what we refer to as the "cash market." Each week, feedlots provide a list of fed cattle that are available for purchase and packers call to submit bids.[6] Packers have extensive information about the competitive environment on a week-to-week basis, that they obtain from conversations with feedlot managers and daily USDA reports, among other sources. Most transactions in the cash market clear within a few hours late in the week. Prices usually are based either on the carcass weight of the animal as measured at the packing plant, possibly adjusted for the yield and grade of the beef, or on the live weight of the cattle as measured at the feedlot.

[5]One study of transactions over 1992-1993 finds that 53% of cattle is shipped under 100 miles, 32% is shipped between 100 and 300 miles, and 15% is shipped more than 300 miles (Capps et al., 1999).

[6]By custom, the first packer to bid on the cattle is "on the cattle" and is given an opportunity to revise its bid in the event that a higher bid is received. This appears to provide an incentive for packers to make a first bid, but may discourage competing bids. A recent investigation by the USDA concluded that "most pens with bid data only showed one packer bidding" (USDA, 2014).

Other transactions are conducted under *alternative marketing arrangements* (AMAs). Under an AMA, the feedlot agrees to sell its cattle to a packer at some future date, with the price determined by some formula. There are two types of AMAs that are typical. In the first—what we refer to as a "formula contract"—prices are pegged to those realized in the cash market near the delivery date of the cattle. Average cash market prices are publicly known because the USDA collects and disseminates data on prices. In the prototypical arrangement, the feedlot informs the packer when it has cattle that are ready for purchase, and the packer then sets the delivery date. The payment to the feedlot equals the average cash market price from the week prior to delivery, with adjustments for the yield and grade; the payment may incorporate a small premium.[7]

Under the second type of contract—a forward contract—the payments are pegged to the futures price on the Chicago Mercantile Exchange (CME).[8] The futures price can fluctuate over time, although it converges with cash market prices as the delivery month approaches. The feedlot determines when to exercise the option to set the transaction price at the futures price, at some point between the contracting date and the delivery date. Whereas formula contracts eliminate the risk to a feedlot of not finding a buyer on the cash market, forward contracts also mitigate price risk.

Figure 2 plots the fraction of fed cattle sales that occur through the cash market, with formula contract, and with forward contracts. Historically, the cash market has accounted for the bulk of sales, but this remains true only in the early years of our sample. By the later years, the cash market accounts for between 20% and 30% of sales, with formula contracts accounting for most of the change. As smaller packers usually rely exclusively on the cash market (e.g. RTI International, 2007; MacDonald and McBride, 2009), this trend is even more pronounced within the major packers individually. As formula contracts are pegged to the cash market and forward contract prices are pegged to futures prices (which ultimately converge to the cash market), increasingly the prices that packers pay feedlots for cattle is determined by a relatively small number of cash market transactions.

2.2 Data and Summary Statistics

Our main data source—the Agricultural Marketing Service (AMS) website of the USDA—provides information on fed cattle purchase quantities and prices. Under the Livestock Mandatory Reporting (LMR) Act of 1999, any packer who slaughters at least 125,000 cattle a year must provide the USDA with twice-daily reports on the volumes and terms of trade for fed cattle transactions and boxed beef sales (Perry et al., 2005; Mathews, Jr. et al., 2015). According to the USDA, the reports

[7]In our empirical analysis, we find that cash market prices and formula prices indeed are nearly identical on a week-to-week basis; this also is corroborated in Perry et al. (2005).

[8]The futures contracts available for trade on the CME require that cattle be delivered to an approved livestock yard within 18 months, during a specific February, April, June, August, October, or December. Typically, the futures contract is selected so that the delivery month of the contract aligns with the expected shipment of cattle from the feedlot to the packer.

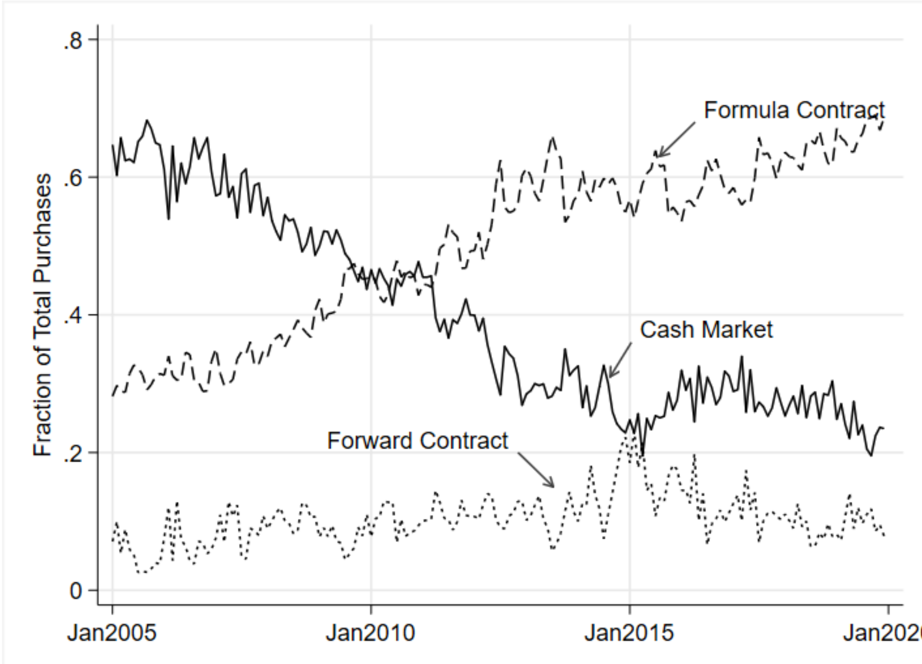

Figure 2: The Prevalence of Purchase Methods Over Time

cover 92% of all fed cattle transactions. The USDA aggregates these reports to the region-week level and disseminates the resulting data in order to facilitate price discovery.

Specifically, we cull our data from the Weekly Direct Slaughter Cattle Detail Reports over 2005-2020,[9] which provide detailed information about the cattle purchases, including the date, region of procuring packer plant is located, whether formula and forward contracts are used, the number of heads, the free-on-board (FOB) price, and the average weight of the cattle. In some of our reduced-form empirical work, we aggregate the data to construct a time-series with observations at the nation-week level (Section 3). For the structural model, we aggregate the data to construct observations at the region-year level (Section 4).

Table 3 provides summary statistics on average price and total quantity, based on the region-year observations.[10] As shown, the USDA provides information for nine distinct regions that differ in the quantity of cattle purchased. The price of a head of cattle is around $\$2,000$. The majority of purchases occur in the High Plains, including the Kansas, Nebraska, and Texas regions.

[9]See `https://www.ams.usda.gov/market-news/national-direct-slaughter-cattle-reports`, last accessed November 10, 2021. We exclude earlier data available for 2002-2004 because disease (BSE) discovered in the American and Canadian herds over 2002-2003 likely affected equilibrium outcomes in a manner difficult to model empirically (RTI International, 2007).

[10]We deflate prices to be in real 2015 dollars. We use the Consumer Price Index: Total All Items for the United States. See `https://fred.stlouisfed.org/series/CPALTT01USM661S`, last accessed November 11, 2021. As the AMS purchase quantities do not reflect all transactions, we scale them by a multiplicative constant so that they align with data from the Census of Agriculture. See Appendix A.

Table 3: Summary Statistics

	Average Price		Total Quantity	
Region	Mean	St. Dev.	Mean	St. Dev.
Western States	1,977	274	81,380	15,790
Colorado	2,035	295	151,290	38,676
Western Cornbelt	2,032	304	207,942	44,554
Kansas	1,965	280	470,144	126,744
Nebraska	2,048	304	446,718	73,607
Northeastern States	1,860	308	7,803	2,438
Texas Region	1,915	270	488,022	104,080
Eastern Cornbelt	1,921	290	30,916	6,646
Eastern Mountain	2,030	306	85,873	17,708

Notes: Units of observation are at the region-month level over 2005-2019. Average price is in January 2021 dollars per head, and represents the average amount paid by packing plants in the region. Total quantity is the number of heads purchased by packing plants in the region and is in live animal equivalent units, where a dressed animal is equal to 1.59 live animals. The western states include Arizona, California, Idaho, Nevada, Utah, and Oregon. The western cornbelt includes Iowa, Minnesota, and Missouri. The northeastern states include Ohio, Virginia, West Virginia, and all states to the northeast of those three. The Texas region includes New Mexico, Texas, and Oklahoma. The eastern cornbelt includes Illinois, Indiana, Kentucky, Michigan, and Wisconsin. The eastern mountain region includes Montana, North and South Dakota, and Wyoming. Based on data obtained from the *Agricultural Marketing Service* of the USDA.

As the USDA defines these regions for reporting purposes, they should not be interpreted as economically independent geographic areas. Indeed, fed cattle can be (and often are) transported from one region to another. To support the estimation of an economic model with realistic spatial relationships, we obtain information on the location of packing plants and the location of fed cattle. For the former, we use proprietary data obtained from *Cattle Buyers Weekly* on the largest U.S. packing plants over 2005 to 2020, including their capacity and their location.[11] For the latter, we rely on the Census of Agriculture, which provides the quantity of fed cattle sold from each county at five-year intervals.[12] We interpolate across years using monthly data published by the Economic Research Service (ERS) of the USDA on the total (national) slaughter.[13] Appendix A provides details on the interpolation.

We obtain the average price that packers receive for boxed beef from the monthly ERS data.[14] This variable is referred to as the wholesale value in the ERS data, and is measured in cents per pound. We also obtain a measure of the price paid to feedlots from the same data source, which we

[11] We consider only packing plants that process fed cattle, and exclude those that process only cows and bulls. The latter typically are located near dairy farms away from the High Plains.

[12] The data can be downloaded from the Census of Agriculture Quick Stats website: `https://quickstats.nass.usda.gov/`, last accessed November 11, 2021. We obtain data that cover the years 2002, 2007, 2012, and 2017.

[13] The data can be downloaded from the website of the ERS. See `https://www.ers.usda.gov/data-products/meat-price-spreads/`, last accessed November 11, 2021.

[14] The monthly price data is available here: `https://www.ers.usda.gov/data-products/meat-price-spreads/`, last accessed March, 25, 2022.

construct as the gross farm value measured in cents per ton minus the value of byproduct created in the production of beef. We refer to the packer spread as the difference between these values. For the structural model, we aggregate these data to construct a time-series of annual observations. We expect the average price reported by ERS to reflect well the prices obtained by individual packers because boxed beef typically is considered a commodity product: transportation costs are low, boxes of equivalent quality and yield grades are essentially homogeneous, and downstream customers purchase on a weekly basis under short-term contracts.[15]

Finally, we obtain the national market share of fed cattle slaughter volume for Tyson, Cargill, JBS, and National Beef in each year over 2011-2017 by reverse engineering an exhibit that is provided in a recent legal document.[16] The raw data are obtained from a proprietary report of *Cattle Buyers Weekly* titled "Steer and Heifer Slaughter Market Share," to which we do not have access.[17] The volume-based market shares are somewhat higher than the capacity-based market shares (Table 1), consistent with the major packers having relatively low marginal cost.

3 Empirical Pricing Patterns

3.1 Prices and the Packer Spread

Packer are intermediaries that connect the upstream portion of the beef supply chain (i.e., ranchers, stockers, feedlots) to retailers that sell beef to final consumers. Thus, their ability to earn profit depends on the prices that they pay for cattle, the prices they obtain from retailers, and whether the gap between the two—what we refer to as the "packer spread"—exceeds the average cost of processing cattle.

In Figure 3, we plot the average price that packers pay for cattle and the average price they receive for beef, in each month over 2005-2019 (in cents per pound). We observe two patterns of interest. First, these prices fluctuate over the sample period, probably due to relative shifts in the supply of cattle and demand for beef.[18] Second, although the price series track each other to a reasonable degree for most of the sample period, they diverge over 2015-2019, as the price paid to feedlots falls without a commensurate decrease in the price received from retailers.

Figure 4 plots the gap between the two price series—the packer spread—over the sample period.

[15]For example, see paragraph 24 of the Complaint filed by the DOJ in 2008 to enjoin the acquisition of National Beef by JBS. The Complaint is available at the DOJ website: `https://www.justice.gov/atr/case-document/complaint-137`, last accessed November 11, 2021.

[16]The legal document is a Complaint filed by R-CALF, an association of ranchers, stockers, and feedlots, against the major packers. It is available for download: `https://www.r-calfusa.com/wp-content/uploads/2019/05/Cattle-complaint.pdf`, last accessed November 11, 2021. See Figure 1 (page 3) in the Complaint.

[17]See `http://www.cattlebuyersweekly.com/users/rankings/packerssteerheifer.php`, last accessed November 11, 2021.

[18]The R-Calf Complaint claims that the increase in prices over 2009-2014 are due to due to strong beef demand and shortage of fed cattle due to droughts of 2011-2013 (page 4).

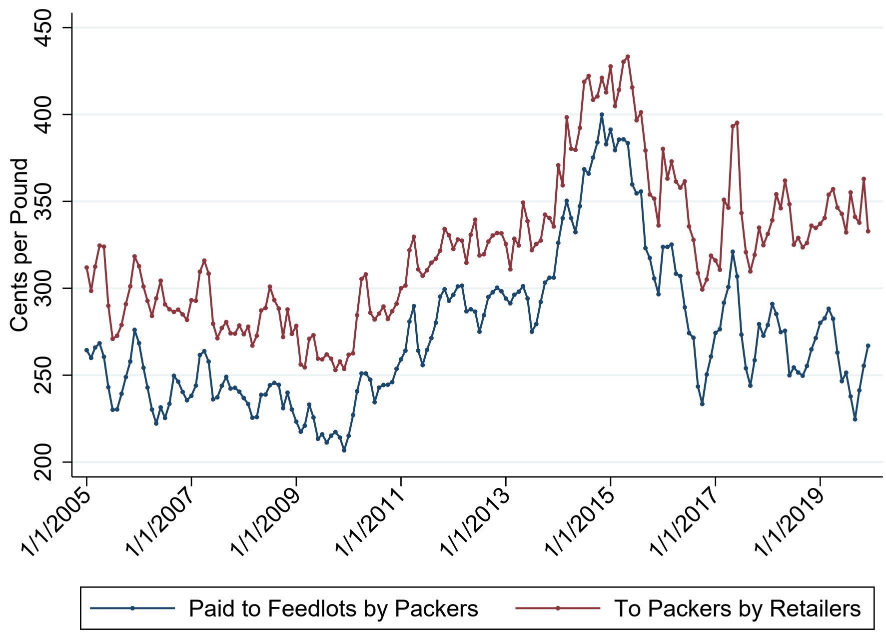

Figure 3: Prices Over Time

Between 2005 and 2014, the packer spread exhibits a modest decline, with an average around 40 cents per pound. Then, over 2015-2019, it trends sharply upwards, and in most months near the end of the sample, the packer spread exceeds 80 cents per pound. The simplest explanation for the increasing spread would be an increase in the marginal cost of processing cattle—however, we are not aware of any empirical support for that explanation. Therefore, it is natural to explore whether the increase in the packer spread might be attributable to an increased exercise of market power on the part of the packers.

3.2 Alternative Marketing Arrangements and Prices

We now develop the idea that AMAs distort the pricing incentives of packers in the cash market. We start with a counterfactual in which profit-maximizing packers acquire all their cattle in the cash market. In this counterfactual, each packer faces the standard pricing trade-off: a higher bid on a lot of cattle increase the probability that the packer wins the cattle, but reduces the profit that can be earned on the cattle. In the presence of AMAs, an additional consideration is introduced, as a higher bid also raises the price that the packer must pay for cattle acquired with AMAs. As a result, economic theory suggests that cash market prices are likely to be lower, the greater the prevalence of AMAs. As the prices that feedlots obtain with AMAs are linked to realized prices on cash market—either directly or indirectly through the CME future prices—the presence of AMAs broadly depresses the prices paid for cattle.

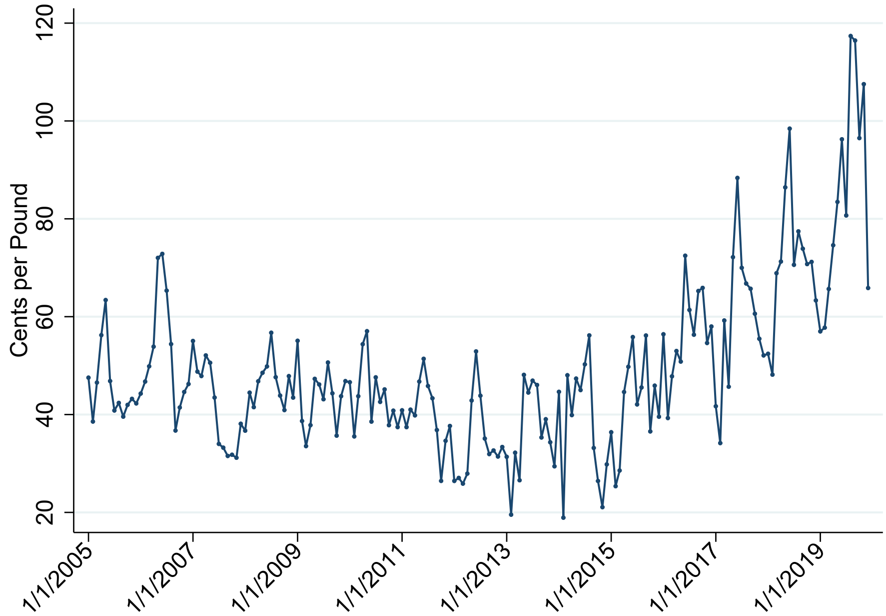

Figure 4: The Packer Spread Over Time

That AMAs or equivalent contracts can distort pricing incentives has been recognized in the economics literature both as a general matter (Mahenc and Salanie, 2004) and in the specific context of the cattle industry (Xia and Sexton, 2004).[19] As we formalize later, economic theory indicates that the extent to which realized prices respond to these incentives depends primarily on the relative amount of cattle transacted through the cash market and the AMAs, and on the ability of packers to influence cash market prices.[20] Thus, the dramatic increase in the prevalence of AMAs over the sample period (Figure 2) paired with the high national market shares of the major packers (Table 1), suggests that AMAs may contribute to the increase in the packer spread.

To provide some empirical support for the economic theory, we examine whether cash market prices tend to be lower when a larger fraction of cattle is purchased under AMAs. We focus on the weekly time-series of purchases in the High Plains, which accounts for the bulk of cattle purchases nationally. As we cannot rule out that cash market prices have a unit root,[21] we specify our regression equation in differences:

$$\Delta \log(p_t) = \beta_0 + \beta_1 \Delta \log(w_t) + \beta_2 \log(p_t) + \beta_3 \Delta \log(q_t) + \epsilon_t \tag{1}$$

[19] See also the discussion in MacDonald (2006).

[20] Thus, if packers do not have the ability to influence cash market prices, then economic theory suggests that AMAs should be competitively benign.

[21] A Dickey-Fuller test of the hypothesis that a unit root exists obtains p-value of 0.5121.

Table 4: Time-Series Regression Analysis

Variable	Parameter	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Δw_t	β_1	-0.059	-0.055	-0.045	-0.028	-0.059	-0.075
		(0.005)	(0.009)	(0.009)	(0.015)	(0.016)	(0.020)
$\log(p_t)$	β_2		-0.005	-0.005	0.050	-0.005	-0.029
			(0.003)	(0.003)	(0.021)	(0.006)	(0.013)
$\Delta \log(q_t)$	β_3		0.005	0.015	0.019	0.022	0.003
			(0.009)	(0.009)	(0.014)	(0.016)	(0.018)
Fixed Effects		None	None	Week	Week	Week	Week
Sample Period		Full	Full	Full	Early	Mid	Late
Observations		772	772	772	261	250	261

Notes: The table summarizes the results of OLS regression. The dependent variable is $\Delta \log(p_t)$, the change in the cash market price (in logs). The units of observation are weeks over the period 2005-2019. In columns (iv), (v), and (vi), estimation is conducted on the subsamples of weeks overs 2005-2009, 2010-2014, and 2015-2019, respectively. Shown are the regression coefficients and the standard errors (in parenthesis).

where $\Delta \log(p_t) = \log(p_t) - \log(p_{t-1})$ is the change in the cash market price (in logs), $\Delta \log(w_t) = \log(w_t) - \log(w_{t-1})$ is the change in the fraction of cattle purchased under AMAs (in logs), $\Delta \log(q_t) = \log(q_t) - \log(q_{t-1})$ is the change in the total quantity of cattle purchased (in logs), and ϵ_t is a stochastic error term.[22] We specify our variables using the natural logs solely to ease interpretation of the parameter estimates. Estimation is with ordinary least squares (OLS). Whether our estimate of β_1 as reflects a causal effect of AMAs on cash market prices depends in part on whether it is reasonable to think of quantities being exogenously determined, a matter to which we return shortly.

Table 4 summarizes the regression results. In column (i) we use only the fraction of cattle purchased under AMAs as an independent variable; the point estimate is statistically significant and suggests that a one percent increase the fraction of cattle purchased under AMAs is associated with a 5.9% reduction in the cash market price. Columns (ii) and (iii) control for cash market prices (in levels) and the total quantity of cattle purchased; the latter column also includes week fixed effects. Comparing across columns, we obtain coefficients on AMA purchases that similar in magnitude and statistical significance. Columns (iv)-(vi) focus on 2005-2009, 2010-2014, and 2015-2019, respectively, and suggest that the relationship between AMA purchases and cash market prices might be more pronounced in the later years.

This negative correlation between the AMA purchases and cash market prices has been developed earlier in the literature (e.g., RTI International, 2007; Taylor, 2008). A question of inter-

[22]For the purposes of this analysis, we exclude cattle transacted with forward contracts because the connection between cash market prices and forward contract prices are unclear on a week-to-week basis. Data are not available for three weeks in 2014 due to a government shutdown, and we exclude weeks on either side of that window in order to accommodate estimation in differences.

pretation is whether this indeed reflects the causal effect of AMAs that is suggested by economic theory. From an econometric standpoint, our regression coefficients obtain an unbiased estimate of a causal effect if the fraction of cattle purchased under AMAs is orthogonal to the error term, which itself can be interpreted as a price-shifter. Therefore, it matters whether quantities are exogenously determined.

This is a interesting question in the context of the cattle industry. Over a period of years, the quantity of cattle available for purchase adjusts with demand conditions, as ranchers determine the level of breeding. Over a somewhat shorter time horizon, spanning perhaps multiple months, the quantity of cattle available for purchase is effectively fixed because all fed cattle are slaughtered to produce beef. Indeed, we maintain an assumption of fully inelastic supply in our structural model of the industry (below), which we estimate on annual data. Yet over an even shorter time horizon, perhaps no longer than a handful of weeks, supply elasticity reemerges, as feedlots have some ability to substitute inter-temporally in order to obtain better pricing terms.

It is this shortest time horizon that is relevant for our time-series regression analysis. The specific threat to causal inference is that feedlots may increase their cash market sales more than their AMA sales in response to favorable pricing conditions, which could generate or contribute to a negative correlation between AMA purchases and cash market prices. As we currently do not have enough information to rule out such a supply response, we simply interpret the regression as providing empirical evidence that is consistent the economic theory that AMAs reduce cash market purchases.

4 Empirical Model of Oligopsony Competition

We present a model of oligopsony competition that incorporates the presence of formula contracts. The model generalizes the findings of (Mahenc and Salanie, 2004; Xia and Sexton, 2004) beyond the duopoly setting, and provides a framework for empirical analysis. In this second, we describe the model, and analyze the pricing incentives that arise. We plan to estimate or calibrate the structural parameters in our future work, and develop policy implications for the cattle industry.

4.1 Framework

We examine a model of oligopsony competition among packers in the cash market. The model incorporates the most notable features of the industry, including the cost of transporting fed cattle, the short term inelasticity of supply, and the presence of formula contracts and forward contracts. We take as given the locations of the plants and the cattle on feed, as well as the contract positions of the packers. In the baseline model, we also assume that each packer sets prices that maximize its profit; we extend the model to price coordination in an extension.

Formally, the model is a game of perfect information that plays out over $t = 1, 2, \ldots$ periods. We interpret periods as years in the empirical implementation. In each period, there exist $f \in \mathcal{F}_t$

packers, each with a set $\mathcal{J}_{ft}$ of processing plants that have a fixed physical location. There also exist N counties, each of which contains a mass Q_{nt} of infinitesimally small feedlots. Thus, in period t, there are $Q_t = \sum_n Q_{nt}$ cattle available for slaughter; these can be purchased via formula contract or on the cash market.[23]

In each period, packers observe the economic state, Ψ_t, which includes demand and cost conditions, the number and location of cattle available for slaughter, and the formula contracts. Letting the quantity of cattle purchased via formula contract by each packer f from each county j be $(x_{fnt})_{f \in \mathcal{F}_t, \forall n}$, the quantity of cattle available for purchase in the cash market is given by $M_{nt} = Q_{nt} - \sum_{f \in \mathcal{F}_t} x_{fnt}$.

Packers then simultaneously determine the upstream price that each plant $j \in \mathcal{J}_{ft}$ offers for cattle of each county n in the cash market, i.e., $(p_{jnt})_{j \in \mathcal{J}_f, \forall n}$. The proportion of fed cattle in county n that are sold to plant j in the cash market is determined by a supply function, $s_{jnt}(\boldsymbol{p}_{nt}; \Psi_t)$, where $\boldsymbol{p}_{nt}$ is the vector of prices in county n.

As all fed cattle are (eventually) sold for slaughter,[24] we assume that market supply is perfectly inelastic, in the sense that feedlots select among the packing plants, without an outside option:

$$\sum_j s_{jnt}(\boldsymbol{p}_{nt}; \Psi_t) = 1 \tag{2}$$

and that packers convert fed cattle into boxed beef in fixed proportions. Thus, the total quantity of boxed beef—aggregating across packers—is determined by the stock of fed cattle, Q_t. As boxed beef is a commodity product, we let its downstream price be determined by an inverse demand schedule that we denote $p_t^d(\Psi_t)$.[25]

The prices set by packers in the cash market determine the terms-of-trade for purchases made with formula contracts. Specifically, we assume that the contract price equals the average cash

[23] We treat formula contracts and forward contracts as identical for the purposes of the model, which is appropriate because—given the time horizon of one year—the prices that are obtained with both are ultimately determined by cash market outcomes.

[24] We have confirmed this with multiple industry experts. The conversion of feed into muscle slows once cattle reach around 1250-1350 pounds, which dictates the timing of slaughter. Feedlots that are unable to find a nearby buyer at the economically optimal time—typically a 2-4 week period—may choose to ship the cattle greater distances or feed the cattle until a nearby buyer emerges. Thus, although feedlots and packers have some ability to substitute between weeks, the short run elasticity of supply is essentially zero. Ranchers can adjust the size of the herd in the long run. The adjustment process itself is interesting in and of itself. An increase in the value of beef can initially shrink the supply of fed cattle, as ranchers withhold more calves for breeding purposes (e.g., Rosen et al., 1994).

[25] Thus, we do not incorporate packer market power in the downstream market. Consider a thought experiment that tracks the durable goods monopoly problem of Coase (1972). If packers attempt to sell less beef at a higher price, their may be no buyers, even if some have a willingness-to-pay that exceed the higher price. The reason is that the packers cannot commit not to subsequently selling the remaining beef at a lower price. The buyers, anticipating this, may prefer to delay their purchases. Thus, there is at least some theoretical justification for our approach.

market price:

$$\overline{p}_t(\boldsymbol{p}_t;\Psi_t) = \sum_{n=1}^{N} \frac{M_{nt}}{M_t} \sum_{j\in\mathcal{J}} s_{jnt}(\boldsymbol{p}_{nt};\Psi_t)p_{jnt} \tag{3}$$

where $M_t = \sum_n M_{nt}$ and $\boldsymbol{p}_t$ is a vector of all cash market prices. Finally, we denote the marginal cost of packer f as $c_{ft}(\Psi_t)$.

With these assumptions in place, the profit of packer f in period t is given by

$$\begin{aligned}\Pi_{ft}(\boldsymbol{p}_t;\Psi_t) = (p_t^d(\Psi_t) - c_{ft}(\Psi_t) - \overline{p}_t(\boldsymbol{p}_t;\Psi_t))x_{ft} \\ + \sum_{j\in\mathcal{J}_{ft}} \sum_n (p_t^d(\Psi_t) - c_{ft}(\Psi_t) - p_{jnt})s_{jnt}(\boldsymbol{p}_{nt};\Psi_t)M_{nt}\end{aligned} \tag{4}$$

where $x_{ft} = \sum_n x_{fnt}$ is the total quantity of cattle purchased by packer f with formula contracts. This expression embeds that marginal costs are constant in throughput. We maintain that assumption for our preliminary estimation but plan on incorporating upward-sloping marginal costs in the next version, leveraging the data that we have on plant-level capacity.

In the profit function, the first term represents the contribution of formula contract purchases, and the second term represents the contribution of cash market purchases. We conceptualize the *markdown* obtained by a plant as the net revenue that the plant obtains from the cattle less the price it pays to procure the cattle:

$$\text{markdown} \equiv p_t^d(\Psi_t) - c_{ft}(\Psi_t) - p_{jnt} \tag{5}$$

Differentiating the profit function with respect to a plant- and county-specific price p_{kn}, for some $k \in \mathcal{J}_f$, obtains the following first order condition:

$$\left(p^d - c_f - p_{kn}\right)\frac{\partial s_{kn}}{\partial p_{kn}}M_n - s_{kn}M_n + \sum_{j\in\mathcal{J}_f, j\neq k}(p^d - c_f - p_{jn})\frac{\partial s_{jn}}{\partial p_{kn}}M_n = \frac{\partial \overline{p}}{\partial p_{kn}}x_f \tag{6}$$

The left side captures the net marginal benefit that packer f obtains in the cash market from increasing p_{kn}. A higher price increases the volume of cattle procured at plant k, but it also decreases the markdown at plant k and cannibalizes profit at the packer's other plants. In the absence of formula contracts, $x_f = 0$, and the packer f chooses a price that makes this net marginal benefit equal to zero. The right side of the equation (6) captures the influence of formula contracts. To the extent that a higher price increases the market average price, it reduces the profit earned on cattle procured with formula contracts. Therefore, the presence of formula contracts tends to exert downward pressure on the prices paid to feedlots.

A cash market equilibrium in period t is defined by a set of prices, $(p_{jnt})_{\forall j,n}$, that satisfy equation (6) for every plant and county. We assume that a unique equilibrium exists. With the parameterizations of the model that we use (and that are described next), we have never encountered a game without an equilibrium. Furthermore, in a number of numerical experiments, we have not found multiple equilibria in any game.

4.2 Parameterizations

We place parametric restrictions on the supply and marginal cost functions in order to make empirical progress. For supply, we assume that the market share that packing plant j obtains in county n takes a logit form:

$$s_{jn}(\boldsymbol{p}_n; \Psi, \boldsymbol{\theta}_0) = \frac{\exp\{\beta_1 p_{jn} + \beta_2 d_{jn}\}}{\sum_{k \in \mathcal{J}} \exp\{\beta_1 p_{kn} + \beta_2 d_{kn}\}} \tag{7}$$

where d_{jn} is the straight-line distance between the packing plant and the centroid of the county, $\beta_1 > 0$ is a price sensitivity parameter, and $\beta_2 < 0$ is a distance sensitivity parameter (we remove period subscripts henceforth for notational brevity). The ratio β_2/β_1 is a measure of feedlots' willingness-to-pay for proximity to the packing plant. We interpret it as the cost of transportation, though the concepts are not equivalent if distance affects feedlot preferences for other reasons.[26]

For marginal cost, we assume that

$$c_f(\Psi, \boldsymbol{\theta}_0) = \alpha_0 + \boldsymbol{w}_f' \boldsymbol{\alpha}_1 + \zeta_f \tag{8}$$

where $\boldsymbol{w}_f$ is a vector of (potentially time-varying) cost shifters, $(\alpha_0, \boldsymbol{\alpha}_1)$ are parameters, and ζ_f is a packer-specific fixed effect. Among the cost shifters that we consider are capacity (aggregated to the packer level) and a linear time trend; these have limited explanatory power. In our preliminary calibrations, we therefore do not include cost-shifters. We assume that the same fixed effect applies to Swift, Smithfield, and JBS; recall that JBS entered the market by acquiring the other two packers. As with the supply function, our specification of the marginal cost function restricts the sources of heterogeneity that affect equilibrium outcomes. Again, in the next version of the paper, we plan on incorporating that marginal costs may increase with throughput.

To estimate the model, we require information on $(x_f)_{f \in \mathcal{F}}$ and $(M_n)_{\forall n}$. We obtain the county-specific quantity of cattle (Q_n) using data from the Census of Agriculture and ERS (Section 2.2). We obtain the total quantity of cattle procured with formula contracts $\left(\sum_{f \in \mathcal{F}} x_f\right)$ from the AMS data, and allocate it across the major packers in proportion to their capacity shares to obtain $(x_f)_{f \in \mathcal{F}}$.

[26] The logit supply system conveys two practical advantages in estimation. First, it provides simple analytical solutions for supply of cattle. Our estimation routine requires that equilibrium be computed numerically for every candidate set of parameters, so the lighter computation burden is meaningful. Second, it implies that cattle supply is a continuous function of prices. Again because we compute equilibrium for each candidate set of parameters, this translates to continuity in the objective function.

We assume that fringe packers rely exclusively on the cash market. We also assume that formula contracts are distributed across counties in proportion to Q_n, which allows us to infer $(M_n)_{\forall n}$.

4.3 Formula Contracts and Pricing Incentives

To explore the implications of formula contracts on cash market outcomes it is useful to consider the case in which firms are symmetric with respect to the feedlots in some arbitrary county, n. Within the context of the model, symmetry can be created if each packer has the same marginal cost ($c_f = c$), the same quantity of formula contracts ($x_f = x$), and a single plant that is the same distance from the county ($d_{fn} = d_n$). With symmetry and the logit supply assumption, the first order conditions of equation (6) simplify to obtain the following characterization of equilibrium markdowns:

$$\underbrace{p^d - c - p_n}_{\text{markdown}} = \underbrace{\frac{1}{\beta_1}\left(\frac{1}{1 - s_{fn}}\right)}_{\text{standard oligopsony}} + \underbrace{\frac{1}{\beta_1}\left(\frac{1}{1 - s_{fn}}\right)\frac{x}{M}}_{\text{formula contract effect}} \tag{9}$$

A greater number formula contracts increases the markdown; for a given marginal costs and downstream price, this lowers the price paid to feedlots.

If a packing plant procures 100 cattle with formula contracts, and a total of 500 cattle are traded on the cash market (across all packers), then the ratio x/M is 0.20, and the presence of the formula contract increases markdowns by 20%. If the ratio between a packer's formula purchases and the size of the cash market is 0.75 then formula contracts increase markdowns by 75%. As formula contracts and forward contracts together appear to account for 80% of transactions by 2019, and these are split among the largest four packers, to a rough approximation the value of x/M that obtains in 2019 is 1.00, suggesting the formula contracts may increase markdowns by 100%. Another manipulation of the first order conditions yields

$$p^d - c - p_n = \frac{1}{\beta_1}\left(\frac{1}{1 - s_{fn}}\right)\left(1 + \frac{x}{M}\right) \tag{10}$$

which makes clear that the effect of formula contracts interacts with the amount of standard oligopsony power. In dollar terms, the impact of formula contracts is greater, the greater is the markdown that would arise without formula contracts. Thus, formula contracts may have substantial consequences for the terms of trade in some settings but (at least in dollar terms) not in other settings.

5 Calibration/Estimation

Allowing the marginal cost constant to be absorbed by packer fixed effects, the structural parameters to be recovered include $(\beta_1, \beta_2, \zeta_f)$. We employ a nonlinear least squares estimator that is used in Miller and Osborne (2014) among other articles. For each candidate parameter vector, we compute equilibrium given the exogenous data, which include the plant and cattle locations and the forward contracts. The equilibrium is characterized by prices that vary at the plant-county level. As there are 40 plants and about 2,000 counties with fed cattle, there are around 80,000 prices and equations in each year. With constant marginal costs, the game in each county is separate, which eases computation burden. We also apply the common markup (here, markdown) property of logit, which allows us to search for one markup per firm in a given county, rather than one markup/price per plant. We have explored the additional computation requirements associated with incorporating upward-sloping marginal costs and think that it is feasible.

Having computed the equilibrium for a given candidate parameter vector, we then aggregate the equilibrium predictions to the level of the endogenous price and packer share data. The price data are observed at the region level and the share data are observed at the national level. This allows us to construct a loss function and search over candidate parameter vectors. Formally, the estimated parameters result from

$$\hat{\theta} = \arg\min_{\theta} \begin{bmatrix} (\overline{P}_{rt} - \overline{p}_{rt}(\theta, \Psi_t))_{\forall r,t} \\ (S_{ft} - s_{ft}(\theta, \Psi_t))_{\forall f,t} \end{bmatrix}' W \begin{bmatrix} (\overline{P}_{rt} - \overline{p}_{rt}(\theta, \Psi_t))_{\forall r,t} \\ (S_{ft} - s_{ft}(\theta, \Psi_t))_{\forall f,t} \end{bmatrix}$$

where W is a positive definite weighting matrix, $\overline{P}_{rt}$ is the average price in region r in period t, and S_{ft} is the market share of packer f in year t. We could also incorporate total quantity purchased by plants in each region, which would provide a path to identification for the distance parameter—matching quantities in this fashion though would better be implemented with a model that respects capacity constraints of plants and the implied upward-sloping costs. Therefore, for the purposes of this draft, we remove β_2 from the nonlinear search, and instead simply select a $\beta_2(\theta)$ such that the average shipping distance is 100 miles, a number that we obtain from Capps et al. (1999).

Two comments on identification are in order. First, price endogeneity does not arise in this framework because observed prices can be interpreted as a dependent variable, rather than as an independent variable (which would be more standard). However, a similar concern may arise nonetheless. Equilibrium is possible to compute for a given set of parameters because there is no unobserved cost/quality heterogeneity (e.g., a ξ_j term in BLP notation), aside from the logit error terms. If unobserved heterogeneity is an important feature of the empirical setting then this creates a misspecification bias that can be similar in effect to endogeneity bias. In our setting, the approach likely is reasonable. It is unlikely that feedlots systematically prefer one plant over another for reasons other than distance and price, in a significant way, and feedlot-specific preferences are well-modeled with the logit error. On the cost-side of the model, we include packer fixed effects, which should account for much or all of the heterogeneity (at least once capacity is incorporated). Previous studies that have employed this estimation strategy have attempted to compare various predictions of the model to engineering estimates as a validation check, and we plan to do the same to the extent it is possible.

Table 5: Estimation Results

Parameter	Estimate
Price (β_1)	12.0
Distance (β_2)	-18.8
Marginal cost (ζ_f)	
Tyson	0.36
JBS	0.54
Cargill	0.35
National	0.21
Fringe	0.65

Notes: The table summarizes the results of nonlinear least squares regression. Standard errors are in progress.

Second, an important source of empirical variation that identifies the price parameter is that both the packer spread and contracts are relatively low early in the sample period and then relatively high later in the sample period. In the model, the increase in contract usage is one of the only ways to generate an increase in the packer spread. Furthermore, from equation (10), the extent to which contracts affect markdowns (and thus the packer spread) depends on the price parameter. Thus, in principle, we are identifying the price parameter off of the *assumption* that the increase in contracting is what leads to the observed increase in the packer spread. While it does seem natural that a supply-side factor is involved, and to our knowledge costs have not increases, an alternative explanation that has been invoked is collusion. And indeed there currently is a DOJ investigation into that possibility, and a class action lawsuit that is winding through the court system.

Therefore, we may shift how we identify the price parameter going forward. In particular, we can place an assumption on the magnitude of packer markdowns over 2005-2007 and calibrate a price parameter that rationalizes the markdowns. We do have one possible data source for markdowns – the Sterling Beef Profit Tracker – that we are currently vetting. More likely is that we examine different markdowns then forward simulate to see the extent to which (given each) the rise of contracting can explain the observed increase in the packer spread.

6 Estimation Results

Table 5 shows the point estimates that we obtain with nonlinear least squares. The price parameter implies an average markdown for the Big 4 packers in the range of 10%-60% depending on the year. The distance and price parameter together imply a transportation cost of about \$0.03 per pound per hundred miles, which is about 2% of the price of live cattle. Based on our understanding of engineering estimates, this is in the ballpark but perhaps a bit low. The results also imply that the fringe packers have the highest marginal cost.

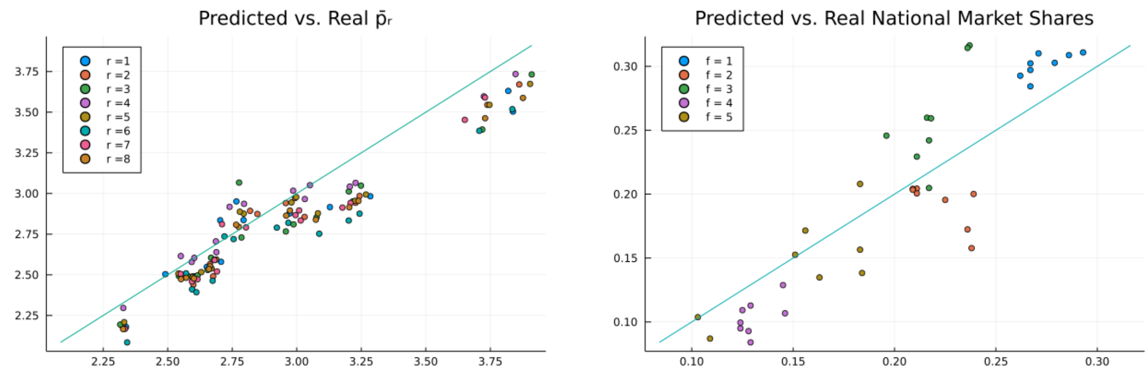

Figure 5: Model Fits

Notes: The horizontal axes are data and the vertical axes are model predictions. In the left panel, each dot is a region-year price, and observations from the same region have the same color. In the right panel, each dot is a firm-year market share, and observations from the same firm have the same color. A 45-degree line is provided in blue.

Figure 5 provides an analysis of the model fits. The left panel considers the region-year prices. The vertical axis is for the predictions and the horizontal axis is for the data. As the dots cluster around the 45-degree line, the model fits the price data well. The right panel considers the firm-year market shares. The predictions and the data are correlated but the fit is somewhat less precise; we expect it to improve with the incorporation of capacity data. Not shown are the (out-of-sample) fits to region-year quantities, which also should improve with the capacity data.

Figure 6 provides histograms of shipping distances. The top panel considers a counterfactual in which distance does not affect decisions (equivalently, transportation costs are zero). The bottom panel shows considers our model estimates. As the distribution that we estimates is shifted to the left, we interpret the estimated distance parameter as having meaningful implications for shipping distances. In a future iteration of the paper we will be able to provide estimates of concentration at the local level, which should be of independent interest because local market concentration can diverge from national market concentration in the presence of transportation costs, and the former typically is more relevant for the competitive environment. We are not aware of other estimates of local market concentration in the literature.

We observe that the packer spread increases from about \$0.50 to \$0.75 in the data during the sample period (currently we estimate through 2018, and need to extend the period through 2019, or use the forward simulation approach discussed previously). The model predicts an increase from \$0.54 to \$0.68. Therefore, the model generates a rise in the packer spread, albeit one that is smaller than what is observed in the data. As the main mechanism that creates this in the model is the increase in contracting, a back-of-the-envelop calculation indicates that contracts account for $(0.68-0.55)/(0.75-0.50) = 56\%$ of the increase in the spread. This estimate will be refined with future work.

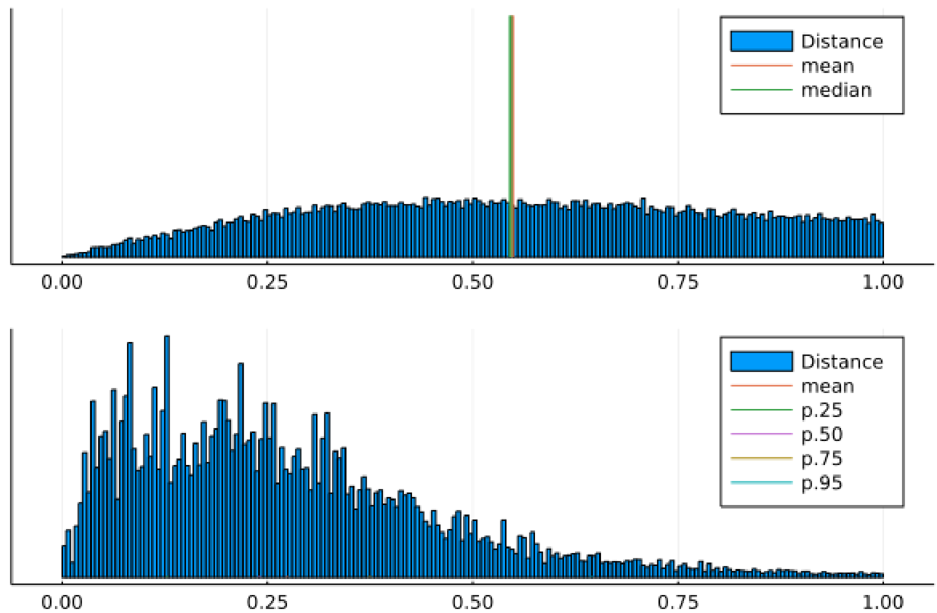

Figure 6: Histograms of Shipping Distances

Notes: The top panel provides the histogram of shipping distances that would arise if the distance parameter (or transpiration costs) were zero. The bottom panel provides the distribution of shipping distances that we estimate.

7 Counterfactual Simulations

These will be completed after the next round of calibration/estimation. But we plan to do much of the following:

- Look at the effects of limiting packers to making 20% or 50% of their purchases with contracts, in line with recent legislative proposals in Congress.
- The extent to which plant divestitures mitigate the competitive effects of contracts. There is an interesting interaction to be explored because smaller packers have less ability to shift the cash market price.
- Explore the implications of contracts for mergers. Due to the same interactions, mergers can have competitive implications even if the plants of the firms involved do not compete directly for the same cattle.

8 Comments

8.1 The Benefits of Contracts

Our understanding from market participants and industry reports is that there are some benefits associated with contracts, relative to the cash market. For packers seeking to obtain consistently high levels of utilization, contracts can help them obtain a "base" of supply that then can be supplemented week-to-week with cash market purchases, as feedlots not packers control the precise week in which contract transactions occur. This approach can be more reliable that using the cash market for all purchases. For feedlots, a contract eliminates the risk that they cannot find a buyer for their cattle at the most economical time (it does not reduce price risk though). The interesting aspect of these benefits is that they arise because the cash market is thin, and thus more volatile. Yet the the cash market is thin because of contracts. Restated, *the primary non-strategic benefits of contracts appear to arise because of the contracts themselves.* We are uncertain about the research benefits of formalizing this within the context of a search model where having fewer packers/feedlots in the cash market increase search costs, especially as it is not obvious that we have the empirical variation to operationalize that extension. In our current draft, we simply take contracts as exogenously determined—what we do can be conceptualized as studying the second-stage of a two-stage game. However, we speculate that this dynamic may explain why the shift toward contracting occurred gradually over the sample period.

8.2 The Long-Term Implications of Contracts

We have maintained the assumption that the downstream price of boxed beef is determined by an inverse demand schedule and the (fixed) supply of cattle. Thus, we assume that packers have no ability to exercise downstream market power, and that the prices that packers pay for cattle have no direct bearing on downstream prices. It is possible that these are reasonable approximations in the short run. However, in the long run, the supply of cattle adjusts with the price of fed cattle. If packers are able to exercise greater buyer power, and therefore lower the price of fed cattle, then the incentive to supply fed cattle diminishes. This creates a long run connection between the upstream and downstream markets. If fewer cattle are produced, the packers must sell less boxed beef and, all else equal, this raises downstream prices. Therefore, it is possible that formula contracts may increase the packer spread from both sides in the long run, raising the price of boxed beef and lowering the price of fed cattle. Empirically quantifying this connection is likely to be beyond the scope of the research project but it is an interesting and perhaps important thought experiment.

9 Conclusion

TBD.

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Appendix Materials

A Data and Estimation Details

A.1 Data

As described in Section 2.2, we obtain information about the quantity of fed cattle produced in each county from the Census of Agriculture. The census provides snapshots at five-year intervals. To approximate quantities in the intervening years, we use linear interpolation, adjusted to better match the time-series of national-level quantity as reported in ERS data. We detail the process here. The steps are as follows:

1. Starting with the Census of Agriculture for 2002, 2007, 2012, and 2017, we linearly interpolate the quantity of fed cattle produced in each county across years. For 2018 and 2019, we use the 2017 data. The creates initial estimates for each county over 2002-2019.

2. We compare the total fed cattle reported in the Census of Agriculture for 2002, 2007, 2012, and 2017 (summing across counties) to the total slaughter quantity reported by the ERS for the same years (summing across month). The ERS quantities are somewhat higher because they include imported fed cattle from Canada and Mexico as well as "packer-owned" cattle for which a transaction between a feedlot and a packer does not exist. [27]

3. We linearly interpolate the gap between total Census of Agriculture quantity and total ERS quantity across years. This creates time-series with estimates for the annual amount of imported cattle and packer-owned cattle. We subtract this gap from the total ERS quantities to obtain an estimate of the total quantity of fed cattle purchased from feedlots in the United States. This is a time-series with annual observations; it aligns exactly with the total quantities in the Census of Agriculture in the years 2002, 2007, 2012, and 2017.

4. We adjust the initial county-level estimates from Step 1 by applying a multiplicative factor such that the county-level estimates, summed, equal the total quantities obtained in Step 3.

A related issue is that AMS data obtained by the USDA from mandatory reporting covers does not include the purchases of the smaller packing plants. We apply a multiplicative factor to the region-year observations on purchase quantities so that (when summed across regions) they align with our calculations from Step 3 above.

B Additional Figures and Tables

[27] USDA (2014) reports that packer-owned cattle accounted for 7.5% of the cattle slaughtered, in data spanning January 2001-June 2010.

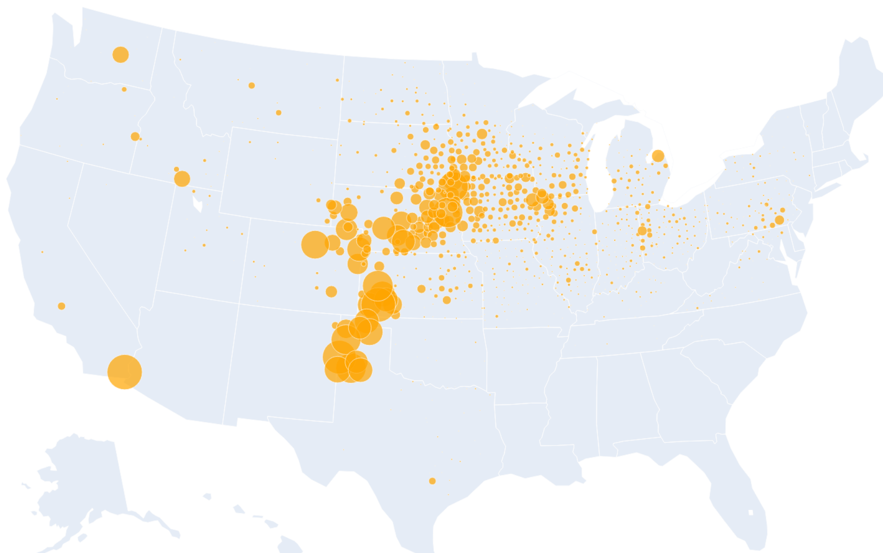

Figure B.1: Location of Fed Cattle by County, 2017

Notes: Counties that contribute to fed cattle sales are marked with orange circles; the sizes of the circles represent the quantity of sales. Data are from the 2017 Census of Agriculture.

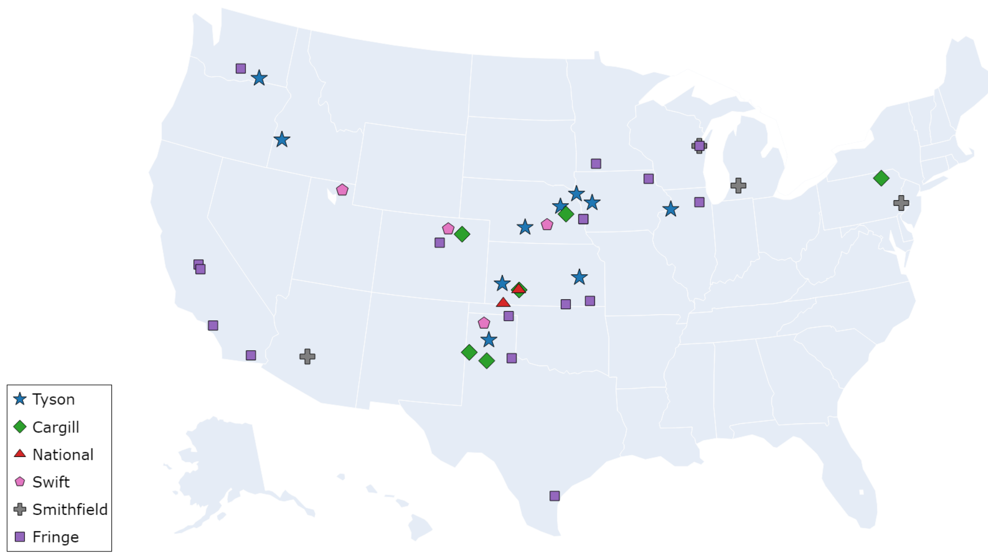

Figure B.2: Locations of Large Beef Packing Plants in 2005

Notes: The map plots the locations of large beef packing plants, including those of Tyson, Cargill, JBS, and National Beef, based on data obtained from *Cattle Buyers Weekly*.